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Sruti Subramanian

Designing Movement-Based Interactive Technology Supporting Balance Training in Older Adults

Doctoral thesis

NTNU
Norwegian University of Science and Technology
Thesis for the Degree of Philosophiae Doctor
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

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To my father

Abstract

With an increasing global population of older adults, falls are a critical problem resulting in numerous injuries, loss of independence, and fatalities. In this regard, balance training and rehabilitation play a major role in maintaining, improving, or restoring functional balance.

While traditional balance training exercises have shown to be effective in improving balance, current advancements in information and communication technology (ICT) have resulted in numerous interactive movement-based applications, some of which have shown potential in training balance. This has resulted in increasing applications of movement-based interactive technology within the healthcare sector for purposes such as balance training and rehabilitation. However, despite the identified potential and increasing attention given to movement-based interactive technology, there is limited knowledge of designing for balance training and rehabilitation.

The overall aim of the thesis is to inform the design of movement-based interactive technology supporting balance training in older adults.

The research conducted as part of the thesis has resulted in five journal and conference papers (see Part II) that address various aspects of designing for balance training among older adults: *design recommendations, movement characteristics, motivational factors,* and *tangible interactive technology.*

While the individual research papers provide specific insight into the various aspects of designing movement-based interactive technology for balance training in older adults, the thesis as a whole provides the following key findings:

- Effective balance training design solutions do not require strict puppeteering.
- Perceived health effects and joy are the main motivational factors for older adults.
- Simple, tangible interactive solutions show promise for balance training.
- As a tool for physiotherapists, a key success factor for balance training solutions is that they are easily tailorable.

In conclusion, the thesis suggests looking beyond conventional screen-based solutions. Simple, tangible interactive technology shows potential in physiotherapy for overcoming various drawbacks associated with screen-based solutions.

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) in partial fulfillment of the requirements for the degree of Philosophiae Doctor.

The Ph.D. work was performed at the Department of Computer Science, NTNU, Trondheim, under the supervision of Professor Dag Svanæs (primary supervisor), Associate Professor Yngve Dahl (co-supervisor), and Professor Beatrix Vereijken (co-supervisor).

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Sruti Subramanian
June 02, 2021

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Paper-II-Motivation

Subramanian, S., Dahl, Y., Skjæret-Maroni, N., Vereijken, B., and Svanæs, D., "Assessing Motivational Differences Between Young and Older Adults When Playing an Exergame," *Games for Health Journal*, 2019. 9(1).

Paper-III-Review

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Paper-IV-Framework

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Paper-V-Tangibles

Subramanian, S., Dahl, Y., Vereijken, B., and Svanæs, D., "ExerTiles: A Tangible Interactive Physiotherapy Toolkit for Balance Training with Older Adults," Accepted for publication in the Proceedings of the 2020 *Australian Conference on Human-Computer Interaction.*

Part I: Synthesis

1 Introduction

Motion is the basis of physicality, and as such, bodily movement is the basis of human existence. As stated by philosopher LaMothe [1]: "Humans are bodies, and bodies are movement." This interpretation of *bodies as movement* is reflected in everything from involuntary actions performed by the physical body (e.g., breathing, heartbeat, and eye reflexes) to consciously coordinated physical activities (such as walking, running, and writing), thereby establishing how fundamental movement is in our day-to-day life.

From a very young age, there is an instinctive inclination toward being in movement and being physically active. While physical movement is mainly predominant in one's younger years, with advanced age, one's inclination toward being physically active is increasingly challenged by the natural process of aging. With age, typically there occurs a natural decline in various physiological (e.g., loss of muscle mass and muscle strength) and cognitive (e.g., reduced memory and attention) functionalities, contributing to an overall decrease in physical activity [2-4].

Yet, despite the physiological challenges and tendency to become more sedentary in old age, evidence shows that regular physical activity is necessary for an active and healthy aging process [5-7]. Nevertheless, physical inactivity remains a global health concern among older adults, contributing to various chronic ailments such as diabetes, high blood pressure, heart disease, functional decline, and falls [8-10].

With an increasing global population of older adults (65+), falls among this group is a severe problem, accounting for 40% of all deaths resulting from injury and more than 50% of all injury-related hospitalization within the age group [11]. Overall, fall injuries are also responsible for physical dysfunction, significant disability, loss of independence among older adults, and various physical and psychological after-effects such as increased fear or falling [12].

Research shows that regular exercise can effectively improve one's balance—the ability to maintain a position without losing control or falling by supporting the body's center of mass within the base of support while in static positions and while moving (dynamic) [13, 14]. Studies show that one's balance can be improved by reducing postural sway, increasing flexibility, and strengthening lower-limb and core muscles [15]. Exercises improving balance have been shown to aid in preventing falls among older adults [16]. Balance training has particularly been identified as one of the most critical components in exercise interventions to reduce falls among older adults [17]. Balance training exercise interventions are widely used in the healthcare sector to train balance and prevent falls in older adults, and are also used by physiotherapists to rehabilitate frail older adults [18-21].

While traditional balance training exercises have shown to be effective in improving balance, current advancements in information and communication technology (ICT) have resulted in numerous interactive movement-based applications, some of which have shown potential in training and rehabilitating balance (Figure 1) [22-25]. Poor postural control, which is identified as one of the major risk factors associated with falls, is a physiological condition targeted in fall prevention programs currently using movement-based video games [26]. With older adults further constituting the single largest sector of people requiring healthcare in modern-day society, the use of serious gaming technology for this population has rapidly grown during the last decades [27]. In this regard, such movement-based interactive applications are also being used by physiotherapists for balance training and rehabilitation in older adults [18-21].

Within the field of human-computer interaction (HCI), the overlap between interactive technology and the human body has become a widely appealing area of interest (e.g. [28-31]).

Figure 1: Older adult training with the SilverFit balance training game (Retrieved from [32] photo: Thor Nielsen).

However, despite the potential and increasing attention given to movement-based technology, there is limited knowledge about designing for balance training and rehabilitation [33] due to the challenges of designing for the human body [34, 35], and the limited research conducted on movement characteristics (quality of movement) in commercial exergames [36, 37]. There is also the concern that most of the interactive technology currently available for physiotherapists has not been designed based on an understanding of how physiotherapists work and what they need; instead, they are products made largely for other purposes (e.g., entertainment).

Within HCI, numerous studies [38-40] accentuate various aspects of designing movement-based interactive technology, with no specific focus on designing for movement itself. The limited studies [41-43] that do reflect on designing for movement provide little to no reflection on designing for *specific* movement characteristics to improve health conditions (e.g., balance). The same prevails in movement science, with limited studies [44, 45] focusing on the design of specific movement characteristics during gameplay. Another issue concerns the limited commercial exergaming technologies currently designed for serious purposes, such as balance training and rehabilitation, to induce specific movement characteristics during gameplay.

The limitations mentioned above (lack of design knowledge and commercial exergames designed for serious purposes), in conjunction with the criticality of the context, exacerbate the need for more research contributions in this regard.

The overall aim of the thesis is to inform the design of movement-based interactive technology supporting balance training in older adults.

1.1 Relevant Disciplines

The specific area of focus is multidisciplinary, as it requires substantial knowledge corresponding to the movement of the human body, which informs the process of game design and the implied player–game interactions. Research on movement-based interactive technology for balance training is therefore multidisciplinary, with the focus overlapping three main areas of study: HCI [46], movement science [47], and game design [48] (Figure 2).

HCI is multifaceted and focuses on an array of topics corresponding to the design and use of various types of digital technology. Within HCI, of particular relevance for the thesis is *movement-based interaction* [49-51], i.e., the interaction with digital interfaces through body movements.

Movement science encompasses various topics corresponding to the movement of the human body. Within movement science, of specific relevance for the thesis is *functional training and rehabilitation* [52-54], i.e., specialized healthcare exercises to improve, maintain, or restore physical function.

Similarly, while game design can be seen as a vast field of study pertaining to the design and aesthetics of developing games for various contexts, of particular relevance for the thesis is that of *exergaming* [55-57], i.e., playing digital games that require physical exertion.

Thus, the Ph.D. thesis is framed between the fields of movement-based interaction, functional training and rehabilitation, and exergaming. While the overall thesis is a HCI contribution, particularly to movement-based interaction, it also contributes to the other fields of exergaming, functional training and rehabilitation, as the area of focus is multidisciplinary (Figure 2).

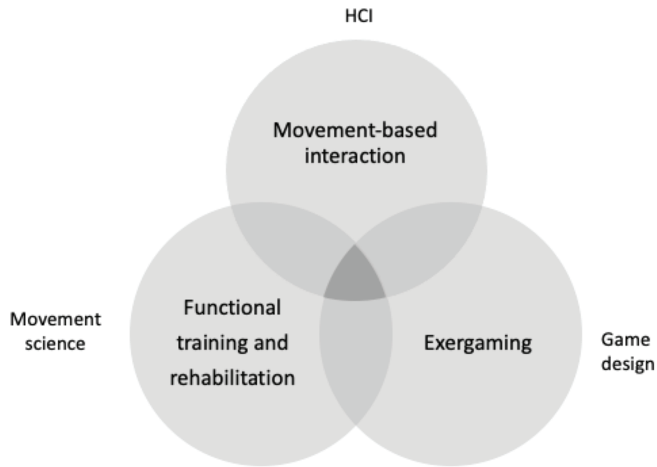


Figure 2: Relevant disciplines.

1.2 Research Questions

The following research questions help address various aspects of the overall aim of the thesis, which is to contribute toward designing movement-based interactive technology to train balance in older adults. While the thesis raises a variety of concerns related to designing for balance training, the following are the specific issues focused on in the thesis.

Considering the overall aim of the thesis, the primary need was to identify existing design knowledge pertaining to movement-based interactive games that use the entire body (full-body). The focus was placed on games, as most of the research in this area has been on full-body interactive games [58-60]. Though the overall thesis focuses on balance training, it was necessary to have an extensive overview of design knowledge that was not limited to the context of balance training. This led to the first research question (RQ).

RQ 1. What are the existing *design recommendations* for full-body movement-based games?

The italicized words in the research questions intend to capture the overall essence of the individual questions and are used throughout the thesis while referring to individual research questions.

Research indicates that to serve as an effective tool for balance training and rehabilitation, interactive technology needs to be designed to elicit specific movement characteristics relevant to the function being trained [45]. This suggested the second research question.

RQ 2. How to design for specific *movements characteristics* beneficial for balance training?

Research also shows that the use of interactive technology for purposes such as training and rehabilitation strongly relies on adherence [60]. Since further studies [61, 62] have identified a lack of motivation to be a main factor responsible for low adherence to exercise, it was necessary to ask the following third research question:

RQ 3. What are the *motivational factors* influencing older adults while training using an exergame?

The findings from exploring the above questions through the process of design and evaluation prompted to look beyond screen-based interfaces and were the motivation for the fourth and last research question.

RQ 4. How can *tangible interactive technology* support physiotherapy practice?

The type of research questions identified suggest qualitative research; hence, the work that has been performed within the thesis is largely qualitative in nature.

The research questions further aid in illustrating the contributions of the thesis. The association between the research questions and the various research papers is provided in Table 2 (Chapter 4).

1.3 Thesis Structure

This thesis is based on five research papers. The thesis mainly comprises two parts. Part I provides an introduction and an overview of the collection of research papers, which are presented in Part II. Following the current introduction, the remainder of the thesis is structured as follows. Chapter 2 presents the background and motivation for the thesis. Next, the research framework is presented in Chapter 3. This is followed by a description of the employed research design in Chapter 4. The results of the individual research papers are summarized in Chapter 5. This is followed by a discussion of the thesis's contributions is presented in Chapter 6, and the methodological considerations are presented in Chapter 7, respectively. Finally, summary, concluding remarks, and suggestions for future work are presented in Chapter 8.

2 Background and Motivation

2.1 Functional Training and Rehabilitation

While it is only through our bodies that we know and experience the world, it is also through the movement of our bodies that we interact with and express ourselves in the world around us.

However, considering the natural decline in physical movement associated with the process of aging [63, 64], training and rehabilitation play a significant role in keeping older adults active and helping them sustain an independent lifestyle [65, 66].

While promoting physical activity, in general, is of significance among older adults to instigate a healthy aging process [67], specific health issues call for more specifically tailored exercise regimes. For instance, balance issues are a common problem among older adults, caused by the structural and functional deterioration of numerous systems within human anatomy [68]. In this regard, exergames are being used for balance training and fall prevention, while also being used for rehabilitation after suffering health issues (such as a stroke or hip fracture) [26, 69]. Such applications are being used by physiotherapists to both train and rehabilitate balance in older adults [18-21].

The increasing use of exergames is also due to their acceptance by older adults [70, 71]. This user group favors exergames, and the technology further shows potential in overcoming several barriers that are generally associated with traditional exercise programs, such as lack of access and social support or the challenges of getting to exercise venues [72].

However, despite the various prominent features of exergaming, there is no overlooking the lack in the design of exergames. Most commercially available exergames, and those used mainly in training and rehabilitation contexts, are not explicitly designed for such a purpose, since the primary design focus of the exergames is neither targeting older adults [59, 73, 74], nor the concerns of eliciting movements beneficial for improving users' balance [69].

2.1.1 Balance Training

Balance is defined as the ability to maintain a position without losing control or falling by supporting the body's center of mass within the base of support while in static positions and while moving (dynamic) [13, 14]. Balance is a skill that must be maintained through consistent practice throughout ones' lifespan. This is particularly true for older adults who experience various physiological (e.g., loss of muscle mass and muscle strength) and cognitive (e.g., reduced memory and attention) deterioration due to aging [2-4], which may impair their balance. In this regard, balance training exercise interventions have shown potential and are widely used in the healthcare sector to train balance and prevent falls in older adults, and are also used by physiotherapists to rehabilitate frail older adults with increased risk of falling [18-21]. Such interventions focus on reducing postural sway, increasing flexibility, and strengthening lower-limb and core muscles [15]. The exercises show potential in improving balance and preventing falls among older adults [17]. The Ottago exercises [130] are examples of balance training exercises (Figure 3), which provide explicit instructions on how to exercise (e.g., knee bending, backward walking, sideways walking).

Figure 3: Ottago balance exercise, walking backward (Reprint from [130], p. 60).

In this regard, previous research has identified the need for exercises to elicit specific movement characteristics relevant to the function being trained [45]. With respect to balance training, weight-shift—shifting body weight from one leg to the other (Figure 4)—is identified as one of the most beneficial movement characteristics (ibid.), as incorrect weight-shift is a common cause of falls in older adults. In this regard movement characteristic is a quality of movement, in the sense that many different movements can have the same characteristics (such as weight-shift).

Figure 4: Weight-shift movement characteristic beneficial for balance training.

2.2 Movement-Based Interaction

A growing body of research within the HCI community on movement-based interaction has primarily focused on the body as a medium of interaction [75]. In such a context, the body has been treated like an object used as a controller for interaction. However, Dourish [76] and Svanæs [77] elaborate on embodied interaction by opening up different perspectives of the human body, emphasizing that the body is not just an object in the world, but rather the source of experiencing the world from a first-person perspective.

Dourish [76] proposed the term *embodied interaction* to denote that the physical, bodily, and social aspects unfold in real time and space as a part of the world we are situated in, thereby reflecting the need for interaction design to focus on the aspects as inseparable from each other. He projects embodied interaction by illustrating that “you cannot separate the individual from the world in which that individual lives and acts” [76] (p. 18).

The concept of the “*lived body*”—the body through which we experience the world and body-based experiences—has largely influenced the evolution of current HCI [78, 79]. Svanaes [77] states that “The design of everyday technologies such as mobile phones, social media, and full-body interaction games should consequently have much to gain from a phenomenological approach” (p 8:2)—exploring a first person perspective.

From a pure entertainment (*hedonic)* point of view*,* the design of technology with a phenomenological approach has been primarily reflected in various studies that have contributed toward designing interactive technology for the human body by placing the body at the center of user experience [34, 80, 81].

The interdisciplinary field of somaesthetics initially proposed by Richard Shusterman [82] by combining the words *soma* (the body) and *aesthetics* (sensory perception) reflects on the sensory perception of the human body and the significance of the body not only as a source of perception but also as a source of expressing ourselves through our bodies. Somaesthetics is seen as an approach to analyzing and improving the connection between sensations, feelings, emotions, and subjective understanding and values [83]. As such, studies [83, 84] report the implementation of a somaesthetic approach to support a meditative bodily introspection through the design of the Soma Mat and Breathing Light, intended for stimulating body awareness through introspection, enriching somatic sensitivity, and as a medium for relaxation.

The above philosophical foundations have inspired the work presented in this thesis, though it is not a part of the theoretical framework itself. The above studies further aid in positioning the thesis and illustrating how the work presented in the thesis relates to the broader field of movement-based interaction.

While the above studies [83, 84] primarily focus on the experiential aspect of the body without much need for physical activity, other studies also focus on using interactive technology to promote physical activity. Mueller and Young [85] investigated various sport perspectives (e.g., walking, swimming) in designing for exertion. Jensen et al. [86, 87] present a throwball-based exertion game while illustrating how to design sport-based training games. Mueller et al. [88] have illustrated an exertion framework for developing sport-based exertion games. Nylander and Tholander [43] have also contributed to sport-based interaction design by evaluating various sports themes.

Similarly, the potential of dance-based games has also been researched. For instance, Allen and Holzer [89], Charbonneau et al. [90, 91], and Tang et al.[92], have evaluated the potential of various full-body dance games (e.g., Jingle Jigsaw and RealDance) based on factors such as usability, player experience, performance, and/or enjoyment.

On a similar note, the aspects of *bodily play* have also been analyzed in various other studies [93, 94]. Overall, such perspectives of exploring the design of body-based applications have given rise to more playful and engaging interactive technology.

Shifting to more serious (*utilitarian*) purposes, many movement-based technologies are used to promote physical activity with a specific focus on improving health as well as being used in the context of physical therapy and rehabilitation [95-97]. Some studies further focus on the user experience and the usability of technology in this regard [98, 99].

The growing interest in the field has led researchers and designers to explore different ways of working with movement as input to interactive technology. For instance, studies [100, 101] recommend conceptualizing movement as a design material, and that designers need design tools, techniques, knowledge, awareness and skills that support their search for expressive, rich behavior in bodily movement. Hansen and Morrison [101] further suggest that for interaction design, movement may be parsed by *Velocity, Position, Repetition,* and *Frequency*. Uzor and Baille [60] additionally suggest modeling interactive games for serious purposes on the basis of evidence- based therapy to promote an ideal quality of movement for an effective therapy.

The limited studies [60, 100, 101] focusing on movement in movement-based applications reflect on the design of movement. However, they provide little to no reflection on designing for specific movement characteristics (e.g., weight-shift characteristics beneficial for balance training [33, 45]) within the HCI community.

2.3 Exergaming

Advancements in ICT over the last decades have provided us with various comforts and conveniences in everyday life. This progress has contributed to the epitome of a sedentary lifestyle in present-day society [102]. Nevertheless, the surge of technological developments has also given rise to various technologies, such as exergames, to endorse physical activity and counteract the notion of being sedentary.

As stated by Mueller et al. [103] (p. 1), exergames or exertion games can be defined as "computer game systems that foster physical exertion as part of the interaction."

With reference to the *History of Exergames* [55], the very first exergame was introduced in 1980 with the launch of the Ataria *Joyboard*—a balance board peripheral for its 2600 game console model. The Joyboard was used to steer the game by standing on it and leaning in different directions.

Forty years from the launch of the first exergame, and today there exists a variety of commercial exergaming systems (Figure 5) that make use of various input devices such as exercise bikes, balance boards (e.g., Wii balance board), floor mats, 3D cameras/motion recognition sensors (e.g., Microsoft Kinect), or handheld controllers (e.g., PlayStation Move, Wii remote). Currently, exergames are played on popular consoles such as the Nintendo Wii[1], Microsoft Xbox[2], or the Sony PlayStation[3].

Figure 5: Commercial exergaming consoles (a) Nintendo Wii gaming console (b) The Playsation Move controller and Eye camera (Retrieved from Nintendo and Sony).

Exergaming was initially used for the purpose of entertainment. However, as it was later used for more serious purposes such as physical therapy and rehabilitation [104-106], a growing body of research emerged on the various health effects of exergaming. This further emphasized that most commercial exergames are not designed for serious purposes, as they neither target specific health conditions nor specific user groups. Nevertheless, such technologies are still widely used for serious purposes, such as physical therapy and rehabilitation.

[1] https://www.nintendo.com
[2] https://www.xbox.com
[3] https://www.playstation.com

An exception to most commercial exergaming technology, are products from MIRA Rehab[4], Dividat AG[5], and SilverFit[6], which provide training and rehabilitation systems based on evidence-based therapy. The SilverFit BV in the Netherlands provides games specifically designed for older adults to be used in therapeutic sessions for e.g., fall prevention [2]. The exergames available from the aforementioned companies (e.g., The SilverFit Mole game and Fox game) are screen-based exergames that largely use the Microsoft Kinect to train specific movements, as the games are designed to elicit movements that match the specific exercises required for balance training and rehabilitation.

This limited pool of commercial technology designed for the specific health concern (balance training and rehabilitation), targeting a specific user group (older adults), suggests that there is both the room and the need for additional research and knowledge.

The missing gap in all three fields essentially reflects a lack of design knowledge in developing interactive technology to encourage movement elicitations that help improve balance. The overall limitations suggest the need for more research contributions in this regard. The primary focus of the thesis is to help address this concern by contributing toward a better understanding of how to design interactive technology for the functional training and rehabilitation of older adults to elicit movement characteristics beneficial for improving balance.

[4] http://www.mirarehab.com
[5] https://dividat.com/en/
[6] https://silverfit.com/en/

3 Research Framework

This chapter presents the research framework, including the strategies, data generation, and data analysis methods that have informed and guided the work presented in the thesis.

3.1 Model of the Research Process

The research process used in the thesis is based on Oates's definitions, as provided in his book *Researching Information Systems and Computing* [107]. Figure 6 gives an overview of the research process in computer science and its components, as given by Oates (ibid.). As Oates [107] largely focuses on performing empirical research, the empirically driven research questions within the thesis (RQs 2, 3, and 4) were guided by his model of the research process (Figure 6). The following sections further describe the research process relevant to the thesis.

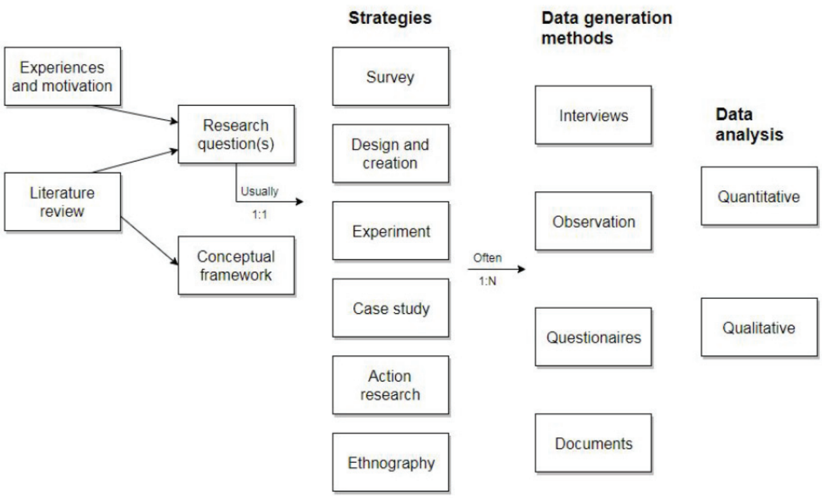


Figure 6: Model of the research process (Based on Oates [107]).

3.2 Preliminary Phase

3.2.1 Experiences and Motivation

The research questions for studies usually emerge either from personal experiences and motivation and/or from a literature review [107]. Oates [107] states that it is necessary to remind ourselves of why we are doing research and to think about the motivation to do so. He adds that personal experiences, such as likes or dislikes, can also aid in thinking about possible research questions and addressing the questions.

3.2.2 Literature Review

Oates [107] describes literature review as a preliminary step aiding in identifying existing research and research gaps, and further deciding on viable research questions, while also referring to it as an ongoing process throughout the research time that helps keep up to date on published research.

By supporting researchers' claims that a topic is worthwhile, that research is not repetitive of existing work, and that the research contributes to new knowledge, Oates states that reviewing existing literature is meant to address the following objectives:

- Providing awareness in a chosen area of research.
- Aiding in positioning work in the context of existing research.
- Pointing to strengths and weaknesses in existing work.
- Identifying critical issues and gaps in the research community.
- Identifying theories that may be tested or explored.
- Identifying research methods that can be used.

As suggested by Oates [107], while the literature review conducted as a part of the thesis (Paper-III-Review) aided in identifying RQ 4 (tangible interactive technology), the literature review primarily helped address the preliminary RQ 1 (design recommendations).

3.2.3 Research Question

As previously mentioned, Oates [107] states that research questions can be identified based on motivation and existing literature. With respect to motivation, it is suggested to ask oneself what is motivating, the type of research, and the type of knowledge outcome that one is inclined to pursue. Based on suggestions in the literature, research questions can then arise based on factors such as where more research is needed, or calls for papers in journals or conferences on a particular topic.

3.2.4 Conceptual Framework

Oates [107] states that a conceptual framework explains how one structures and thinks about the research topic and process. Thereby, the conceptual framework clarifies things such as the relevant theory and the research approach chosen to tackle the research question.

The next step in the research process lies in opting for suitable research strategies to answer the research question(s).

3.3 Research Strategies

Oates [107] defines a research strategy as an overall approach to answering research questions and highlights the following six main strategies:

- *Surveys*: focuses on retrieving the same kind of data from large groups of people in a standardized and systematic way.
- *Design and creation*: focuses on developing new IT products or artifacts.
- *Experiment*: investigates the cause and effect, tests hypotheses, and supports or disproves a causal link between factors and observed outcomes.
- *Case study*: focuses on an instance of the 'thing' to be investigated, either an organization, department, information system, a development project, decision, etc., to obtain detailed insight.
- *Action research*: focuses on doing something in real-world situations and reflects on what happened or what was learned.
- *Ethnography*: focuses on understanding the culture of particular groups of people by spending time in the field rather than being detached observers.

The following sections elaborate on the relevant strategies for the thesis: *design and creation, and experiment.*

3.3.1 Design and Creation

The design and creation research strategy focuses on developing new IT products called artifacts and is an expected research mode in areas such as computer science and software engineering.

Oates [107] refers to Vaishnavi & Kuechler [108], who state that *design and creation* generally involves a problem-solving approach in a five-step iterative process involving awareness, suggestion, development, evaluation, and conclusion.

- *Awareness* is referred to as the recognition and articulation of a problem, which arises from studying existing literatures as the authors identify areas for improvement and further research, from practitioners or clients expressing the need for something, or from field research, or from new developments in technology.
- *Suggestion* is referred to as a leap from the problem to offering tentative ideas of how the problem may be addressed.
- *Development* is the third step, which involves implementing tentative design ideas, depending on the IT artifact being proposed.
- *Evaluation* is the next step and involves examining the developed artifacts and assessing their worth.

- *Conclusion* is the final step, which involving consolidated written-up results from the design process, where the acquired knowledge is identified as well as any unexpected or anomalous results which can serve as the basis of further research.

The steps are described as fluid and iterative cycles, rather than rigid steps to be followed.

Figure 7 provides an overview of the research methodology and development methodology, comprising research strategy(ies) and the data generation methodologies.

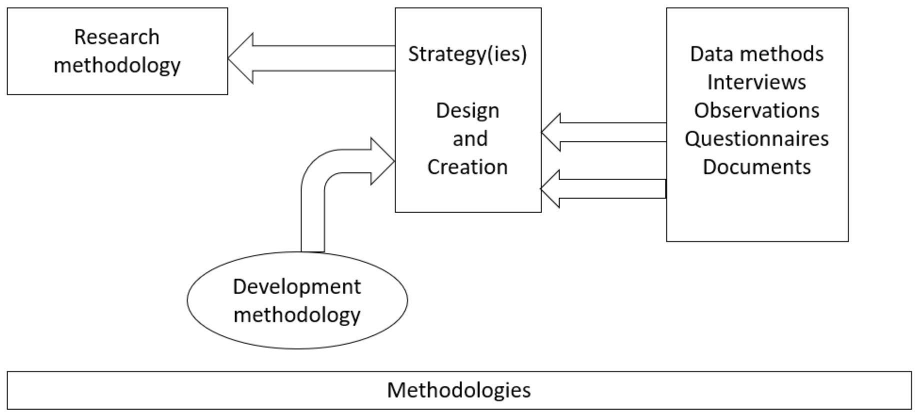


Figure 7: Design and creation research methodology and development methodology (Based on Oates [107]).

With respect to system development, the *waterfall model*—sequential software development process, is one of the most traditional. However, with this method, all analysis is required to be completed before moving to the design, and all design is required to be completed before moving on to implementation. However, as mentioned by Oates [107], it is often only through the process of design and implementation of a possible solution that an increased understanding of the original problem is obtained.

Hence, concerning system development methodologies, Oates [107] states that *prototyping* is a commonly used system development approach that allows for a first version, or a prototype system, to be analyzed, designed, and implemented. The understandings from the first prototype further lead to revised system prototypes. In such a way, the prototype is gradually modified until a satisfactory implementation is obtained. In the context of the thesis, the prototyping that was carried out was user-centric, as users' needs and requirements were the main focus when designing the prototypes.

Further, the evaluation of the developed artifacts involves evaluation based on factors such as functionality, completeness, consistency, accuracy, performance, reliability, usability, accessibility, aesthetics, entertainment, and fit with the organization.

3.3.2 Experiment

In a generic sense, an experiment refers to trying something out to see what happens. In academic research, an experiment is defined as a strategy to investigate cause-and-effect relationships, while allowing to support or disprove links between factors and outcomes [107]. While it is possible to initially have a hypothesis and further conduct an experiment to test the hypothesis empirically, the research conducted as a part of this thesis was largely exploratory in nature.

Oates [107] states that experiments are characterized by the following:

- Observation and measurement of outcomes and changes when a factor is introduced or removed.
- Series of observation or measurement, manipulation of circumstances, and re-observation or re-measurement of factors.
- Proving or disproving relationships between two or more factors.
- Identifying causal factors by discovering factors which are the cause, and which are the effect.
- Explanation and prediction by providing explanation of the link between factors.
- Repetition, by repeating experiments several times under varying conditions.

Experiments can either be conducted in their natural environment (i.e., the field) or in a controlled environment (i.e., the laboratory). Both contexts present benefits and limitations.

Conducting research in a laboratory provides control over numerous factors and often makes it easier to collect data and replicate the study. It can also in some cases, be cost-efficient, as equipment does not need not to be moved and set up in multiple locations.

However, sometimes it is impractical or impossible to generate the data needed in a laboratory when dealing with long-term use, and in studies where the context of use is crucial. In such cases, it may then be necessary to conduct field research. However, field research yields less control, and collecting data can sometimes be harder as it may not be possible to set up equipment, such as cameras from all angles, and avoid distractions.

3.4 Data Generation Methods

This section describes the data generation methodologies used in the thesis.

3.4.1 Interviews

An interview is a particular type of conversation where one or more of the participants aim to gather information from the other(s). The topic of the conversation is generally planned to an extent by the interviewer. Depending on how much the interviewer guides the topic, it can either be a structured, semi-structured, or unstructured interview [107].

A structured interview uses a set of predefined and standardized questions for each interview and does not encourage casual conversation. A semi-structured interview also has predefined questions, but allows the interviewer to change the order of the questions to fit the conversation more naturally, and allows for unplanned questions if the interviewee says something the interviewer would like more information about.

These two types of interviews are suited for when the interviewer aims to answer something specific. An unstructured interview only introduces the topic and subsequently allows the interviewee to determine the content of the conversation to a much larger degree. For example, this could be useful if the researcher does not wish to answer a set of questions but looks instead to gather general information about, or someone's view on a given topic [107].

How the data is analyzed can also be a deciding factor as to which type of interview should be conducted. For example, a quantitative analysis might not benefit from an unstructured interview, as the data acquired in each type of interview can be very different, and appropriate for different types of analysis [109].

3.4.2 Observations

While observation refers to paying attention to something as it happens, the process of observation is used in research to determine and record what happens, and not what people report.

As mentioned by Oates [107], there is often a mismatch between what people do and what they believe they do. Observation is often associated with watching something, but the observer can use other senses as well such as hearing, smelling, touching, and tasting (ibid.). In the thesis, sight and hearing were the senses used during observations.

There are many ways researchers can conduct observatory research. It could involve a short five-minute observation, or it could span over multiple years. The researcher can observe without informing anyone or make it clear to everyone involved. Oates defines a range of factors that differentiates between the various types of observations [107] (p. 203). While simple note-taking can help keep records, other approaches for keeping notes can include audiotapes, cameras, stopwatches, and two-way mirrors.

3.4.3 Questionnaires

Questionnaires are predefined sets of questions, assembled in a predefined order, that participants answer to provide researchers with data that can be further analyzed and interpreted [107]. Questionnaires can be used for various research strategies, such as surveys, case studies, action research, and design and creation.

The questions presented in questionnaires can either be open questions or closed questions.

Open questions allow respondents to decide what answer to provide, as they are merely provided with a blank space to fill as they want to. However, closed questions require respondents to choose from a range of answers that are predefined by the researcher.

3.5 Data Analysis

Both quantitative and qualitative analysis has been performed in this thesis. Quantitative analysis, as defined by Oates, focuses on numeric data, which can be analyzed using statistics, such as average and range; qualitative analysis focuses on themes in the words used [107]. The research presented in the thesis is explorative, with no stated hypothesis to test. Our main research approach was qualitative. However, the results presented in the thesis are a combination of both quantitative and qualitative results.

3.5.1 Quantitative Data Analysis

Oates [107] stated that quantitative data refers to data, or numerical evidence, which is largely associated with experiments and surveys. The primary focus in analyzing quantitative data is to look for patterns and to draw conclusions. Quantitative analysis generally makes use of tables, charts, or graphs to provide illustrations.

Statistical analysis is largely used for quantitative data to identify whether there are trustworthy links and patterns within data. To describe the central tendency of the data, i.e., where the majority of data is found, three statistical measures are used: mean, median and mode.

- *Mean* refers to the average, (i.e., the total of all values divided by the number of cases).
- *Median* refers to the midpoint in a range of data results (list values in ascending or descending order and read off the middle value).
- *Mode* refers to the value most common in the data set.

In addition to the central tendency of data, there is also the need to know how widespread data sets are, in order to find the distribution of data. Standard deviation is a commonly used measure of distribution, which indicates the average distance of each data value from the mean. The numerical data analysis allows for further interpretations and implications to be made.

3.5.2 Qualitative Data Analysis

Qualitative data comprises of non-numeric data, such as words, pictures, and audio found in interview tapes. Oates states that to analyze this type of data, it is common to also use qualitative analysis methods, although it is also possible to count the occurrences of a word, the number of pictures containing a specific element, and so on to do a quantitative analysis [107].

It can be beneficial to get as much of the data in the same format as possible, making it easier to compare them. Since text is easier to analyze than for example audio, it is necessary to transcribe audio files. When the data is in a workable format, it should be sorted into categories based on importance to the study. Oates suggests three categories: relevant to the research question(s), relevant to the context, and irrelevant to the study [107].

A common way to analyze the qualitative data is to further categorize it by themes once it is organized properly. This can be done using Post-it notes or digital tools like Nvivo [110]. From these themes, one can find patterns and possibly the answers to the research question(s) [107]. Oates (ibid.) states the importance of researchers pursuing qualitative analysis with an open mind without any preconceived notions about what is relevant and useful in categorizing data.

In this regard, Oates proposes three phases of coding:

- *Open coding:* This is the primary process of labeling units of data based on terms and concepts found in the data.
- *Axial coding:* Following the emerging list of codes, researchers move to either a higher or more abstract level of analysis to identify relationships between the codes.
- *Selective coding:* In this phase, the researcher focuses on just the core codes that emerged as critical in the context being investigated.

The analysis requires employing a constant comparative method, as new emerging codes or categories are consistently compared with previously coded data.

However, non-textual data, however, is often hard to categorize and analyze the way explained above. In many cases, images are used to substantiate the results from textual data [107]. However, images can also be used to look for patterns, similarities, and differences, which can aid in answering research question(s).

3.6 Research Quality

It is necessary for research to be conducted in such a manner that the results are of high quality, and to further ensure that they are accepted by the readers. It is, therefore, critical to employ the correct measures while conducting research.

3.6.1 Research Paradigms

Oates [107] defines research paradigms (positivism, interpretivism, critical research), and how to judge their quality, while explaining how the different research strategies are linked to different paradigms. Of relevance for the thesis is that of *positivism,* which focuses on finding universal laws, patterns, and regularities [107].

3.6.2 Quality Criteria

Below are the quality criteria for positivist research as described by Oates [107].

The criteria for judging the quality of positivist research are as follows:

- *Objectivity*: ensuring that the research is free from researcher bias and distortion.
- *Reliability*: ensuring that research instruments are neutral, accurate, and reliable, thereby ensuring the same results when repeating an experiment (i.e., repeatability).
- *Internal validity*: ensuring that research was well designed enough to examine the correct phenomena and collect the correct data from the correct sources.
- *External validity*: ensuring that research findings are generalizable to different people, settings, and time.

4 Research Design

This chapter provides an overview of how the research process was applied to address the individual research questions.

4.1 Research Questions and the Research Process

This section presents the individual research questions, the corresponding research process chosen, and the rationale for addressing it as such within the thesis.

4.1.1 Research Question 1

What are the existing *design recommendations* for full-body movement-based games?

The initial stages of the Ph.D. focused specifically on full-body games, as this was and still is the most conventional form of training when it comes to interactive technology. As a result, it was necessary to identify existing design knowledge pertaining to full-body games and consequently answer RQ 1.

The nature of RQ 1 required performing a literature review to identify existing design knowledge that was relevant, but not restricted to, the context of balance training and rehabilitation alone. A systematic literature review of studies from five major databases resulted in the inclusion of 22 relevant studies, which revealed 107 design guidelines for full-body games, which were further coded for themes and categorized based on relevance—thereby addressing RQ 1 (design recommendations) in Paper-III-Review.

4.1.2 Research Question 2

How to design for specific *movement characteristics* beneficial for balance training?

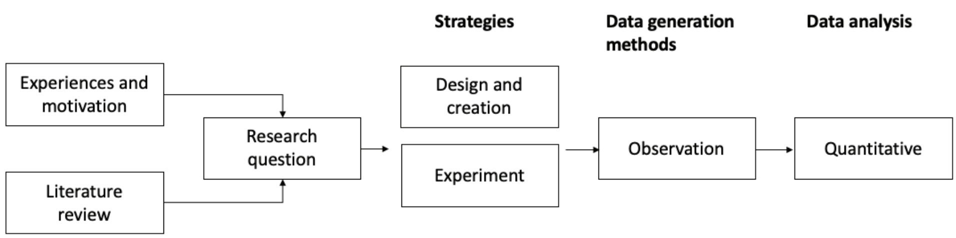


Figure 8: Model of the research process to address RQ2.

The preliminary phase of identifying RQ 2 originated from the review of existing literature, which suggested several relevant movement characteristics that should be part of exercises to ensure balance training effective for fall prevention [111-115]. Additionally, previous experience and research within the research group also indicated the need to design movement-based interactive technology to elicit specific movement characteristics beneficial in training balance [33, 45]. Hence the need emerged to identify how to design for specific movement characteristics beneficial for balance training and thereby answer RQ 2.

As presented in Figure 8, the research strategies opted to address RQ 2 (movement characteristics) were that of design and creation, and experiment. RQ 2 could have been answered using various other research strategies, such as ethnography or experiments without design and creation. Opting for such strategies would have involved either studying people in their own homes or testing out existing exergames, for instance.

However, the main rationale for building my own prototype (*Celestial Shower*) was that to the best of my knowledge, there were no similar open-source systems available that would allow for implementing or modifying system behavior. So building a prototype enabled me to have complete control of the system, which would not have been possible otherwise, resulting in a customized prototype, that was adaptive and designed to elicit specific movement characteristics beneficial for training balance [45].

Following the prototype development, a laboratory-based experiment was conducted using the prototype to address the research question. In this regard, video recordings from the experiment, referred to as *multimedia documents* by Oates [107] (p. 235), served as the main source of data generation. The experiments' multimedia documents were analyzed to provide quantitative data illustrating how players move while training using an exergame compared to how the game was designed to make them move—thereby addressing RQ 2 in Paper-I-Movement.

4.1.3 Research Question 3

What are the *motivational factors* influencing older adults while training using an exergame?

The preliminary phase of identifying RQ 3 originated from the review of existing literature, which revealed that player adherence to exergames for an extended period remains an open problem [116, 117]. Further research indicated that despite the advantages associated with exergaming, it is necessary to design interactive technology for older adults based on their specific preferences, motivation, and needs to ensure better performance and adherence [118-120].

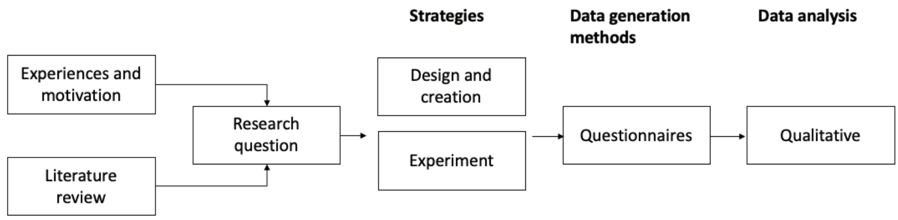


Figure 9: Model of the research process to address RQ3 (motivational factors).

Figure 9 illustrates the research process opted to address RQ 3 (motivational factors), involving design and creation, and experiments. It is worth mentioning that the experiments conducted to address the previous RQ 2 (movement characteristics) also allowed for generating the necessary data to address RQ 3 (motivational factors).

RQ 3 (motivational factors) could have possibly been answered using other research strategies such as surveys or experiments without design and creation. However, opting for surveys, for instance, would have been problematic considering that very few older adults have experience with movement-based interactive technology, and it would not have been reasonable to ask them about technology that they were not familiar with. Hence, the implemented approach of allowing people to try out a specific technology and later asking them about their experience seemed more appropriate. Additionally, while one could argue for conducting experiments using existing technology without the need for a design and creation process, as previously mentioned, the experiments conducted to address RQ 2 (movement characteristics) allowed for generating the necessary data to also address RQ 3 (motivational factors).

Therefore, as shown in Figure 9, the research strategies chosen (design and creation, and experiment) are the same as those of the previous research question. However, while RQ 2 was addressed based on observation from the experiments, RQ 3 was addressed based on the questionnaires obtained from the same experiment.

Participants' responses to questions in the questionnaires served as the main source of data generation in addressing RQ 3 (motivational factors). The data was further analyzed by generating codes—an iterative data analysis process where categories are added until inductive thematic saturation. The described research process thereby allowed for addressing RQ 3 (motivational factors) in Paper-II-Motivation.

4.1.4 Research Question 4

How can *tangible interactive technology* accommodate physiotherapy practice?

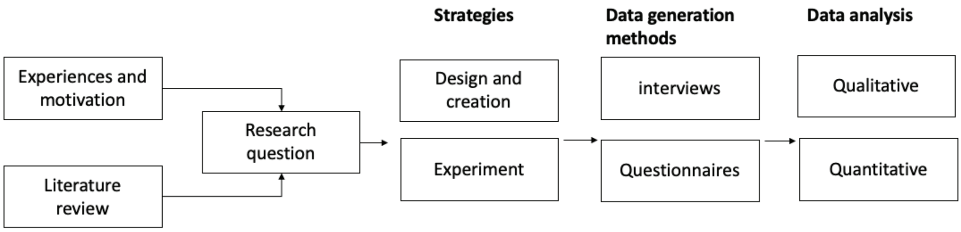


Figure 10: Model of the research process to address RQ4 (tangible interactive technology).

The preliminary phase of identifying and answering RQ 4 originated from the review of existing literature, which suggested that despite current technological advancements, technology is still not a standard part of physiotherapists' toolboxes [121], and the need for interactive technology to integrate with their work practice[122-124]. The initial phase of the thesis work additionally provided the necessary insights in this regard.

The design and creation of the *Celestial Shower* prototype resulted in Paper-I-Movement and Paper-II-Motivation, addressing RQs 2 and 3, respectively. It was also at this point that several drawbacks associated with screen-based solutions came to the forefront. Furthermore, the structured literature review for Paper-III-Review revealed the large emphasis placed on screen-based solutions compared to tangible, non-screen-based interactive technology.

These findings prompted to broaden the horizons and explore more tangible solutions, while shifting focus from merely structured and conventional screen-based games to less structured and more explorative forms of tangible interactive technology, such as the *ExerTiles*. This shift toward a more tangible solution was also necessary to ensure better integration of the technology with physiotherapists' current work practice.

Figure 10 shows a model of the research process chosen to address RQ 4 (tangible interactive technology). RQ 4 (tangible interactive technology) could have also been addressed using other research strategies, such as surveys or experiments, without the need for design and creation. However, it did not seem appropriate to question physiotherapists about technology that they might not be familiar with. Furthermore, the main rationale for building interactive tiles was that, to our knowledge, there were no open tangible interactive systems available that would allow implementing the requirements obtained from the initial workshops.

Therefore, design and creation, as well as experiments were the opted research strategies in this regard. The data generation required to inform design and creation involved co-design workshops with physiotherapists to understand their design considerations for tangible interactive technology for balance training. This understanding further informed the design of the prototype, which was later evaluated in laboratory-based experiments with both physiotherapists and older adults.

The results from the prototype assessment, which illustrate the physiotherapists' perceived value of the *ExerTiles*, provided the main empirical basis for addressing RQ 4 (tangible interactive technology) in Paper-V-Tangibles. The data was generated in the form of interviews and questionnaires.

A coding approach was further used to analyze the transcribed interviews, which were iteratively coded for themes. The codes were checked for consistency to match the categories that came up during the interviews. Additionally, the questionnaires where participants rated the *ExerTiles* were evaluated to present the min, max, and median values for various factors associated with the technology.

The overall research process described thus allowed for addressing RQ 4 (tangible interactive technology) in Paper-V-Tangibles.

4.2 Study Design

The research questions addressed in the thesis were based on literature reviews and experiences and motivation from earlier research. The research strategies applied to address the concerns included a systematic literature review, design and creation (prototyping and game development), and laboratory-based experiments (usability tests and prototype assessments). Data was collected through observations, interviews, and questionnaires, resulting in both quantitative and qualitative data. The research process chosen to address the individual research questions is illustrated in Table 1.

RQ 2 and RQ 3 were addressed by performing laboratory-based experiments assessing player movement strategies and motivational differences between young and older adults while playing a whole-body exergame. RQ 1 was addressed by performing a systematic literature review to identify existing design guidelines for full-body exergames, while RQ 4 was addressed by opting for a user-centered design research approach that focused on the use of tangible interactive technology as a tool for physiotherapists to train balance among older adults. In this regard, RQ 4 was addressed by performing co-design workshops with physiotherapists and prototype assessments with both physiotherapists and older adults.

Table 1: Research process chosen to address the research questions.

Research Strategy	RQ 1 (Design Recommendations)	RQ 2 (Movement characteristics)	RQ 3 (Motivational factors)	RQ 4 (Tangible interactive technology)
Systematic Literature Review	●			
Laboratory-Based Experiment		●	●	●
Design and Creation		●	●	●

Data Generation Methods				
Observation		●		
Questionnaire			●	●
Interview				●
Data Analysis Methods				
Quantitative		●		●
Qualitative	●		●	●

4.3 Relation Between the Research Questions and Papers

All papers presented in the thesis focused on designing movement-based interactive technology addressing various concerns of designing for balance training and rehabilitation (RQs 1, 2, 3, and 4). Table 2 provides an overview of the research questions addressed in the individual papers.

Table 2: Research questions addressed in the papers.

	RQ 1 (Design Recommendations)	RQ 2 (Movement characteristics)	RQ 3 (Motivational factors)	RQ 4 (Tangible interactive technology)
Paper-I-Movement		●		
Paper-II-Motivation			●	
Paper-III-Review	●			
Paper-IV-Framework				●
Paper-V-Tangibles				●

The main focus of Paper-I-Movement was to identify how to design for specific movement characteristics beneficial for training balance by comparing player movement strategies during gameplay with the design-intended movements. In this regard, the study addresses the concern of designing for specific movements, thereby addressing RQ 2 (movement characteristics).

The primary focus of Paper-II-Motivation was to identify the motivational factors influencing older adults while training using an exergame and to compare it with that of young adults, thereby addressing RQ 3 (motivational factors).

Paper-III-Review focuses on providing an overview of existing design recommendations for full-body games and addresses RQ 1 (design recommendations).

Paper-IV-Framework provides an overview of the software framework implemented in the development of the *ExerTiles Toolkit*. This tangible interactive technology served as the basis for the study reported in Paper-V-Tangibles. Paper-IV-Framework does not contribute to the empirical findings, but serves as the technical documentation of the

ExerTiles Toolkit. Nevertheless, the paper provides insight into designing tangible interactive technology, thereby helping address RQ 4 (tangible interactive technology) and was therefore included in the thesis.

Paper-V-Tangibles focuses on designing tangible interactive technology for physiotherapists to train older adults and addresses RQ 4 (tangible interactive technology).

4.4 Data Collection and Analysis

All the experiments reported in the thesis are laboratory-based assessments conducted at the Computer Science Department's usability laboratory at the Norwegian University of Science and Technology.

4.4.1 Paper-I-Movement

The results presented in Paper-I-Movement compare and analyze player movement strategies during gameplay of the *Celestial Shower* exergame with the actual design-intended postures of the game based on a video analysis of players' movements while playing the game. The coding of the video was performed using a Labanotation-inspired [125] coding scheme to code and categorize the various player postures during gameplay.

4.4.2 Paper-II-Motivation

The results presented in Paper-II-Motivation, which aimed to identify the motivational differences between young and older adults playing a balance training exergame, were based on participants' answers to a questionnaire comprising several questions about the game. An open coding approach was then used to analyze the participants' answers [126], thereby checking for similarities and differences among the codes and further grouping them into relevant categories.

4.4.3 Paper-III-Review

Paper-III-Review presented results from a systematic literature review based on searches performed in five major databases. The final corpus of papers, which survived the various rounds of exclusion, was read in full and analyzed iteratively to extract numerous study details. Additionally, individual design guidelines and the context in which they were derived were extracted separately and served as the paper's main findings.

4.4.4 Paper-IV-Framework

Paper-IV-Framework provides an overview of the software framework implemented in the development of the *ExerTiles Toolkit*, which served as the basis for the study reported in Paper-V-Tangibles. While the paper itself does not contribute empirical findings to the thesis, it merely serves as a technical documentation of the *ExerTiles Toolkit*. Therefore, Paper-IV-Framework was included as a part of the thesis to provide a complete overview of the research performed throughout the duration of the Ph.D.

4.4.5 Paper-V-Tangibles

The research process reported in Paper-V-Tangibles was based on a series of co-design workshops and assessments. The results from the experiment, which served as the main empirical basis for the study, were obtained by analyzing the audio recordings from the interviews and the video recordings from the assessment. The Nvivo 12[7] was used to perform an open coding analysis of the audio and video recordings and further group the emergent codes into relevant categories.

[7] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

5 Summary of the Papers

This section provides an overview of the results of the research papers presented in Part II. The studies reported in the research papers were conducted per the Declaration of Helsinki and approved by the Norwegian Social Science Data Services and the Norwegian National Ethics Committee.

5.1 Paper I-Movement

Subramanian, S., Dahl, Y., Skjæret-Maroni, N., Vereijken, B., and Svanæs, D., "Twelve Ways to Reach for a Star: Player Movement Strategies in a Whole-Body Exergame," ***2019 IEEE 7th International Conference on Serious Games and Applications for Health (SeGAH)*****, Kyoto, Japan, 2019, pp. 1-8.**

This work analyzed player movement strategies when playing the full-body balance training exergame *Celestial Shower* and compared it with the health beneficial weight-shift movements (for improved balance) the game was originally designed to elicit. *Celestial Shower* was designed to elicit a total of six postures among players during gameplay. A laboratory-based assessment of the game was performed with six older adults and six younger adults.

Labanotation is a formal notation for analyzing human movement, originally developed for dance and other performance arts [125], and served as relevant background literature for this paper. A Labanotation-inspired coding scheme was used in Paper-I-Movement to describe various observed characteristics of the participants' body movements. Instead of using a pre-constructed coding scheme (e.g., Labanotation), it was decided to follow a bottom-up coding approach, allowing the coding scheme to emerge from the collected data. The opted approach was also pragmatic in the sense that it allowed for adjusting the level of coding detail to a level found appropriate for the corresponding research question.

Video analysis of the players' movements during gameplay revealed that contrary to our expectations, only 23% of the observed player postures corresponded to the specific body postures the exergame was designed to elicit. On average, 77% of the observed postures were not specifically intended. However, what was even more surprising was that despite the low number of intended movements, 49% of the unintended postures nevertheless involved *weight-shift*.

The findings suggest that when designing balance training exergames for able-bodied players, designers can worry less about "puppeteering" able-bodied players with a strict choreography to elicit specific body movements. Instead, it is suggested that designers should embrace a less rigid design approach, where the goal is to elicit desired movement characteristics (e.g., weight-shift) through a more open and playful behavior.

5.2 Paper II-Motivation

Subramanian, S., Dahl, Y., Skjæret-Maroni, N., Vereijken, B., and Svanæs, D., "Assessing Motivational Differences Between Young and Older Adults When Playing an Exergame," *Games for Health Journal*, 2019. 9(1).

This work compares the motivational factors influencing young and older adults when playing a balance training exergame by analyzing their assessment of the same game. A laboratory-based assessment of the custom-made balance training exergame, *Celestial Shower,* was conducted. The study was performed with 12 healthy young adults and 10 healthy older adults. After playing the game for 20 minutes, the participants filled out a questionnaire, providing their assessment (pros, cons, etc.) of the exergame.

The self-determination theory (SDT) [127] served as the relevant background literature for this paper, as SDT expands the traditional view of motivation by also taking into account the orientation (or type) of motivation (i.e., intrinsic and extrinsic motivation).

A qualitative analysis of participants' answers to the questionnaire indicated that both age groups were motivated by a combination of intrinsic and extrinsic motivational factors.

Results indicated that younger adults were intrinsically motivated by the game challenge and extrinsically motivated by the in-game rewards (scores). In contrast, the evaluation showed that older adults were intrinsically motivated by the joy of playing and extrinsically motivated by the perceived health effects (both physical and cognitive) of playing.

The study indicated that the differences in motivational factors identified between young and older adults have several design implications. Therefore, when designing for older adults, it is recommended to focus less on designing the in-game reward system and downplaying the competition aspect while focusing more on showing players the potential health effects of their play and making the gaming experience as joyful as possible.

5.3 Paper-III-Review

Subramanian, S., Skjæret-Maroni, N., Dahl, Y., " Systematic Review of Design Guidelines for Full-Body Interactive Games," Accepted for publication in *Interacting With Computers,* 2020.

This work presents a systematic literature review of design guidelines for full-body interactive games.

Searches were performed in five major databases. A series of screening processes resulted in the final inclusion of 22 papers from an initial corpus of 3,562 studies of potential interest. A total of 107 design guidelines were extracted from the resulting papers, which were further classified into 12 categories based on relevance. A structured overview of the individual guidelines was provided, including the context of derivation and details about the exergaming technology used in the studies.

The paper provides a generic overview of all the included studies, as well as an elaborate overview of exergaming technology and its specifications.

Overall, the review revealed concerns related to the present state of design guidelines for full-body games, such as: (1) the hedonic–utilitarian divide in movement-related design guidelines of relevant literature; (2) the lack of common structure for specifying guidelines; (3) the lack of systematic development of guidelines; (4) issues related to the validity of existing guidelines; and (5) the limited focus on tangible interfaces in the present state of the art.

The review shines a light on the various quality issues of design guidelines that can potentially reduce the value of design guidelines in the development of full-body interactive games if these issues are left unattended.

5.4 Paper-IV-Framework

Svanæs, D., Lyngby, A. S., Bärnhold, M., Subramanian, S., " UNITY-Things: An Internet-of-Things software framework integrating Arduinoenabled remote devices with the UNITY game engine," Accepted for publication in *HCI International,* 2021.

Paper-IV-Framework provides an overview of the software framework implemented in the development of the *ExerTiles Toolkit*, which served as the basis for the study reported in Paper-V-Tangibles. As previously mentioned, while Paper-IV-Framework does not provide empirical basis for the thesis, it has been included as a part of the work to provide a complete overview of the research.

5.5 Paper-V-Tangibles

Subramanian, S., Dahl, Y., Vereijken, B., and Svanæs, D., "ExerTiles: A Tangible Interactive Physiotherapy Toolkit for Balance Training with Older Adults," Accepted for publication in the Proceedings of the 2020 *Australian Conference on Human-Computer Interaction*.

This paper reports a user-centered and design research that aims to investigate the potential value of tangible interactive technology as a tool for physiotherapists in their work with older adults to train their balance.

Existing literature describing physiotherapy practice served as the relevant background literature for the paper [121-124, 128]. Of particular relevance was the reflection of physiotherapists as *bricoleurs,* handyman/women using available materials to address a problem at hand [123, 124, 127]. The reflection on current physiotherapy practice provided the necessary background knowledge for exploring tangible interactive technology that can integrate with and add value to physiotherapy practice.

In this regard, co-design workshops were conducted with physiotherapists to identify their requirements and design considerations for such tangible interactive technology, which they could potentially use for balance training and rehabilitation among older adults.

The results from the design workshops served as input in the development of the *ExerTile* toolkit prototype.

Following the development of the *ExerTile* toolkit, a laboratory-based assessment of the final prototype was performed with both physiotherapists and older adults, and this served as the main empirical basis for Paper-V-Tangibles.

The results revealed that tangible interactive technology has strong potential as a tool that can support physiotherapy work practice. It was identified that five key factors (tailorability, versatile training, fun, creativity, and portability) contributed to the success of the *ExerTiles*. Overall, the research indicated that tangible interactive technology has a high potential to integrate with and add value to the physiotherapy work practice.

6 Contributions

This chapter showcases the thesis's multidisciplinary contributions and further discusses the implications of the contributions for designing interactive technology to facilitate balance training and rehabilitation.

6.1 Contributions of the Research Papers

While the overall work in the thesis is an HCI (movement-based interaction) contribution, the individual research papers also contribute to the other fields of exergaming and functional training and rehabilitation, as the contributions lie in the overlap of HCI and the two other disciplines of movement science and game design.

In particular, the individual contributions of the thesis lie in addressing RQs 1 (design recommendations), 2 (movement characteristics), 3 (motivational factors), and 4 (tangible interactive technology), resulting in five research papers providing contributions C1–C4, respectively (Figure 11).

C1 (design recommendations) provides a review of the state-of-the-art design recommendations for designing full-body games. Here, the primary focus is on designing movement-based interactive games, and the corresponding study presented in Paper-III-Review includes design guidelines pertaining to functional training and rehabilitation while not being limited to this context alone. Thus, C1 provides insight into movement-based interaction (HCI), using exergames (game design) to facilitate functional training and rehabilitation (movement science). Hence, C1 lies in the overlap of all three fields and contributes to all three fields.

C2 (movement characteristics) provides an understanding of how an open and explorative approach to design can facilitate movement characteristics beneficial for balance training without the need for strict choreography. Here, the primary focus is on how players use their bodies to interact with the technology and the movement characteristics they elicit while training their balance, as illustrated in Paper-I-Movement. Thus, C2 provides insight into movement-based interaction (HCI), using exergames (game design) to facilitate functional training and rehabilitation (movement science). Hence, C2 lies in the overlap of all three fields and contributes to all three fields.

C3 (motivational factors) provides an understanding that perceived health effects and the joy of playing are the main motivational factors influencing older adults while training using an exergame. Here, the focus is on factors motivating older adults to use movement-based interactive exergames, as presented in Paper-II-Motivation. Thus, C3 provides insight into motivational factors influencing movement-based interaction (HCI) with exergames (game design). Hence, C3 lies in the overlap of movement-based interaction and exergaming and contributes to these two fields.

C4 (tangible interactive technology) provides an understanding that tangible interactive technology has strong potential as a tool to support physiotherapy practice. Here, the focus is on how movement-based interactive technology can accommodate functional training and rehabilitation facilitated by physiotherapists as presented in Paper-IV-Framework and Paper-V-Tangibles. Thus, C4 provides insight into movement-based interactive technology supporting functional training and rehabilitation. Hence, C4 lies in the overlap of movement-based interaction and functional training and rehabilitation, thereby contributing to these two fields.

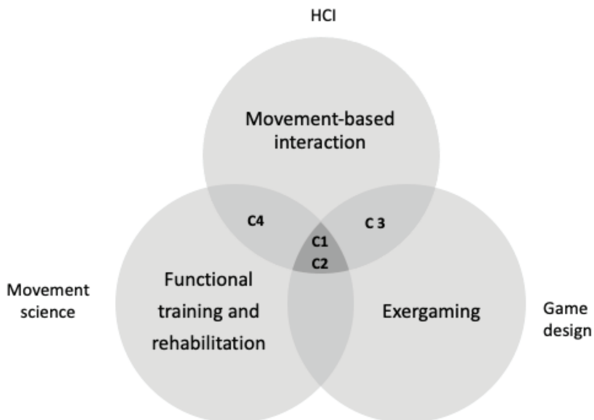


Figure 11: Contributions of the thesis.

6.1.1 Contributions of Paper-III-Review (C1)

C1 Provides a review of the state-of-the-art design recommendations for designing full-body games.

Design guidelines or recommendations are fundamental to ensure a positive user experience, easy usability, and an overall acceptance of applications such as exergames. However, the growing body of design guidelines for movement-based games has made it increasingly challenging to get an overview of current design knowledge and what aspects of design the existing guidelines cover. Hence, despite the prominence of research on movement-based interactive games, there is still a lack of well-established design knowledge in this area.

The contribution of the thesis through Paper-III-Review is a systematic literature review of available design guidelines for full-body interactive games. The paper contributes to addressing RQ1 (design recommendations). While the review provides an overview of 107 different design guidelines addressing various aspects of design, the results also point to several concerning issues. The study shines light upon concerns such as the unstructured and unsystematic nature of existing design knowledge, potentially uprooting the significance of *design guidelines* in HCI.

The review of the guidelines itself serves as the main result, presenting existing guidelines in a structured and consistent format. The guidelines are presented with the context of derivation and are further categorized on different aspects of design: *Movement elicitation, Mapping of movement, Explicit movement guidance, Player representation and game world, Attention, Feedback on player performance, Player agency and customization, Exertion, Safety, Universal design,* and *Social aspects*.

The categorization of the guidelines further provides an overview of those aspects of design that existing research focuses upon, while also reflecting those aspects that lack focus. The 107 different design guidelines were largely based on assessments performed with screen-based technology, and discussions with experts, with no focus on tangible solutions.

While pointing out the prominence of screens in full-body interactive technology, the review further suggests the lack of attention given to tangible solutions and the need to look beyond screens toward more tangible interactive solutions. The latter part of the thesis, which explores tangible solutions, was a further compelling consequence of the above results.

While several of the extracted guidelines provide advice on designing for movement, very few studies, such as Skjæret et al.'s [45], provide guidelines for designing for specific movement characteristics. The lack of attention given to designing for specific movement in movement-based games was once again reinforced through the findings of Paper-III-Review.

While the study included design guidelines derived from the context of training balance in older adults, thereby appropriate for implementation in a similar context, the extracted guidelines for the review are not limited to this context alone, as the overall scope of the paper was to provide an extensive overview of existing design knowledge.

While referring to the guidelines as a manual for design, it is critical to consider the corresponding context from which the guidelines were derived before implementation. The design of technology for serious purposes, such as training for older adults, is likely to benefit from guidelines derived from a similar context, as they are more relevant for the context and user group. C1 serves as a systematized overview of existing design knowledge, which future research can build upon while also serving as a design manual for developing full-body games.

C1 provides insight into movement-based interaction (HCI), using exergames (game design) to facilitate functional training and rehabilitation (movement science), thereby contributing to all three fields.

Overall, the thesis's first contribution (C1) consists of a systematic literature review (Paper-III-Review) of research articles published between 2010 and mid-2018 that offered design guidelines for full-body interactive games for recreational purposes and physical exercise. The study presents 107 design guidelines categorized based on relevance in a structured and systematic format—the identified body of design guidelines related to multiple aspects of designing full-body interactive games. While identifying design recommendations, the study also identified various pressing concerns related to design knowledge, such as (1) the hedonic–utilitarian divide in movement-related design guidelines of relevant literature; (2) the lack of common structure for specifying guidelines; (3) the lack of systematic development of guidelines; (4) issues related to the validity of existing guidelines; and (5) the limited focus on tangible interfaces in the present state of the art. Overall, C1 presents the state-of-the-art design guidelines while also highlighting various concerns put forth by existing literature.

6.1.2 Contributions of Paper-I-Movement (C2)

C2 Provides an understanding of how an open and explorative approach to design can facilitate movement characteristics beneficial for balance training without the need for strict choreography.

While several of the existing studies focusing on inducing *specific movements* during gameplay essentially suggest either puppeteering players through manipulating various factors or primarily focusing on designing technology to prompt specific movement characteristics [33, 44, 45], the contributions of Paper-I-Movement in this regard are different. The paper contributes to addressing RQ 2 (designing for specific movement characteristics), as the findings specifically reflect on how to design for specific characteristics.

While the design of *Celestial Shower* involved substantial consideration of the specific postures that have weight-shifting characteristics beneficial for balance training that players were intended to elicit, the outcome was that only a mere 23% of the total number of postures performed by the participants were design-intended postures. It was observed that players could play the game and get a high score without necessarily moving the way the game was designed to make one move and interact. Although one could argue that this merely suggests the need for a more strictly puppeteered game where the only way to play would be in a highly constricted manner, the analysis suggested otherwise. A further 49% of the unintended postures nevertheless had the intended weight-shift characteristic (which is beneficial for balance training) that the game aimed to elicit. Therefore, it was seen that it is not essentially about the *specific* movements or postures themselves; instead, the significance is in the characteristics that made them desirable to elicit. Hence, when designing for specific movements (e.g., balance training), where the user group comprises *able-bodied* individuals, a more explorative approach can be adopted rather than stringently trying to puppeteer players' every move, as a more open approach can result in diverse movements that can nevertheless have the *critical* movement characteristics.

Paper-I-Movement provides an alternative perspective to designing for specific movement, and contributes to addressing RQ 1 (designing for specific movement characteristics) by placing the emphasis on movement characteristics rather than the movements and postures themselves.

C2 provides recommendations on designing for specific movement characteristics beneficial for balance training, which are presented in Paper-I-Movement. The paper describes findings from a laboratory-based assessment of a customized balance training exergame to observe and compare player body movements during gameplay to that of specific weight-shift movements the game was designed to elicit. The findings suggest that designers can worry less about puppeteering player movements and embrace a less rigid approach where desired movement characteristics can be achieved through more open and playful behavior.

While highlighting that player movement strategies during gameplay can contradict the intentions of the game design, the study also emphasizes that the suggestions may only be applicable when designing for able-bodied individuals. Additionally, on the basis of Norman's concept of affordance (i.e., properties of objects which show users the actions they can take) [129] and constraints (i.e., limitations), the paper discusses various in-game and real-world affordances and constraints that could be employed to encourage specific movement characteristics.

6.1.3 Contributions of Paper-II-Motivation (C3)

C3	Provides insight that perceived health effects and the joy of playing are the main motivational factors influencing older adults while training using an exergame.

It is well known that regular physical activity is associated with a multitude of health benefits, such as reducing the risk of numerous chronic diseases, preserving mental and physical health into older age, and extending longevity [5-7]. Though older adults acknowledge the significance of regular physical activity for healthy aging, they lack the motivation to adhere to a consistent exercise regime. Several inconveniences associated with the traditional form of exercising have been overcome by technology, such as exergames, which have made exercising more convenient and enjoyable than before. However, the lack of motivation remains a persistent challenge. Therefore, it was of interest to identify the motivational factors that influence older adults when they play an exergame.

Ongoing advancements in ICT have contributed to a variety of emerging technologies that are robust, efficient, and convenient. While such advances in technology and research have addressed a wide range of exergaming issues, one persistent problem is adherence. Several studies have identified declining adherence levels in long-term exergaming interventions [116, 117].

These low adherence levels are seen as repercussions, as most commercial exergaming technologies are not designed for specific user groups or to address particular health concerns. Additionally, little is known about motivational factors influencing specific user groups, and not designing motivating games can therefore lead to boredom and declining adherence.

The contribution of the thesis, in this regard, by addressing RQ 2 (designing for motivation) is toward identifying motivational factors influencing the two dominant exergaming user groups—young and older adults (Table 3). An analysis of the two user groups playing the age-neutral balance training exergame *Celestial Shower* revealed the following.

Table 3: Intrinsic and extrinsic motivation among young and older adults

	Young adults	**Older adults**
Intrinsic Motivation	Game challenge	Joy of playing
Extrinsic Motivation	In-game rewards	Perceived health effect

The findings provided in Paper-II-Motivation indicate that young adults are motivated by *game challenge* and *in-game rewards,* while older adults are motivated by the *joy of playing* and the *perceived health effects.* These findings further suggest emphasizing different aspects of gaming when designing for user groups.

Therefore, the results are interpreted such that when designing for older adults, more focus can be placed on providing players feedback on health effects and toward designing a more joyous gaming experience than on aspects such as in-game rewards and competition.

This is not to say that none of the older adults are motivated by the game challenge and in-game rewards, and that no younger adults are not motivated by the joy of playing and the perceived health effects. This is also not to say that these are the only motivating factors associated with these two user groups. However, the identified motivational factors were the most prominent ones that were recognized in this particular study. Considering that most commercially available exergaming technologies are designed for the younger population, these contributions can serve as a baseline of comparison when designing for the user groups. Additionally, the results and interpretations serve as guidelines for moving toward a more competent design process with increased adherence levels where games are individually designed for specific user groups based on what motivates them.

C3 identifies the motivational factors influencing older adults training using an exergame, while comparing motivational factors between healthy young and older adults in Paper-II-Motivation and suggesting design recommendations for the two user groups.

By providing insight into motivational factors influencing movement-based interaction (HCI) while training using exergames (Game design), C3 contributes to the two fields.

In addition to identifying the main intrinsic and extrinsic motivational factors influencing older adults, the study highlights the contrast in motivational factors influencing the two significant user groups of exergames. This also reflects the need to design for specific user groups based on influencing motivational factors.

6.1.4 Contributions of Paper-V-Tangibles (C4)

C4 Provides insight that tangible interactive technology has strong potential as tools to support physiotherapy practice.

Despite the pace of ICT advancements, there is a lack of technological artifacts that integrate with physiotherapists' work practice. Paper IV-Framework is seen as a contribution toward enabling the technology, which is further expanded on in Paper-V-Tangibles. The contributions of Paper-V-Tangibles can be seen as a depiction of the potential of tangible interactive technology in physiotherapy work practice to seamlessly integrate with and add value to their *bricoleur* [124] way of working. By addressing RQ 4 (tangible interactive technology), the contributions of Paper-V-Tangibles are toward how tangible interactive technology can be designed to integrate with and add value to physiotherapy work practice.

Though progress has been made within HCI in designing more entertaining exergames, there are also several limitations involved in the type of movements or exercises that can be performed. For instance, most commercial exergames are screen-based, meaning that they require players to constantly face the display, limiting exercises such as rotation or bending of the body. Screen-based platforms also require the game to be played in a particular area of the living environment and occupy significant space which not all older adults may have. Furthermore, in the context of training and rehabilitation, physiotherapists have little to no control over the training and the type of movements that patients can perform using existing technology, as these are largely inbuilt in the system, and not allowing for much flexibility in this regard. These limitations motivated the search for technology platforms with the potential of overcoming the limitations.

The contributions of Paper-V-Tangibles lie in illustrating that simple, tangible interactive technology has the potential to integrate with physiotherapy work practice by overcoming several of the limitations normally associated with most commercial movement-based technology. In particular, the contributions lie in identifying the five main factors that contribute toward the acceptance of tangible interactive technology (*ExerTiles*) by the physiotherapists: tailorability, versatile training, creativity, fun, and portability.

While allowing for flexibility and tailorability, the *ExerTiles* enabled physiotherapists to dictate how patients can and should move during training by reinforcing creative rules. In this way, the tiles served as available material that the physiotherapists employed as *bricoleurs* to address the wide variety of individual older adults' balance issues. The creativity of physiotherapists as *bricoleurs* was illustrated through the diverse exercise solutions designed throughout the assessments.

Paper-V-Tangibles provides insight into movement-based interactive technology (HCI) supporting functional training and rehabilitation (movement science) and contributes to both these fields.

Overall, the contributions highlight the significance of physiotherapists' *bricoleur* work practice while suggesting the need for technology to support physiotherapists as *bricoleurs* and serve as a tool in their toolbox through the significance of the aforementioned five main attributes.

6.2 Key Findings

Overall, the thesis aims to contribute toward a better understanding of how to design interactive technology, with a specific focus on balance training for older adults. While the individual papers in the thesis contribute to addressing the various research questions in this regard, and as such to the overall aim of designing for balance training and rehabilitation, the main findings of the thesis provide the following key findings (KF).

6.2.1 KF1: Effective Balance Training Design Solutions Do Not Require Strict Puppeteering

Norman's concept of affordance (i.e., properties of objects which show users the actions they can take) [129] and constraints (i.e., limitations) also have relevance for how movements can be elicited during gameplay. In Paper-I-Movement, the term *affordances* is used to describe elements of the exergame encouraging players to interact (using their bodies) in a certain way, and *constraints* to describe elements that discourage certain interactions.

One of the thesis's primary insights was the need to design solutions that allow for flexibility without the concern of "puppeteering" players, i.e., attempting to rigidly control their movements through explicit movement guidance and instructions. Specific balance training exercises, such as the Ottago exercises [130], which provide explicit instructions on how to move (e.g., place one foot in front of the other and hold the position for 10 seconds), are examples of puppeteering (Figure 12).

However, the insights obtained suggests the need to move away from such rigid and restricted applications to more flexible solutions, which are open and explorative. In this regard, in-game affordances can be used to encourage a wider variety of movements that can have the necessary *movement characteristics* (e.g., weight-shift) without rigidly

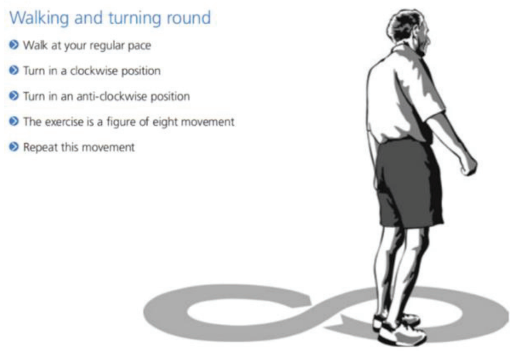


Figure 12: Ottago strength and balance training exercises program (Reprint from [130, p. 52]).

forcing players to elicit specific postures and movements. This can be achieved by designing both in-game and physical affordances that inspire a variety of movements during gameplay, which are likely to have the required characteristics, with the possible exception of disabled or more frail user groups.

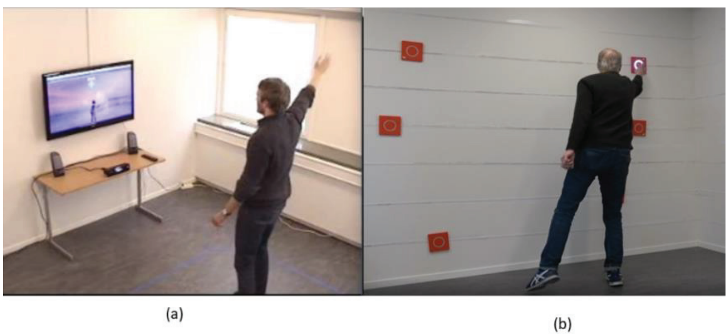


Figure 13 : The *Celestial Shower* exergame and the *ExerTiles Toolkit* (a) Participant playing the *Celestial Shower* exergame. (b) Older adult training with the *ExerTiles*.

With respect to the *Celestial Shower* prototype (Figure 13 a), the approaching stars served as affordances, which players had to catch to gain points, and the asteroids, which players had to dodge were the constraints. Although the game was designed with the intention of using the affordances and constraints to elicit the design-intended postures and movements during gameplay, there were no strict constraints implemented regarding how they could potentially move, and this was reflected during the experiment as players depicted a variety of unexpected movements.

Furthermore, with respect to the *ExerTiles Toolkit* (Figure 13 b), the blinking of the lights was the affordances, while the constraints were the positioning of the tiles and additional rules which may have been provided by physiotherapists. Depending on the user group (i.e., able-bodied/frail older adults) the *ExerTiles* allowed for an open and explorative training without the need to pupeeter older adults' movements, while also being capable of supporting numerous constraints to facilitate cautious training for frailer older adults.

6.2.2 KF2: Perceived Health Effect and Joy Are the Main Motivational Factors for Older Adults

The findings from Paper-II-Motivation reinforce the notion that different user groups may have different motivational factors, and thereby reflect the need for basing the design process on those motivational factors influencing specific user groups. Seeing that young and older adults are two prominent user groups of movement-based interactive technology, it was insightful to see the contrast in factors motivating them to train using an exergame.

While acknowledging that the positive health effects associated with exergaming are beneficial for all user groups, it is of particular relevance for older adults as regular exercise is beneficial for a healthy aging process and helps prevent falls. Therefore, additional design implementations to illustrate their personal fitness level (e.g., heart rate, speed, balance) could be beneficial and motivating.

With respect to the *Celestial Shower*, players physically exerted themselves by moving from side to side while catching stars and dodging asteroids. Cognitively, they were exerted by focusing on which side they had to move and coordinating their movements. Similarly, in the case of the *ExerTiles Toolkit*, the physical exertion was in moving around and taping on the tiles while cognitively focusing on which tile lit up, and the additional rules applied in terms of coordinating their body movements.

Next, the joy of playing was identified as an influencing motivating factor. In the case of *Celestial Shower*, the joy could potentially be accredited to factors such as the joy of moving the body while interacting with the in-game affordances and constraints, such as quoted by Po08 (p. 4) in Paper-II-Motivation.

Furthermore, while the joy of training with the *ExerTiles Toolkit* was not a part of the results presented in Paper-V-Tangibles, it can be speculated that the interactivity of the technology contributes to the joy of the training sessions. During the experiments, physiotherapist P01 stated that he performed the same exercises using Post-it notes, but the replacement of Post-it notes with tiles made the process more enjoyable and fun. While further research is required in this regard to identify the notion of joy or fun, the interactivity of technology can be seen as a contributing factor to a joyful experience.

6.2.3 KF3: Simple Tangible Interactive Solutions Show Promise For Balance Training

Seeing that the storyline of the Ph.D. involved moving away from screen-based solutions to non-screen-based applications, the necessity to look beyond screens came up as a main reflection.

The initial focus of the Ph.D. was on screen-based solutions, as also reflected in the *Celestial Shower* exergame, which required using a screen and a Microsoft Kinect, which were also the most common platforms in this regard. As *Celestial Shower* further resulted in Paper-I-Movement and Paper-II-Motivation addressing corresponding research questions, it was also at this point that certain drawbacks associated with such screen-based solutions came to the forefront. However, the structured literature review performed for Paper-III-Review revealed the focus being given to screen-based solutions compared to tangible, non-screen-based interactive technology. The review presented in Paper-III-Review reflected the under-researched area of tangible technology, as the vast majority of identified guidelines were derived from studies of full-body games where large displays (e.g., TV screens and projected screens) played a central role in player–game interaction. Many of the guidelines, for example, those concerning the use of animations, avatars, and text, will only be applicable in the design of games that actually make use of large displays as the primary output channel. However, more generalized design knowledge (e.g., exploit physical risk sensibly) could potentially be applied to tangible solutions. Though some generalized guidelines seem applicable to tangible solutions as well, the design knowledge originated from screen-based solutions intended for similar solutions, and thereby reflecting a potential gap.

The reflections prompted to broaden the horizons and explore more tangible interactive technology, i.e., the *ExerTiles*. Doing so revealed that in practice, while overcoming several limitations associated with screen-based solutions, the shift toward more tangible applications contributed to a more effective and seamless integration of technology with the practice-oriented approach of physiotherapy. It was seen that by looking beyond screen-based solutions, the tangibility of the technology itself contributed to the integration of technology with real-world practice. In this regard, the materiality of the technology allowed for it to be easily used as a physical tool in physiotherapists' toolbox, which is at their disposal to aid training patients. Figure 14 illustrates some of the various exercises that were configured by the physiotherapists during the experiments.

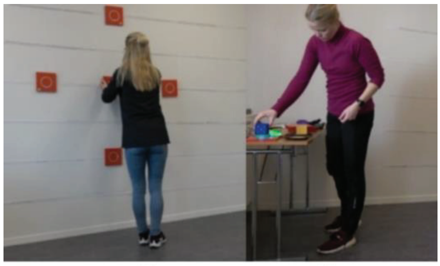
Figure 14: Examples of configured exercises.

Furthermore, in the case of the *ExerTiles Toolkit* as presented in Paper-V-Tangibles, it was seen that a simple form of technology with simple system behaviors and no extravagant graphics or captivating features was nonetheless well-received, as the technology served the purpose. This was also reflected in Paper-II-Motivation, which revealed that while younger adults focused on factors such as in-game rewards, graphics, and music, the older adults were concerned with the perceived health effect, the joy of playing, and the feedback system. The findings from Paper-V-Tangibles suggests designing simple technology which serves the primary purpose of addressing the concerned issue, as the results indicate that simple technology works.

6.2.4 KF4: As a Tool For Physiotherapists, a Key Success Factor for Balance Training Solutions is That They are Easily Tailorable

Research on how physiotherapists work reveals that a core skill of physiotherapists is their ability to tailor exercises to the specific needs of individual patients [122, 131, 132]. As such, the significance of designing solutions that support tailorability of movements and specific exercises was reflected through the studies performed (design workshops and assessments) as a part of Paper-V-Tangibles. With respect to physiotherapy practice, it was seen that tailorability makes all the difference in terms of the efficiency of the training sessions while significantly contributing to technology acceptance by physiotherapists. It is seen that each older adult or patient requires a different level of training depending on their physical ability, and the ability to tailor training sessions for each individual in such regard contributes to effective training.

Furthermore, it was seen that the *ExerTiles* allowed for easy and quick tailorability (Figure 15), which was achieved by the physiotherapists through factors such as physical placement of the tiles (i.e., physically adding/removing tiles or increasing/decreasing distance between tiles as shown in Figure 15 a), interactivity (i.e., system behavior and speed as shown in Figure 15 b), and exercise goals and rules (i.e., additional rules for the exercises). The physiotherapists' tailoring went beyond choosing between a predefined set of exercises or tweaking a set of parameters. The physiotherapists came up with new exercises and challenges that were neither proposed by us nor specifically designed for. From this perspective, the tiles were a material for constructing exercises, much in the same way as LEGO bricks are elements allowing children to materialize the products of their imagination.



(a) (b)

Figure 15: Physiotherapists tailoring the exercises (a) Physically moving the location of the tiles (b) Modifying the system behavior and speed to tailor the exercise.

Overall, seeing that tailorability is a significant skill in physiotherapy practice, the potential of the *ExerTiles*, which allows for such easy tailorability, contributes to the acceptance by physiotherapists and its seamless integration with physiotherapy practice. Therefore reflecting that as a tool for physiotherapists, easy tailorability is a key success factor for balance training solutions.

6.3 From the Celestial Shower to the ExerTiles Toolkit

Overall, the work described in the thesis can be seen as:

- A transition from traditional screen-based and structured full-body games to a more unconventional and explorative form of interactive technology.
- A progression from strict and rigid approaches to training to more open, unrestricted, and explorative approaches to training.
- Incremental steps toward having interactive technology as a part of physiotherapists' toolbox.

KF1, 3, and 4 reflect the shift in focus from screen-based and structured full-body games (i.e., *Celestial Shower*) to an unconventional and explorative form of interactive technology (i.e., *ExerTiles Toolkit*) by suggesting that effective solutions do not need puppeteering and illustrating the potential of explorative and tangible solutions.

Additionally, KF1 reflects the shift in focus from strict and rigid approaches of training to more unrestricted and explorative approaches, as it emphasizes that effective balance training design solutions do not require strict puppeteering.

KF3 and KF4 reflect the potential of tangible interactive technology in balance training and the importance of easy tailorability for tools supporting physiotherapists to train balance. In such regard, the findings indicate progress toward having interactive technology as a part of physiotherapists' toolbox.

These transitions are reflected in the nature of the two prototypes (*Celestial Shower* and *ExerTiles Toolkit*) that have been used in the work presented in the thesis (Table 4), whereas the *Celestial Shower* reflects the former focus, and *ExerTiles* reflects the latter.

Table 4: Comparison between *Celestial Shower* and the *ExerTiles Toolkit*.

Celestial Shower	***ExerTiles Toolkit***
Screen-based solution	Tangible solution
Complex solution	Simple solution
Structured	Unstructured
Inflexible	Flexible
Standalone solution	Practice-oriented solution

7 Methodological Considerations

It is recognized that the thesis has certain limitations. Below are three central methodological considerations in the thesis.

First, all the empirically-based studies performed involved able-bodied older adults who did not need rehabilitation owing to balance problems.

Second, our laboratory-based prototype assessment raises certain issues concerning the ecological validity of the results—that is, the extent to which our findings can be generalized to real-life settings, especially domestic settings.

Third, it is recognized that the relatively limited duration of the laboratory-based prototype assessment does not allow conclusions to be drawn regarding how user groups such as older adults and physiotherapists perceive the use of specific interactive technology over extended periods.

The following sections assess the quality of the conducted research based on the positivism paradigm as provided by Oates [107].

7.1 Objectivity

Although I have a computer science background, I have had other co-authors with a background in movement science and physiotherapy who have contributed toward less research bias. However, this would not have been possible if the thesis was not a part of a multidisciplinary research group. Furthermore, as researchers, there was no vested interest in particular outcomes, as the research project was not funded by any external organization standing to gain from the studies' findings.

7.2 Reliability

The empirical research conducted as a part of the thesis was carried out in a neutral and unambiguous manner. This also applies to the questions framed in the questionnaires and the questions asked during the interviews, where participants were not influenced to respond in a particular way. While conducting interviews, it was ensured that the same questions were asked in the same manner.

Furthermore, with respect to the coding of the data for example, it was ensured that analyzed sets of categories were similarly identified by all the co-authors in the same manner such that it was from a neutral perspective.

7.3 Internal Validity

Overall, while the performed research was well designed and allowed for collecting and examining the required data, I realize that there are other research strategies and data collection methods that could have been chosen.

First, it is recognized that the relatively limited duration of the laboratory-based prototype assessment does not allow conclusions to be drawn regarding how user groups such as older adults and physiotherapists perceive the use of specific interactive technology over extended periods.

Second, additional field studies could have been performed to gain better insight and have first-hand experience observing user groups such as older adults and physiotherapists in their own environment. In particular, it would have been ideal to observe physiotherapists' work practice in real life. However, I had co-authors with physiotherapy practice who provided the necessary insights in this regard. Additionally, with reference to Paper-II-Motivation, interviews could have been conducted to ask participants about influencing motivational factors, rather than having them answer questionnaires. Nevertheless, the same questions would have been asked in the interviews.

Third, there are various other aspects that could have potentially been logged and further analyzed from the experiments. For instance, the logging of the interaction between physiotherapists and older adults might have led to additional insights. Furthermore, several factors could have been logged over extended periods, such as adherence levels, improvement in balance, and the efficacy of various technologies.

While overall, I see that several things could have been done differently, it would not have changed the outcome of the results and the conclusion of the thesis.

7.4 External Validity

First, the empirically-based studies performed in Papers-I-Movement, II-Motivation, and V-Tangibles involved able-bodied older adults with no physical or cognitive disorders. Thus, this raises issues concerning the extent of generalizing the results to other categories of older adults, such as frail older adults or older adults with functional limitations that are explicitly in need of specific rehabilitation owing to balance problems. For instance, in the case of frail older adults, safety concerns and functional limitations are more likely to be significant, requiring additional safety measures such as embedding *ExerTiles* to the floor, for instance, or additionally designing for physical support during training.

Second, the laboratory-based prototype assessments raise certain issues concerning the ecological validity of the results—that is, the extent to which the findings can be generalized to real-life settings, such as homes and clinical contexts.

Third, all the studies were conducted in Norway with a focus on Norwegian older adults and Norwegian physiotherapy practice. The implementation of physiotherapy practice might be different in various other countries, which further limits the extent of generalizability.

Therefore, further studies are necessary to verify further the extent of generalizability with respect to different user groups, real-life contexts, and countries.

8 Summary, Conclusion, and Future Work

8.1 Summary

The Ph.D.'s overall aim was to inform the design of movement-based interactive technology supporting balance training in older adults. In this regard, the work presented in the thesis answers four research questions addressing specific concerns related to *design guidelines, movement characteristics, motivational factors,* and *tangible interactive technology.*

RQ 1. What are the existing *design recommendations* for full-body movement-based games?

RQ 1 is addressed in Paper-III-Review, which provides a systematic review of the state-of-the-art design recommendations for designing full-body games. Additionally, the review shines a light on the various quality issues of design guidelines that can potentially reduce the value of design guidelines in the development of full-body interactive games if unattended to.

RQ 2. How to design for specific *movement characteristics* beneficial for balance training?

RQ 2 was addressed in Paper-I-Movement. The findings suggest that when designing balance training exergames for able-bodied players, designers can worry less about "puppeteering" able-bodied players with a strict choreography to elicit specific body movements. Instead, it is suggested that designers embrace a less rigid design approach, where the goal is to elicit desired movement characteristics (e.g., weight-shift) through a more open and playful behavior.

RQ 3. What are the *motivational factors* influencing older adults while training using an exergame?

RQ 3 was addressed in Paper-II-Motivation. The study indicated that the differences in motivational factors identified between young and older adults have several design implications. Therefore, when designing for older adults, it is recommended to focus less on designing the in-game reward system and downplaying the competition aspect while focusing more on showing players the potential health effects of their play and making the gaming experience as joyful as possible when designing for older adults.

RQ 4. How can *tangible interactive technology* support physiotherapy practice?

RQ 4 was primarily addressed through Paper-V-Tangibles. The results revealed that tangible interactive technology has strong potential as a tool that can support physiotherapy work practice. It was identified that five key factors (tailorability, versatile training, fun, creativity, and portability) contributed to the success of the *ExerTiles*. Overall, the research indicated that tangible interactive technology has a high potential to integrate with and add value to physiotherapy work practice.

The overall research process comprised systematic literature reviews, design and creation, and laboratory-based experiments resulting in quantitative and qualitative results presented in the four main research papers. In particular, the design and creation of functional prototypes in the thesis (i.e., the *Celestial Shower* and the *ExerTiles Toolkit*) allowed for better understanding and evaluating the addressed concerns, which would not have been possible with the use of inoperative prototypes or existing technology that could not have been modified to the needs of the research.

8.2 Conclusion

The thesis as a whole provides the following key findings concerning designing interactive technology for balance training and rehabilitation of older adults presented through research Papers I to V:

- KF1: Effective balance training design solutions do not require strict puppeteering.
- KF2: Perceived health effect and joy are the main motivational factors for older adults.
- KF3: Simple, tangible interactive solutions show promise for balance training.
- KF4: As a tool for physiotherapists, a key success factor for balance training solutions is that they are easily tailorable.

The first two key findings were based on experiments conducted with screen-based solutions, while the last two findings are based mainly on investigating tangible interactive technology. This is a consequence of the Ph.D. storyline that has traversed from initially focusing on traditional and structured full-body games to more unconventional and explorative forms of interactive technology.

The initial stages of the Ph.D. focused specifically on full-body games, as this was and still is the most conventional form of training when it comes to interactive technology. This primary focus is reflected in the design and development of the *Celestial Shower* exergame, which required using a screen, and the Microsoft Kinect, which was the most common platform in this regard. The *Celestial Shower* resulted in Paper-I-Movement and Paper-II-Motivation, it was also at this point that certain drawbacks associated with such screen-based solutions came to the fore front. Simultaneously the systematic literature review illustrated in Paper-III-Review, revealed the strong focus being given to screen-based solutions compared to tangible, non-screen-based interactive technology. These findings further suggested broadening horizons and exploring more tangible solutions while shifting focus from structured and conventional screen-based games to more unstructured and explorative forms of tangible interactive technology, i.e., *ExerTiles*.

The investigation of the *ExerTiles Toolkit* provides a prominent contribution to the Ph.D. thesis, as two of the four key findings (KF3, 4) are based on the exploration of the tangible interactive solution. The findings illustrate the significance of the materiality of the technology, which allows for simple tailorability and integration with physiotherapy practice.

Overall, screen-based solutions largely contributed toward answering RQ 1 (design recommendations), RQ 2 (movement characteristics), and RQ 3 (motivational factors), while tangible solutions supported in answering RQ 4.

The complete overview of the thesis suggests the need to look beyond conventional screen-based solutions, as simple, tangible interactive technology can overcome various drawbacks associated with screen-based solutions and further shows potential in the practice-oriented approach of physiotherapy.

8.3 Future Work

The work presented in the thesis suggests various directions for future work. As pointed out in the Methodological Considerations in Chapter 7, validity is limited in the case of laboratory-based experiments. In this regard, though we are confident that the physiotherapists acted out as they would in their practice, it is recommended to further investigate the practical use of the *ExerTiles* by physiotherapists in a clinical setting.

Similarly, in laboratory-based experiments, little is known about the long-term use of technology. Therefore, it would be beneficial to evaluate the use of the *ExerTiles* over extended time periods to analyze factors such as adherence and efficacy of the technology.

Furthermore, similar user-centered design approaches can be employed to explore other ways of augmenting physiotherapists' work practice with interactive technology (e.g., balls and other exercise equipments).

References

1. Lamothe, K.L., *Why We Dance: A Philosophy of Bodily Becoming*. 2015, New York: Columbia University Press.
2. Atwal, A. and A. Mcintyre, *Occupational Therapy and older people.* Psychology, 2013.
3. Horak, F.B., C.L. Shupert, and A. Mirka, *Components of Postural Dyscontrol in the Elderly: A Review.* Neurobiology of Aging, 1989. **10**: p. 727-738.
4. Volkow, N.D., et al., *Association between decline in brain dopamine activity with age and cognitive and motor impairment in healthy individuals.* The Americian Journal of Psychiatry, 1998. **155**(3): p. 344-349.
5. Ahlskog, J.E., et al., *Physical exercise as a preventive or disease modifying treatment of dementia and brain aging.* Mayo clinic proceedings, 2011. **86**(9): p. 876-884.
6. Geda, Y.E., et al., *Physical Exercise, Aging, and Mild Cognitive Impairment: A Population based study.* Arch Neurol., 2010. **67**(1): p. 80-86.
7. Simioni, C., et al., *Oxidative stress: role of physical exercise and antioxidant nutraceuticals in adulthood and aging.* Oncotarget, 2018. **9**(24): p. 17181-17198.
8. Alves, A.J., et al., *Physical activity in primary and secondary prevention of cardiovascular disease: Overview updated.* World of Journal Cardiology, 2016. **8**(10): p. 575-583.
9. Gillespie, L.D., et al., *Interventions for preventing falls in older people living in the community.* Cochrane Database of Systematic Reviews, 2012(9).
10. Warburton, D.E.R., C.W. Nicol, and S.S.D. Bredin, *Health benefits of physical activity: the evidence.* CMAJ, 2006. **174**(6): p. 801-809.
11. World Health Organization, *WHO global report on falls prevention in older age.* 2007: France.
12. Gillespie, L.D., et al., *Interventions for preventing falls in older people living in the community.* The cochrane Database systematic reviews, 2012. **12**(9).
13. Pollock, A.S., et al., *What is balance?* Clinical rehabilitation, 2000. **14**(4).
14. Winter, D.A., *Human balance and posture control during standing and walking.* Gait & posture, 1995. **3**(4): p. 193-214.
15. Jessup, J.V., et al., *Effects of exercise on bone density, balance, and self-efficacy in older women.* Biol Res Nurs., 2003. **4**(3): p. 171-180.
16. Lopopolo, R.B., et al., *Effects of therapeuic exercise on gait speed in community dwelling elderly people: A meta-analysis.* Physical therapy, 2006. **86**(4): p. 520-40.
17. Sherrington, C., et al., *Effective exercise for the prevention of falls: A systematic review and meta-analysis.* Journal of American Geriatrics Society, 2008. **56**(12): p. 2234-2243.
18. Campbell, A.J., et al., *Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women.* BMJ, 1997. **315**: p. 1065-1069.
19. Conradsson, D., et al., *A novel conceptual framework for balance training in parkinson's disease-study protocol for a randomised controlled trial.* BMC Neurology, 2012. **12**.

20. Sherrington, C., et al., *Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations.* NSW Public Health Bulletin, 2011. **22**(4): p. 78-83.
21. Steadman, J., N. Donaldson, and L. Kalra, *A randomized controlled trial of an enhanced balance training program to improve mobility and reduce falls in elderly patients.* Journal of American Geriatrics Society, 2003. **51**(6): p. 847-852.
22. Brito, M., et al. *Balance assessment in fall-prevention exergames*. in *ACM SIGACCESS Conference on Computers & Accessibility*. 2015. ACM.
23. Ellmers, T.J., W.R. Young, and I.T. Paraskevopoulos, *Integrating fall-risk assessments within a simple balance exergame*, in *9th international conference on virtual worlds and games for serious applications*. 2017, IEEE: Athens, Greece. p. 245-248.
24. Nawaz, A., et al. *Assessing seniors' user experience (UX) of exergames for balance training*. in *Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. 2014. Helsinki, Finland: ACM.
25. Tanaka, K., et al., *A comparison of exergaming interfaces for use in rehabilitation programs and research.* The Journal of the Canadian Game Studies Association, 2012. **6**(9): p. 69-81.
26. van Diest, M., et al., *Exergaming for balance training of elderly: state of the art and future developments.* Journal of NeuroEngineering and Rehabilitation, 2013. **10**(1).
27. Oppermann, L. and M. Slussareff. *Pervasive games*. in *International GI-Dagstuhl Seminar on Entertainment Computing and Serious Games, GI 2015, July 5, 2015 - July 10, 2015*. 2016. Dagstuhl Castle, Germany: Springer Verlag.
28. Fogtmann, M.H., J. Fritsch, and K.J. Kortbek. *Kinesthetic interaction: revealing the bodily potential in interaction design*. in *Australian Conference on Computer-Human Interaction: Designing for Habitus and Habitat*. 2008. ACM.
29. Kjölberg, J. *Designing full body movement interaction using modern dance as a starting point*. in *Conference on Designing interactive systems: process, practices, methods, and techniques*. 2004. ACM.
30. Mueller, F.F., et al., *Designing for bodily interplay in social exertion games.* ACM Transactions on Computer-Human Interaction, 2017. **24**(3): p. 41.
31. Martin-Niedecken, A.L., et al. *ExerCube vs. Personal Trainer: Evaluating a holistic, immersive and adaptive fitness game setup*. in *Conference on Human Factors in Computing Systems*. 2019. ACM.
32. Tveter, N. *Exergames for the elderly*. 07.11.2016 [cited 2020 16 December]; Available from: https://norwegianscitechnews.com/2016/11/exergames-for-the-elderly/.
33. Skjæret-Maroni, N., et al., *Exergaming in older adults: movement characteristics while playing steppin games.* Frontiers in Psychology, 2016. **7**: p. 964.
34. Mueller, F.F. and K. Isbister. *Movement-based game guidelines*. in *Conference on Human Factors in Computing Systems*. 2014. ACM.
35. Segura, E.M., L.T. Vidal, and A. Rostami, *Bodystorming for movement-based interaction design.* Human Technology, 2016. **12**(2): p. 193-251.

36. Berry, T., et al., *Variations in movement patterns during active video game play in children with celebral palsy.* Journal of Bioengineering & Biomedical Science, 2011.
37. Pasch, M., et al., *Movement-based sports video games: Investigating motivation and gaming experiences.* Entertainment Computing, 2009. **1**(2): p. 49-61.
38. Loke, L. and T. Robertson, *Moving and making strange: An embodied approach to movement-based interaction design.* ACM Transactions on Computer-Human Interaction 2013. **20**(1): p. 1-25.
39. Pijnappel, S. and F.F. Mueller. *Designing interactive technology for skateboarding*. in *Conference on Tangible, Embedded and Embodied Interaction*. 2014. ACM.
40. Richards, C. and N.T.C. Graham. *Developing compelling repetetive-motion exergames by balancing player agency with the constraints of exercise*. in *Conference on Designing Interactive Systems*. 2016. ACM.
41. Loke, L. and T. Robertson. *Inventing and devising movement in the design of movement-based interactive systems*. in *Australian conference on Computer-Human Interaction: Designing for Habitus and Habitat*. 2008. ACM.
42. Mentis, H.M. and C. Johansson. *Seeing Movement Qualities*. in *Conference on Human Factors in Computing Systems*. 2013. ACM.
43. Nylander, S. and J. Tholander. *Designing for movement: the case of sports*. in *International Workshop on Movement and Computing*. 2014. ACM.
44. Reynolds, J.E., et al., *Does movement proficiency impact on exergaming performance?* Human Movement Science, 2014. **34**: p. 1-11.
45. Skjæret, N., et al., *Designing for Movement Quality in Exergames: Lessons Learned from Observing Senior Citizens Playing Stepping Games.* Gerontology, 2014. **61**(2).
46. Carroll, J.M., *HCI Models, Theories and Frameworks: Toward a Multidisciplinary Science*. 2003: Elsevier Science.
47. Gentile, A.M., *Movement Science: Implicit and Explicit Processes during Acquisition of Functional Skills.* Scandinavian Journal of Occupational Therapy, 1998. **5**(1): p. 7-16.
48. Rouse, R., *Game Design Theory and Practice*. 2000, TX, USA: Wordware Publishing Inc.,. 608.
49. Eriksson, E., T.R. Hansen, and A. Lykke-Olesen, *Movement-based interaction in camera spaces: a conceptual framework.* Personal and Ubiquitous Computing, 2007. **11**(8): p. 621-632.
50. Loke, L., A.T. Larssen, and T. Robertson. *Labanotation for design of movement-based interaction*. in *Australian conference on interactive entertainment*. 2005. ACM.
51. Matthews, B. *Grammar, meaning and movement-based interaction*. in *Australia conference on Computer-Human Interaction: Design, Activities, Artefacts and Environments.* 2006. ACM.
52. Hu, M. and M. Woollacott, *balance evaluation, training and rehabilitation of frail fallers.* Reviews in Clinical Gerontology, 1996. **6**(1): p. 85-99.
53. Irrgang, J.J., S.L. Whitney, and E.D. Cox, *Balance and proprioceptive training for rehabilitation of the lower extremity.* Journal of Sport Rehabilitation, 1994. **3**(1): p. 68-83.

54. Mausehund, L., A.E. Skard, and T. Krosshaug, *Muscle activation in unilateral barbell exercises: Implications for strength training and rehabilitation.* Journal of strength and conditioning research 2019. **33**(1).
55. Finco, M.D. and R.W. Maass. *the history of exergames: promotion of exercise and active living through body interaction*. in *IEEE 3nd International Conference on Serious Games and Applications for Health (SeGAH)*. 2014. Rio de Janerio: IEEE.
56. Oh, Y. and S. Yang. *Defining exergames & exergaming*. in *Meaningful play*. 2010.
57. Whitehead, A., et al. *Exergame effectiveness: what the numbers can tell us*. in *5th ACM SIGGRAPH Symposium on Video Games*. 2010. ACM.
58. Barenbrock, A., M. Herrlich, and R. Malaka. *Design Lessons from Mainstream Motion-Based Games for Exergames for Older Adults*. in *IEEE Games Media Entertainment*. 2014. IEEE.
59. Gerling, K., et al. *Full-body motion-based game interaction for older adults*. in *SIGCHI Conferencce on Human Factors in Computing Systems*. 2012. ACM.
60. Uzor, S. and L. Baillie. *Investigating the long-term use of exergames in the home with elderly fallers*. in *SIGCHI Conference on Human Factors in Computing Systems*. 2014. ACM.
61. Jurkiewicz, M.T., S. Marzolini, and P. Oh, *Adherence to a home-based exercise program for individuals after stroke.* Top Stroke Rehabilitation, 2011. **18**(3): p. 277-284.
62. Sabin, K.L., *Older adults and motivation for therapy and exercise: issues, influences, and interventions.* Topics in Geriatric Rehabilitation, 2005. **21**(3): p. 215-220.
63. Hebert, R., *Functional decline in old age.* CMAJ, 1997. **157**(8): p. 1037-1045.
64. Merja, R., M. Minna, and R. Taina, *Mobility decline in old age.* Exercise and Sport Sciences Reviews, 2013. **41**(1): p. 19-25.
65. Sarkisian, C.A., et al., *The relationship between expectations for aging and physical activity among older adults.* Journal of General Internal Medicine, 2005. **20**(10): p. 911-915.
66. Spirduso, W.W. and D.L. Cronin, *Exercise dose-response effects on quality of life and independent living in older adults.* Medicine & Science in Sports & Exercise, 2001. **33**(6, suppl): p. S598-S608.
67. Taylor, A. and M.J. Johnson, *Physiology of Exercise and Healthy Aging*. 2007: Human Kinetics.
68. Konrad, H.R., M. Girardi, and R. Helfert, *Balance and Aging.* The Laryngoscope, 2009. **109**(9): p. 1454-1460.
69. Skjæret, N., et al., *Exercise and rehabilitation delivered through exergames in older adults: An integrated review of technologies, safety and efficacy.* International Journal of Medical Informatics, 2016. **85**(1): p. 1-16.
70. Betker, A.L., T. Szturm, and Z. Moussavi. *Development of an interactive motivating tool for rehabilitation movements*. in *Annual international conference of the Engineering in Medicine and Biology Society.* 2005. IEEE.
71. Zheng, L., et al., *Effects of exergames on physical outcomes in frail elderly: a systematic review.* Aging Clinical and Experimental Research, 2020. **32**: p. 2187-2200.

72. Franco, M.R., et al., *Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature.* British Journal of Sports Medicine, 2015. **49**: p. 1268-1276.
73. Li, J., et al., *Exergames designed for older adults: A pilot evaluation on psychosocial well-being.* Games for Health Journal, 2017. **6**(6): p. 371-378.
74. Lange, B.S., et al., *The Potential of Virtual Reality and Gaming to Assist Successful Aging with Disability.* Physical Medicine and Rehabilitation Clinics of North America, 2010. **21**(2): p. 339-356.
75. Mueller, F.F., et al. *Experiencing the body as play*. in *CHI Conference on Human Factors in Computing Systems*. 2018. ACM.
76. Dourish, P., *Where the Action is: the foundations of embodied interaction*. 2004: MIT Press.
77. Svanæs, D., *Interaction design for and with the lived body: Some implications of merleau-ponty's phenomenology.* ACM Transactions on Computer-Human Interaction, 2013. **20**(1): p. 30.
78. Loke, L. and T. Robertson. *The lived body in design: mapping the terrain*. in *23rd Australian Computer-Human Interaction Conference*. 2011. Canberra, Australia: ACM.
79. Rode, J.A., *A theoretical agenda for feminist HCI.* Interacting with Computers, 2011. **23**(5): p. 393-400.
80. Bozgeyikli, L. and E. Bozgeyikli. *Tangiball: dynamic embodied tangible interaction with a ball in virtual reality*. in *Designing Interactive Systems Conference 2019 Companion*. 2019. ACM.
81. Maurer, B. *Embodied Interaction in Play: Social and Physical Qualities as a Design Material for Digital Play*. in *Annual Symposium on Computer-Human Interaction in Play*. 2017. ACM.
82. Shusterman, R., *Body Consciousness: A philosophy of mindfulness and somaesthetics*. 2008: Cambridge University Press.
83. Höök, K., et al. *Somaesthetic Appreciation Design*. in *Conference on Human Factors in Computing Systems*. 2016. ACM.
84. Ståhl, A., et al. *The soma mat and breathing light*. in *Conference Extended Abstracts on Human Factors in Computing Systems*. 2016. ACM.
85. Mueller, F.F. and D. Young. *Five lenses for designing exertion experiences*. in *CHI Conference on Human Factors in Computing Systems*. 2017. ACM.
86. Jensen, M.M. and K. Grønbæk. *Design Strategies for Balancing Exertion Games: A Study of Three Approaches*. in *ACM Conference on Designing Interactive Systems*. 2016. ACM.
87. Jensen, M.M., et al. *Keepin' it Real: Challenges when Designing Sports-Training Games*. in *33rd Annual ACM Conference on Human Factors in Computing Systems*. 2015. ACM.
88. Mueller, F.F., et al. *Designing sports: a framework for exertion games*. in *SIGCHI Conference on Human Factors in Computing Systems*. 2011. ACM.
89. Allen, J. and A. Holzer. *Jingle Jigsaw - Playful Dance Scaffolding Through Motion Detection*. in *CHI Conference on Human Factors in Computing Systems*. 2020. ACM.

90. Charboneau, E., et al. *Understanding visual interfaces for the next generation of dance-based rhythm video games*. in *ACM SIGGRAPH Symposium on Video Games*. 2009. ACM.
91. Charboneau, E., A. Miller, and J.J. LaViola. *Teach me to dance: exploring player experience and performance in full body dance games*. in *International Conference on Advances in Computer Entertainment Technology*. 2011. ACM.
92. Tang, J.K.T., J.C.P. Chan, and H. Leung. *Interactive dancing game with real-time recognition of continuous dance moves from 3D human motion capture*. in *International Conference on Ubiquitous Information Management and Communication*. 2011. ACM.
93. Matjeka, L.P. and F.F. Mueller. *Designing for Bodily Play Experiences Based on Danish Linguistic Connotations of "Playing a Game"*. in *Annual Symposium on Computer-Human Interaction in Play*. 2020. ACM.
94. Mueller, F.F., et al. *Towards designing bodily integrated play*. in *International Conference on Tangible, Embedded, and Embodied Interaction*. 2020. ACM.
95. Caltenco, H.A., et al. *Designing Interactive Systems for Balance Rehabilitation after Stroke.* in *International Conference on Tangible, Embedded, and Embodied Interaction*. 2017. ACM.
96. Nawaz, A., et al. *Designing simplified exergame for muscle and balance training in seniors: a concept of 'out in nature'*. in *Conference on Pervasive Computing Technologies for Healthcare*. 2014. ACM.
97. Levene, T. and R. Steele. *The Quantified Self and Physical Therapy: The Application of Motion Sensing Technologies*. in *International Conference on Compute and Data Analysis*. 2017.
98. Harrington, C.N., et al. *Assessing Older Adults' Usability Challenges Using Kinect-Based Exergames*. in *International Conference on Human Aspects of IT for the Aged Population. Design for Everyday Life*. 2015.
99. Pyae, A., et al., *When Japanese elderly people play a finnish physical exercise game: A usability study.* Journal of usability studies, 2016. **11**(4): p. 131-152.
100. Hummels, C., K.C.J. Overbeeke, and S. Klooster, *Move to get moved: a search for methods, tools and knowledge to design for expressive and rich movement-based interaction.* Personal and Ubiquitous Computing, 2006. **11**: p. 677-690.
101. Hansen, L.A. and A. Morrison, *Materializing Movement—Designing for Movement-based Digital Interaction.* International Journal of Design, 2014. **8**(1): p. 29-42.
102. Griffiths, M.D., *Trends in technological advance: Implications for sedentary behaviour and obesity in screenagers.* Education and Health, 2010. **28**(2): p. 35-38.
103. Mueller, F.F., et al., *Exertion Games.* Foundations and Trends® in Human–Computer Interaction, 2016. **10**(1): p. 1-86.
104. Clark, R. and T. Kraemer, *Clinical use of Nintendo Wii bowling simulation to decrease fall risk in an elderly resident of a nursing home: a case report.* Journal of geriatric physical therapy 2009. **32**(4): p. 174-80.
105. Flynn, S.M., P. Palma, and A. Bender, *Feasibility of using the Sony PlayStation 2 gaming platform for an individual poststroke: a case report.* Journal of neurologic physical therapy, 2007. **31**(4): p. 9.

106. Jung, Y., et al. *Games for better life: effects of playing Wii games on the well-being of seniors in a long-term care facility.* in *Australian conference on Interactive Entertainment*. 2009. ACM.
107. Oates, B.J., *Researching Information Systems and Computing*. 2006: Sage Publications Ltd.
108. Vaishnavi, V. and B. Kuechler. *Design Science Research in Information Systems*. 2004 [cited 2020 14 December]; Available from: http://desrist.org/desrist/article.aspx.
109. Zacharias, N.T., *Qualitative research methods for second language education: A coursebook*. 2011: Cambridge Scholars Publishing.
110. NVIVO. *Unlock insights in your data with powerful analysis*. [cited 2020 16 December]; Available from: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home.
111. Maki, B.E. and W.E. Mcllroy, *Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention.* Age and Ageing, 2006. **35**(2): p. 12-18.
112. Melzer, I., et al., *Do voluntary step reactions in dual task conditions have an added value over single task for fall prediction? A prospective study.* Aging Clinical and Experimental Research, 2013. **22**: p. 360-366.
113. Moe-Nilssen, R., et al., *Gait variability measures may represent different constructs.* Gait & Posture, 2010. **32**(1): p. 98-101.
114. Mulder, T., W. Zijlstra, and A. Geurts, *Assessment of motor recovery and decline.* Gait & Posture, 2002. **16**(2).
115. Sherrington, C., et al., *Effective Exercise for the Prevention of Falls: A Systematic Review and Meta-Analysis.* Journal of American Geriatrics Society, 2008. **56**(12): p. 2234-2243.
116. Rodriguez Serrano, A., M. Martín-Núñez, and S. Gil-Soldevila, *Ludologic design and augmented reality. The game experience in Pokémon Go!* . Revista Latina de Comunicación Social, 2016. **72**: p. 667-678.
117. Villareale, J., et al. *Enhancing social exergames through idle game design*. in *International Conference on the Foundations of Digital Games*. 2019. ACM.
118. Ijsselsteijn, W., et al. *digital game design for elderly users*. in *Conference on Future Play*. 2007. ACM.
119. Macvean, A. and J. Robertson. *Understanding exergame users' physical activity, motivation and behavior over time*. in *SIGCHI Conference on Human Factors in Computing Systems*. 2013. ACM.
120. Nunes, M., L. Nedel, and V. Roesler. *Motivating people to perform better in exergames: competition in virtual environments*. in *Annual ACM symposium on Applied Computing*. 2014. ACM.
121. Levac, D.E. and P.A. Miller, *Integrating virtual reality video games into practice: Clinicians' experiences.* Physiotherapy Theory and Practice, 2013. **29**(7): p. 504-512.
122. Normann, B., *Facilitation of movement: New perspectives provide expanded insights to guide clinical practice.* Physiotherapy Theory and Practice, 2018. **36**(7): p. 769-778.
123. Pickrell, M., E. Van Den Hoven, and B. Bongers. *Exploring in-hospital rehabilitation exercises for stroke patients: informing interaction design*. in

Australian Conference on Computer-Human Interaction. 2017. Brisbane, Australia: ACM.

124. Shaw, J.A. and R.T. DeForges, *Physiotherapy as bicolage: Theorizing expert practice.* Physiotherapy Theory and Practice, 2012. **28**(6): p. 420-427.
125. Maletic, V., *Body-space-expression: The development of Rudolf Laban's movement and dance concepts*. Vol. 75. 1987: Mouton de Gruyter.
126. Corbin, J.M. and A. Strauss, *Grounded theory research: Procedures, canons, and evaluation criteria.* Qualitative Sociology, 1990. **13**: p. 3-21.
127. Deci, E.L. and R.M. Ryan, *Self-determination theory: A macro-theory of human motivation, development, and health.* Canadian Psychology, 2008. **49**: p. 182-185.
128. Forkan, R., et al., *Exercise Adherence Following Physical Therapy Intervention in Older Adults with Impaired Balance.* Physical Therapy, 2006. **86**(3): p. 401-410.
129. Interaction Design Foundation. *Affordances*. 2002 [cited 2020 14 December]; Available from: https://www.interaction-design.org/literature/topics/affordances.
130. Campbell, A.J. and C.M. Robertson. *Ottago Exercise Programme to prevent falls in older adults*. 2003 [cited 2020 14 December]; Available from: https://www.livestronger.org.nz/assets/Uploads/acc1162-otago-exercise-manual.pdf.
131. Foster, N.E., et al., *A multicentre, pragmatic, parallel group, randomised controlled trial to compare the clinical and cost-effectiveness of three physiotherapy-led exercise interventions for knee osteoarthritis in older adults: the BEEP trial protocol (ISRCTN: 93634563.* BMC Musculoskeletal Disorders, 2014. **15**.
132. Liddle, S.D., G.D. Baxter, and J.H. Gracey, *Physiotherapists' use of advice and exercise for the management of chronic low back pain: A national survey.* Manual Therapy, 2009. **14**(2): p. 189-196.
133. Nawaz, A., Waerstad, M., Omholt, K., Helbostad, J. L., Vereijken, B., Skjæret, N., and Kristiansen, L. (2014). *An Exergame Concept for Improving Balance in Elderly People*. Paper presented at the REHAB 2014: ICTs for Improving Patients Rehabilitation Research Techniques, Oldenburg, Germany.
134. Wiemeyer, J., Deutsch, J., Malone, L. A., Rowland, J. L., Swartz, M. C., Xiong, J., and Zhang, F. F. (2015). Recommendations for the Optimal Design of Exergame Interventions for Persons with Disabilities: Challenges, Best Practices, and Future Research. *Games For Health Journal,* **4**(1), 58-62. doi:10.1089/g4h.2014.0078

Part II: Research Papers

Paper-I-Movement

Twelve Ways to Reach for a Star: Player Movement Strategies in a Whole-Body Exergame

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***Abstract*— This paper describes findings from a laboratory-based assessment of a balance-training exergame developed by the authors. The exergame was designed to elicit specific body movements during gameplay involving weight-shift (transfer of body weight from one foot to the other), which is considered beneficial for training balance. The body movements observed during gameplay were analyzed using a modified Labanotation. The study was conducted with twelve able-bodied adults. All users played the exergame successfully, but contrary to our expectations, only 23% of the observed player movements corresponded to the specific body movements the exergame intended to elicit. Despite the low number of intended movements, 49% of the observed movements involved weight-shift. The exergame was therefore appropriate for balance training, although users moved differently than what we had designed for. Regarding balance-training exergames, our findings suggest that designers need worry less about "puppeteering" able-bodied players with a strict choreography to elicit specific body movements. Instead we recommend that designers embrace a less rigid design approach, where the goal is to elicit desired *movement characteristics* (e.g., weight-shift) through a more open and playful behavior.**

Keywords— Balance training, Body-based interaction; Design; Exergames; Movement characteristics, Weight-shift.

I. Introduction

Balance is the key to all functional movements. It is through our ability to balance that we orient ourselves in this world. However, balance is a skill that can be retained only through consistent practice across the lifespan[1, 2]. Hence, it is vital for people of all ages to train their balance. There is good evidence of improved balance by exercise programs that include balance training [3].

Whole-body exertion games (exergames) and the question of how such applications can be applied for "serious" purposes, such as improving users' health, is gaining increased interest both in serious games research and in the health sciences. Considerable attention has been paid to the motivational aspects of exergames, i.e., how aspects associated with computer games and gaming can help induce increased physical activity in users (e.g., [4-9]). However, whole-body exergames have also shown potential in motor skill and balance training [10-12]. In the context of, for example, physical rehabilitation, the question of *how* users (players) move their bodies becomes central. Rather than encouraging increased physical activity in general (i.e., "any" type of body movement), the goal of exergames, when applied for such purposes, is to elicit movements that yield *specific* health effects (e.g., improved balance). In an earlier study [11], the authors identified what kind of movements are beneficial in training balance. Weight-shift movements were identified as effective in this respect. Weight-shift, in this context, refers to movement of the body's center of mass from one foot to the other.

One strategy for designing such balance-training exergames is to identify a set of specific body movements that result in weight-shift, and design games that elicit these movements. This is similar to how one would design an instruction video for doing weight-shift exercises. Following this design strategy, we designed and implemented a first version of the balance training exergame *Celestial Shower* (Fig. 1). In this paper, we present the results from a laboratory-based assessment of the first version of *Celestial Shower* in use.

Our study was motivated by the following research question: *How do the observed body movements of players during gameplay compare to the specific weight-shift movements the game was intended to elicit?* To answer this question, we performed an analysis of gameplay focusing on (1) the variety of observed movement; (2) the ratio of intended vs. unintended movement; and (3) how many of the unintended movements nevertheless qualified as weight-shift movements.

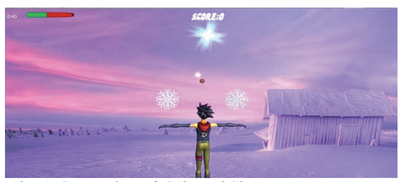


Fig. 1. Screenshot of *Celestial Shower* exergame

II. Background

A. Designing movemen-based games for specific health effects

By utilizing active body movements as a mode of interaction and putting the body at the heart of interactive experiences, movement-based games have presented new challenges. This involves everything from the limitations of the sensor technology used, to considering the movements' cognitive load on players [13].

In response to the challenges that designing for the body entails, recent studies have suggested empirically-based recommendations or guidelines to help inform design of movement-based games. For example, Isbister and Mueller [14] (expanding on earlier work described in [13]) offered a large set of "all-purpose" guidelines, describing strategies for how each guideline should be implemented, suggested strategies for designers to follow, and references to research literature inspiring the guidelines. Their guidelines, however, do not provide advice on how to design for specific movements.

Previous research has also aimed at providing design guidelines of exergame systems for specific rehabilitation purposes, however such guidelines tend to be rather generic. For instance, with respect to the rehabilitation of upper limb motor function, guidelines provided by Ona et al.[15] suggested modifying factors such as user feedback, dynamics, and automatic data acquisition and storage in the exergame. Other relevant guidelines [16] suggest framing exercise goals into speed, stability, and range of motion, such that all exercises can be categorized into one or more of these goals.

While the guidelines described in the studies cited above are highly generalizable, making them applicable to a wide range of movement-based game designs, they provide relatively little guidance on how to design for body movements that can yield *specific health effects*, such as improved balance. Likewise, physical rehabilitation studies that have validated the health effect of exergames (e.g., [17-19]), generally do not provide insights that can help understand what and how aspects of the game design helped produce a positive result. In other words, these validation studies offer little or no practical guidance for exergame designers wanting to design for specific health effects.

This paper aims to contribute to the limited body of evidence on how exergames should be designed to elicit movements that are considered to have a positive effect on a person's balance. While this issue has partially been addressed in previous studies (e.g., [11, 20, 21]), the current work provides new insights regarding *how* players solve game challenges using their bodies, and the possible implications with respect to exergame design.

B. Relevant movement concepts and theories

Various research fields have produced concepts and theories relevant for understanding or describing human movement. Below, we present a brief overview of concepts and theories of particular relevance for the current work.

1) Movement Characteristics

As a technical term, *movement characteristics* describe distinct features of movements such as speed, direction, and coordination. Studies in the health domain have established relationships between specific movement characteristics and specific health effects. For instance, movement characteristics that were identified as significant for stepping exercises in fall prevention exergames were weight-shift, temporal variation, variation in step length and direction, and visual independency [11].

2) Movement Strategies

In a study by Gittoes et al. [22], the term *movement strategy* was used to describe the variety of ways gymnasts performed backward rotating dismounts from a beam. The study and similar investigations (e.g., [23]) show a high between-participant diversity in movement strategies.

Implicit in the term movement strategy is that there is a "movement challenge" that can be solved by moving the body in a certain way. In exergame context, there is little time for the player to stop and think when presented with a "movement challenge". Consequently the movement strategies to a large extent reflect "bodily intelligence" i.e., the ability to use the body in skilled ways for expressive and goal-directed purposes [24 (p. 206)].

3) Laban's Theory of Movement

Labanotation is a formal notation for analyzing human movement, originally developed for dance and other performance arts [25]. Laban described the human movements in this framework as Body, Space, Shape Effort, and Relation. Although Labanotation is a powerful tool for describing human body movement, it is not a theory of human behavior. It has no concepts for movement strategies for solving a "movement problem", as its focus is on using the body as a medium for expression. Despite not being a theory of why people move the way they do, Labanotation is highly relevant as a framework for describing exergaming behavior. Examples of such applications of Labanotation can be found in [26].

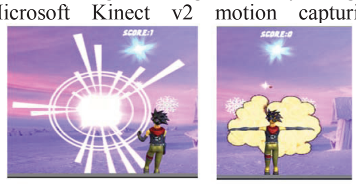
4) Gibson and Norman: Affordances and Constraints

In 1988, Norman [27] introduced J. J. Gibson's [28] concept of *affordance* and added a number of other concepts to aid in the analysis and design of "user friendly" products, including *constraints*. Norman (op. cit. p. 9) defined affordances as "*the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used*". Later, Norman [29] pointed out that the affordances on computer screens are *perceived affordances*, as they are not real in the physical sense. In [30], Norman introduced *signifiers* as signs that signify certain actions, i.e., learned affordances.

Norman's affordance theory has been highly influential in the design of graphical user interfaces for desktop computer systems. However, Norman's concepts also have relevance for how we can elicit movements in exergame players. We will in the following use the term *affordances* to describe elements of the exergame encouraging the player to interact (using his/her body) in a certain way, and *constraints* to describe elements that discourage certain interactions. Moreover, we will make a distinction between affordances and constraints that are in-game (virtual elements) and those that are real-world (physical elements).

III. The Exergame

To explore the extent to which the movement strategies performed by exergame players during gameplay correlate with design-intended movements, we built a prototype video exergame. As explained further below, the game was designed to elicit movements involving weight-shifts, which is a movement characteristic typically associated with balance training and training of functional mobility [31]. The exergame was designed using the Unity 3D game engine[1] and Microsoft Kinect v2 motion capturing system.



a. b.

Fig. 2. (a) In-game affordance (catching a star). (b) In-game constraint (getting hit by an asteroid)

[1] https://unity3d.com

Fig. 3. The trajectories of the stars (left and right) and the asteroids (middle).

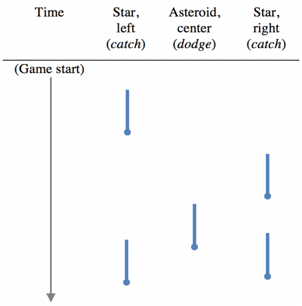


Fig. 4. Conceptual representation of game challenges.

A. *The Game Environment, Perspective and Challenges*

The virtual game environment was designed as a three-dimensional fantasy world where the player, through a body-controlled, human-like game character, was supposed to catch approaching stars and dodge incoming asteroids. Within the context of the game, the stars were intended to be affordances to reach for, and the asteroids were the elements or constraints to avoid. This is further depicted in Fig. 2a and 2b. The game employed a third-person perspective where the game camera showed the player's game character from a (rear) over-the-shoulder perspective, which is also seen in Fig. 2. This enabled a player to simultaneously see both the game character and its response to body-controlled interactions, in addition to game challenges (stars and asteroids) as they appeared in the display.

The game challenges consisted of a combination of reaching/catching and dodging movements. In order to be counted as successful (by the game) the movements had to be performed within a relatively short time-frame, i.e., when a star or asteroid was sufficiently close to the game character. From the moment a new game challenge (star or asteroid) appeared on the "horizon" of the virtual game environment, it took nine seconds before it was close enough to the game character to be caught (star) or dodged (asteroid). Approaching stars and asteroids followed specific trajectories, as shown in Fig. 3, thus limiting the game complexity to some degree. Stars would move either toward the left or the right side of the screen, as indicated by the left and right arrow in Fig. 3. The asteroids always followed the middle trajectory and targeted towards the center of the screen.

The speed of the stars and asteroids was kept constant. However, the frequency at which they appeared on the "horizon" changed dynamically depending on the player's game performance. Fig. 4 shows a conceptual representation of a snapshot of the game challenge. Once the game began and the game time progressed, the players were continuously presented with new game challenges (represented by the vertical lines in Fig. 4). The length of each line corresponds to how long (nine seconds) it took the corresponding star or asteroid from the horizon of the game world, to reach the game character close enough to either be caught (stars) or to hit (asteroids) the game character. Thus, the end of each vertical line corresponds to the moments in which the player needed to perform the catch and dodge movements in order to successfully play the game. A player was awarded one point per star caught (independently of actual player movements involved in the action). Getting hit by an asteroid reduced the game character's health bar by 10%. Points scored and the health status of the game character were continuously displayed during gameplay.

1) Designing for weight-shift

Drawing on related work [11], and with the assistance of professionals in human movement science, the exergame was designed to stimulate weight-shift movements in players. In order to achieve repeated weight-shifts, new stars constantly changed between following the left and right trajectory. Our intention was that such an approach would cause a player to switch between leaning to either side (thus changing body center mass) in order to reach for stars, while maintaining his/her feet in a fixed position. To give the player a clue about how to control the arms of the game character in order to successfully catch stars, we marked the ideal points – one floating snowflake on each side of the character – in the display (Fig. 3). The asteroids served a similar purpose as the stars. However, the asteroids left it open to the player to select which foot to put weight on while leaning away and preventing the game character from getting hit.

Fig. 5 illustrates the player postures, i.e., "snap-shots" of weight-shift movements we hoped to achieve through our exergame design. The first two rows of silhouettes (a-e) represent the intended player postures when reaching for stars, transitioning between the idle position shown in Fig. 5b. The silhouettes in Fig. 5a and Fig. 5c represent postures for catching a single star either on the left or the right side. Fig. 5d and Fig. 5e represent postures for catching two stars simultaneously. Fig. 5f shows the intended posture for avoiding an asteroid. These were the six total intended postures that we had designed for. To check that the intended movements were efficient in terms of scoring points and avoiding asteroids, we performed self-assessments of the game during the design process.

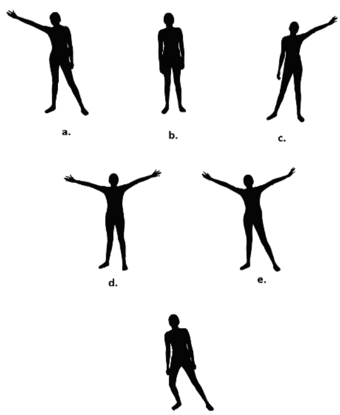


Fig. 5. Design-intended player postures

IV. Experiment

A. Participants

A convenience sample of six older adults (three male and three female), and six younger adults (three male and three female) were recruited for the experiment. The participants were recruited from a local university and a fitness center. The age of the older participants ranged from 60 to 86 years with an average age of 74±9 years. The age of the younger participants ranged from 23 to 28 years with an average age of (26±2). All the participants were healthy able-bodied individuals without known neurological diseases or other conditions affecting balance. Of the 12 participants, only two had previous exergaming experience. Further, only four participants had video gaming experience and played video games regularly. The remaining participants had no video gaming experience.

B. Location and Equipment

The experiment was conducted in a usability laboratory [32] equipped with roof-mounted, remotely controlled cameras (Sony EVI-D70) for video recording. For the experiment we set up a PC with a Microsoft Kinect v2 connected to a wall-mounted 32” high definition LCD-TV with external speakers. Colored tape was used to mark the approximate physical area of the laboratory were the motion sensor was able to correctly infer a player’s body movements, i.e., the *physical gaming area*. The physical gaming area was 1.5 x 1.5 meters. The center of the physical gaming area was approximately 1.5 meters from the center of the TV display. Fig. 6 shows a participant playing the exergame in the usability laboratory.

C. Procedure

Each participant was initially briefed about the purpose of the study and given basic information about the goal of the game and its control mechanisms. Next, each participant played “Celestial Shower” for five minutes. During gameplay, one researcher (the first author) acted as a fly-on-the-wall observer.

D. Data Collection and Analysis

1) Data Collection

The participants’ physical interactions with the game (i.e. their body movements) were video recorded. We also used screen-mirroring software to capture a continuous video stream of the TV display during gameplay. The two recordings were mixed into one video stream showing both the participants’ body movements in physical space, and the corresponding graphical user interface of the game.

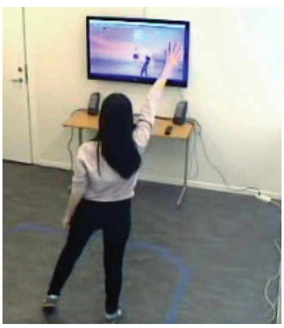


Fig. 6. Participant playing the exergame

2) Data Analysis

The combined video streams from the experiment were analyzed manually (by means of video observation), using a Labanotation-inspired coding scheme to describe various observed characteristics of the participants’ body movements. Instead of using a pre-constructed coding scheme (e.g., Labanotation), we decided to follow a bottom-up coding approach, allowing the coding scheme to emerge from the collected data. Our approach was also pragmatic in the sense that it allowed us to adjust the level of coding detail to a level we found appropriate with respect to our research question.

Early inspections of the video recordings revealed that the participants’ gameplay was generally characterized by two relatively distinctive “states”; one of idleness (e.g., when no stars or asteroids were displayed, or within the proximity of the game character) and another characterized by more active use of the body (e.g., when reaching for a star or dodging an asteroid). The gameplay of a participant was coded as a sequence of postures, alternating between *idle* and *active* postures, with a movement being a transition between two such postures. From our early inspections of the recordings we also learned that the participants tended to use different movement strategies when solving the game challenges. This was particularly evident in the case of the participants’ active postures but was also reflected in the idle postures.

We found that one way of capturing the differences in performed body postures was to code the relative position (i.e., the degree of flexion or extension) of the body’s major joints (i.e. shoulder, elbow, knee and ankle). Such a coding scheme can potentially be used to describe observed postures in relatively high detail. Drawing in part on Laban’s [25] notation system, we decided to limit the coding of each joint to three or four distinct categories, based on the different degrees of rotation, flexion and extension of the various joints. In the coding process, "1" indicated no/minimal rotation, flexion, or extension of the joints, "2" indicated moderate rotation, flexion, or extension of the joints, and "3" indicated extreme rotation, flexion, or extension of the joints. These were the three major coding categories. In addition, a few categories were included for certain joints to capture necessary details. For instance, the ankle joint had more than three categories, as it was essential to capture whether the feet were together or apart in conjunction with the three main categories. Fig.7 provides

Fig. 7. Coding of sample posture, center of body mass (*left, center, or right*), and position.

an example of how a specific posture was coded.

In the following, we will analyze the diversity of resulting postures. A full analysis of all transitions between postures is beyond the scope of this paper. By only counting the unique postures for each participant we disregard the diversity of idle-active transitions but get a good indication of between-participant diversity of movement strategies.

V. RESULTS AND ANALYSIS

The coded observations from the experiment revealed three main findings. These were related to:

- **Shared postures**: Postures that were shared across the participants.
- **Intended vs. unintended postures**: Player postures that had been designed for as compared to unexpected player postures.
- **Weight-shift vs. no weight-shift postures:** Player postures that were not designed for, but nevertheless indicated a weight-shift movement, thereby eliciting the desired effect.

Below, we will account for each of the three main findings in further detail.

A. Shared Postures

Overall, there were a total of 147 different postures portrayed by the participants. Fig. 8 shows the grouping of the diverse postures in terms of postures that were displayed among two or more participants (referred to as the shared postures) and the postures that were only portrayed by one of the participants (unique postures). It was observed that 62 postures out of the total 147 postures were shared by two or more participants. Of only one posture was shared by 10 participants. An overview of the shared postures can be seen in Fig. 8.

The number of different postures per participant ranged from 6 to 56, with an average of 24.8. The mean for younger adults was 31.2, while for elderly this was 18.5. To test for potential differences between groups and gender, independent samples t-tests were used, as these allow for small sample sizes [33]. Although younger participants displayed a higher number of unique postures than older participants, this difference was not significant $p=0.07$. There was no significant difference between male and female participants either.

Of further interest for the current study is the average number of different postures that a random participant A shares with a random participant B. We define the *share ratio* of A to B to be the total number of different postures shared by subject A and subject B, relative to the number of different postures for subject A. If all subjects used the same set of postures, the average share ratio would be 1.

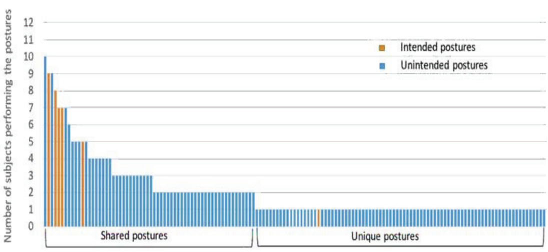


Fig. 8. Distribution of shared and unique postures.

If all subjects used unique postures, this number would be 0. In other words, a low number indicates a high degree of unique postures, and consequently a higher degree of diversity concerning movement strategies. We expected the participants to move in similar ways, therefore our expectation was an average share ratio close to 1, indicating low between-participant diversity.

Table 1 shows the share ratios for all pairs of participants. This table is asymmetrical because the number of different postures differ between participants. The average share ratio for all pairs of participants is 0.27, i.e., on average a participant shares 27% of his/her postures with a random other participant.

This indicates a higher level of between-participant diversity in movement strategies to solve the same movement challenge than what we had anticipated.

TABLE I. SHARE RATIOS BETWEEN PARTICIPANTS

	1	2	3	4	5	6	7	8	9	10	11	12
1		0.13	0.19	0.31	0.31	0.06	0.06	0.19	0.19	0.19	0.25	0.00
2	0.13		0.44	0.44	0.63	0.63	0.38	0.31	0.13	0.31	0.31	0.56
3	0.14	0.32		0.36	0.27	0.36	0.14	0.41	0.09	0.27	0.27	0.27
4	0.22	0.30	0.35		0.61	0.30	0.35	0.48	0.17	0.26	0.48	0.17
5	0.09	0.18	0.11	0.25		0.27	0.18	0.13	0.09	0.18	0.24	0.16
6	0.03	0.33	0.27	0.23	0.50		0.20	0.20	0.03	0.17	0.20	0.37
7	0.06	0.33	0.17	0.44	0.56	0.33		0.33	0.06	0.22	0.28	0.22
8	0.09	0.15	0.27	0.33	0.21	0.18	0.18		0.12	0.30	0.30	0.09
9	0.50	0.33	0.33	0.67	0.83	0.17	0.17	0.67		0.50	0.83	0.00
10	0.12	0.19	0.23	0.23	0.38	0.19	0.15	0.38	0.12		0.23	0.23
11	0.20	0.25	0.30	0.55	0.65	0.30	0.25	0.50	0.25	0.30		0.15
12	0.00	0.33	0.22	0.15	0.33	0.41	0.15	0.11	0.00	0.22	0.11	

B. Intended vs. Unintended postures

Only six out of the 147 different postures portrayed by the participants were the intended postures. The bar chart in Fig. 8 represents all the various postures that were observed along with the corresponding number of participants that performed them. Hence, in addition to the six intended postures (color coded in orange in Fig.8) for which the game was initially designed, the participants displayed 141 alternative postures while playing the game (the unintended postures represented in blue in Fig. 8) that were also successful in solving the game challenges.

Three of the unique postures that were displayed by some of the participants are represented in Fig. 9 (a-c). Fig. 9a and 9b represent postures adopted by participants in an attempt to catch stars, while Fig. 9c represents a unique posture displayed to avoid an asteroid.

Concerning frequency of movements that involved intended vs. unintended postures, we counted the number of times a specific posture was observed for a specific participant. The average number of total postures observed per participant was 95, referring to the total number of postures in the sequence of movements observed for a participant during the five minutes of gameplay. On average

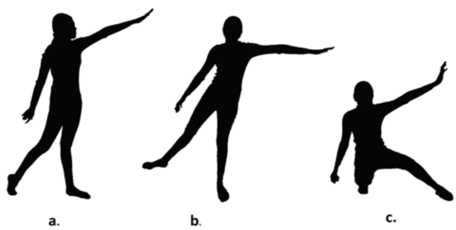


Fig. 9. Example of three observed unique unintended postures.

TABLE II. CLASSIFICATION OF POSTURES.

Intended postures	Weight shift: no	Weight shift: yes	
	51%	49%	
yes	11%	12%	23%
no	40%	37%	77%

unintended postures accounted for 77% (SD 23.8) of the total postures, whereas only 23% (SD 16.9) accounted for the designed intended postures.

When designing the exergame, we had expected some unintended postures by the players, but not a number as high as 77%.

C. *Weigh-Shift vs. No Weight-Shift Postures*

The observed intended and unintended postures were further classified into postures with or without weight-shift. Table 2 shows the resulting classification of the postures. We found that on average only 12% (SD 8.5) of all postures were the intended postures with a weight-shift effect, with an additional 37% (SD 25.8) unintended postures that did include weight-shift as well. Of the unintended postures, 48% had weight-shift (37% of 77%).

Though many of the postures were unintended postures with weight-shift, there were also a large number of postures that were unintended postures without weight-shift. These postures accounted for 40% (SD 27.1) of the overall movements. In addition, there were 11% (SD 10.8) intended movements without a weight-shift. This reflected the idle posture maintained between the active postures. In total, 51% of all postures did not have weight-shift, while 49% did.

When designing the exergame, we wanted to minimize the number of unintended movements as we assumed such movements would have little weight-shift. It is consequently surprising that as many as 48% of the unintended postures had weight-shift.

VI. DISCUSSION

Having presented the main findings from our exergame experiment, what design lessons can we learn from it? Our original intention was to design for a limited set of specific movements that would elicit weight-shift. As such, we did not anticipate a high degree of unintended postures (77%), nor that a high number of these unintended postures would include weight-shift effects (48%).

Taken together these findings highlight how players find numerous ways to solve "movement challenges" in whole-body exergames, such as the *Celestial Shower*. These same findings also open up some interesting perspectives on the level of required choreography (movement guidance) in exergames, and how to choreograph a player's body movements through design.

A. *The Need For Choreographing Player Movements*

Concerning the level of required choreography, unintended movements without a desirable effect will in principle demand some level of choreography to guide the player. The question of whether "strict" choreography is required, however, is in our view intimately linked to the purpose of the exergame and the extent to which unintended movements with a positive effect are considered "problematic". For example, when dealing with user groups such as frail older adults, or patients where the wrong movements could be harmful, a strict choreography of player movements might be required to avoid negative health effects. Such strict choreography could be achieved by the strategies further mentioned below. However, the need for choreographing a player's body movements would be reduced if the purpose of playing was to open up for explorative ways to interact with the game.

B. *Choreographing Player Movements Through Design*

The need for choreographing exergame players' movements in order to achieve specific movements and desired effects during game play, while avoiding negative effects, indicates the relevance of Gibson's and Norman's affordance theories. Drawing on Gibson's theory, Norman considered affordances (design-encouraged user interactions) and constraints (design-discouraged user interactions) in a user interface to act as a symbiosis in guiding a user's interaction. Affordances and constraints, both in the game (on the screen) and in the real world, open up for different ways of redesigning Celestial Shower that potentially can reduce "undesired" player movements. Inspired by our findings and Norman's affordance theory *[27, 29], we provide three design strategies of how such a redesign might potentially be achieved*.

1) Using In-game Affordances and Constraints

One design strategy for discouraging unintended player movements is to focus on redesigning aspects of the virtual game environment by means of affordances and constraints. For example, allowing the game character to carry some sort of catching device in both hands, could be one way of subtly hinting that objects cannot be caught with other parts of the characters body (e.g., the game character's head).

There are also ways to potentially restrict undesired movements in players through the use of constraints, i.e. game world hindrances preventing the game character's mobility. For example, adding pits on either side of the game character, which he or she risks falling into if the player changes physical position too far sideways is an example of how a constraint possibly may guide player movements. Another way to discourage undesired movement strategies, requiring no changes to the game world itself, would be to only award points in cases where intended movements were performed (based on data from the motion capture system).

2) Using Real-World Affordances and Constraints

Above we presented ways in which changes made to the virtual game environment, through the use of affordances and constraints could potentially help guide player movements. However, the same principles may also be applied to the "real-world" dimension of exergames, i.e. the physical gaming area. One potential way to prevent player mobility during game play, would be to attach footprint stickers to the floor, and in this way subtly hint to the user where he or she should keep their feet during gameplay. It is also possible to exploit "hard" real-world constraints to control player movements. For example, strapping the players feet to the floor of the gaming area, or using physical hindrances to prevent certain movements would be a more explicit constraint than the virtual "pit" described above.

3) Using a Combination of In-game and Real World Affordances and Constraints

A third strategy would be to combine the two strategies described above. This can be a pragmatic approach to deal with practical problems that design needs to deal with. For example, while using real-world constraints can be a suitable approach in a dedicated exergame room or a laboratory setting, it is unlikely that this would be acceptable in, for example, a living room.

VII. Limitations of the Study

We recognize that our work has certain limitations. One such limitation is the relatively low number of participants who participated in the exergame experiment. Further, the analysis of player postures was carried out by means of visual observation and coding only. Using sensor technology to analyze the movement strategies of player could potentially yield more detailed results, but we consider it unlikely that such an approach would significantly change our classification of postures (Fig. 8).

Finally, the results of our investigation were based on an analysis of a particular exergame. In effect, our investigation can be considered a *case* study. As such, it is possible that performing similar analyzes on other exergames would produce different results in terms of identified postures. Further, we have not studied the effect of game mechanism such as the scores on participant performance. This, however, does not in itself weaken our argument that the need for choreographing exergame players depends closely on what types of movements strategies should be considered acceptable. As shown by our results, there may potentially be several ways to achieve a specific training or health effect, although the degree of effect may vary.

VIII. Summary and Conclusion

We have described the results from a laboratory-based assessment of a whole-body balance exergame with twelve test participants. The exergame was designed with the intention of eliciting six movements in players during gameplay. Our study was motivated by the following research question:

How do the observed body movements of players during gameplay compare to the specific weight-shift movements the game was intended to elicit?

Regarding how the players solved the game challenges, we found that players used a wide variety of movement strategies. A total of 147 distinctive postures were identified through our data analysis, of which 62 were shared between two or more participants. Overall, the average share ratio was 27%. Among the observed postures, on average 77% were unintended, although 48% of those did involve weight-shift. Keeping in mind the small sample size and use of only one exergame case, we propose the following implications for the design of exergames for specific health effects:

(1) Our participants were all skillful in terms of solving "movement challenges". If a game does not set a "strict" choreography (achieved through in-game or real-world affordances and constraints), it is likely that players will use a wide variety of movement strategies. In addition, many of these strategies may only be shared among a small number of users.

(2) Although explorative gameplay (with a low degree of choreography) will likely lead to a high number of unintended movements, this is not necessarily a problem concerning desired exergame health effects, as many of the unintended movements can still have the desired effect.

(3) The implications of the above is that designers of exergames that intend to elicit weight-shift movements in able-bodied players need not focus on how to "puppeteer" players, i.e., attempt to rigidly control their movements through in-game and real-world affordances and constraints. Rather than adopting a design strategy focusing on eliciting *specific* body movements (our original approach), we recommend that exergame designers instead embrace a more open design approach in which the desired *movement characteristics* are the primary design goal. Desired movement characteristics may, as shown through our analysis be evident in a number of movement strategies. An exergame design approach focusing on movement characteristics encourages game designs that are more open and explorative in terms of player body movements. Applying a user-centered iterative design approach, evaluations of the exergame during the design process need not focus on to what extent specific movements are observed, but on the *movement characteristics* of the observed movements (e.g., weight-shift or not).

Generalizing from this specific case, designing interactive exergames for specific health effects is different from designing an instruction video for the same purpose. For interactive media, we may have to give up the idea of choreographing the user's movements in detail. Focus should instead be on creating game challenges that can be solved in a variety of ways, encouraging movements that have certain health-beneficial *movement characteristics.*

We hope through our work, we are able to inspire further research on how to design whole-body exergames for specific health effects.

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References

[1] Hausdorff, J.M., D.A. Rios, and H.K. Edelberg, *Gait variability and fall risk in community-living older adults: a 1-year prospective study.* Arch Phys Med Rehabil, 2001. **82**(8): p. 1050–1056.

[2] Kannus, P., et al., *Rising incidence of fall-induced injuries among elderly adults.* J Public Health, 2005. **13**(4): p. 212–215.

[3] Gillespie, L.D., et al., *Interventions for preventing falls in older people living in the community.* Cochrane Database Syst Rev 2012;CD007146., 2012. **12**(9 (CD007146)).

[4] Choi, W., et al., *SwimTrain: Exploring Exergame Design for Group Fitness Swimming*, in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 2016, ACM, New York, NY: San Jose, California, USA. p. 1692-1704.

[5] Hagen, K., et al. *Pedal Tanks*. 2015. Cham: Springer International Publishing.
[6] Nawaz, A., et al., *Assessing seniors' user experience (UX) of exergames for balance training*, in *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. 2014, ACM, New York, NY: Helsinki, Finland. p. 578-587.
[7] Mueller, F.F. and D. Young, *Five Lenses for Designing Exertion Experiences*, in *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 2017, ACM, New York, NY: Denver, Colorado, USA. p. 2473-2487.
[8] Ahtinen, A., P. Huuskonen, and J. Häkkilä, *Let's all get up and walk to the North Pole: design and evaluation of a mobile wellness application*, in *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*. 2010, ACM, New York, NY: Reykjavik, Iceland. p. 3-12.
[9] Yoo, S., C. Parker, and J. Kay, *Designing a Personalized VR Exergame*, in *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*. 2017, ACM, New York, NY: Bratislava, Slovakia. p. 431-435.
[10] Richards, C. and T.C.N. Graham, *Developing Compelling Repetitive-Motion Exergames by Balancing Player Agency with the Constraints of Exercise*, in *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. 2016, ACM: Brisbane, QLD, Australia. p. 911-923.
[11] Skjæret, N., et al., *Designing for movement quality in exergames: lessons learned from observing senior citizens playing stepping games.* Gerontology, 2015. **61**(2): p. 186-94.
[12] Vandermaesen, M., et al., *Integrating Serious Games and Tangible Objects for Functional Handgrip Training: A User Study of Handly in Persons with Multiple Sclerosis*, in *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. 2016, ACM, New York, NY: Brisbane, QLD, Australia. p. 924-935.
[13] Mueller, F. and K. Isbister, *Movement-based game guidelines*, in *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. 2014, ACM, New York, NY: Toronto, Ontario, Canada. p. 2191-2200.
[14] Isbister, K. and F.F. Mueller, *Guidelines for the Design of Movement-Based Games and Their Relevance to HCI.* Human–Computer Interaction, 2015. **30**(3-4): p. 366-399.
[15] Ona, E.D., C. Balaguer, and A. Jardon. *Towards a Framework for Rehabilitation and Assessment of Upper Limb Motor Function Based on Serious Games*. in *International Conference on Serious Games and Applications for Health*. 2018. Vienna, Austria.
[16] Borghese, N.A., et al. *A cloud-based platform for effective supervision of autonomous home rehabilitation through exer-games*. in *Internation Conference on Serious Games and Application for Health*. 2018. Vienna, Austria.
[17] Shih, M.-C., et al., *Effects of a balance-based exergaming intervention using the Kinect sensor on posture stability in individuals with Parkinson's disease: a single-blinded randomized controlled trial.* Journal of NeuroEngineering and Rehabilitation, 2016. **13**(1): p. 78.
[18] Rendon, A., Abel, et al., *The effect of virtual reality gaming on dynamic balance in older adults.* Age Ageing, 2012. **41**(4): p. 549-552.
[19] Harris, D.M., et al., *Exergaming as a Viable Therapeutic Tool to Improve Static and Dynamic Balance among Older Adults and People with Idiopathic Parkinson's Disease: A Systematic Review and Meta-Analysis.* Frontiers in Aging Neuroscience, 2015.
[20] Sun, T.-L. and C.-H. Lee, *An impact study of the Design of Exergaming Parameters on Body Intensity from Objective and Gameplay-Based Player Experience Perspectives, Based on Balance Training Exergame.* PLOS ONE, 2013. **8**(7).
[21] Tomitsch, M., et al. *Who cares about the content? An analysis of playful behaviour at a public display*. in *PerDis'14*. 2014. Copenhagen, Denmark.
[22] Gittoes, M.J.R., et al., *Whole-body and multi-joint kinematic control strategy variability during backward rotating dismounts from beam.* Journal of Sports Sciences, 2011. **29**(10): p. 1051-1058.
[23] Bennett, S.J., D. Elliott, and A. Rodacki, *Movement strategies in vertical aiming of older adults.* Experimental brain research, 2012. **216**(3): p. 445-455.
[24] Gardner, H., *Frames of Mind: The Theory of Multiple Intelligences.* 1983: NYC: Basic Books.
[25] Maletic, V., *Body-space-expression: The development of Rudolf Laban's movement and dance concepts*. Vol. 75. 1987: Walter de Gruyter.
[26] Loke, L., A.T. Larssen, and T. Robertson. *Labanotation for design of movement-based interaction*. in *Proceedings of the second Australasian conference on Interactive entertainment*. 2005. Creativity & Cognition Studios Press.
[27] Norman, D.A., *The Psychology of Everyday Things*. 1988: Basic Books Inc., New York, New York.
[28] Gibson, J.J., *The Ecological Approach to Visual Perception*. 1979: Houghton Mifflin Harcourt (HMH), Boston.
[29] Norman, D.A., *Affordance, conventions, and design.* interactions, 1999. **6**(3): p. 38-43.
[30] Norman, D.A., *THE WAY I SEE IT: Signifiers, not affordances.* interactions, 2008. **15**(6): p. 18-19.
[31] Sherrington, C., et al., *Effective exercise for the prevention of falls: a systematic review and meta-analysis.* . J Am Geriatr Soc, 2008. **56**(12): p. 2234–2243.
[32] Svanæs, D., *NTNU health informatics usability and design lab*, in *Interactions*. 2015, ACM: New York,NY, USA.
[33] De Winter, J.C.F., *Using the Student's t-test with extremely small sample sizes.* Practical Assessment, Research & Evaluation, 2013. **18**(10).

Paper-II-Motivation

Assessing motivational differences between young and older adults when playing an exergame

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ABSTRACT

Currently, exergames are used by different age groups for both recreational and training/rehabilitation purposes. However, little is known about how to design exergames so that they are motivating for specific age groups and health outcomes.

Objective: In this paper, we compare motivational factors between healthy young and older adults by analyzing their assessments of the same balance training exergame.

Materials and Method: We performed a laboratory-based assessment of a custom-made balance training exergame with twelve healthy young and ten healthy older adults. Their answers to a semi-structured text input questionnaire were analyzed qualitatively.

Results: Both age groups were motivated by a combination of intrinsic and extrinsic motivational factors. We found that the young adults tended to be motivated by the game challenge and the in-game reward system (scores). In contrast, the older adults were more motivated by the perceived health effects (both physical and cognitive) and the joy of playing, with less regard for the in-game rewards.

Conclusion: The differences in motivational factors that were identified between young and older adults have several design implications. For older adults less effort can be put on designing the in-game reward system, and more on showing the player the potential health effects of their play. Furthermore, the competition aspect can be downplayed, and more focus placed on simply making the gaming experience itself as joyful as possible.

KEYWORDS

Balance training; Body-based interaction; Design; Exergames; Weight-shift; Young adults; Older adults; Motivation.

INTRODUCTION

Although the health benefits of regular physical exercise have been established by studies time and again, physical inactivity remains a major global health concern as it increases the risk of heart disease, high blood pressure, stroke, type 2 diabetes, some forms of cancer, and falls among older adults.[1-3] With the gradual enhancement of traditional physical exercise by innovative technology, exergames are increasingly seen as tools that can motivate physical activity.[4-6] Larsen et al.[7] define exergames as "digital gaming systems with an interface that requires physical exertion to play the game" (ibid, p. 1). Synonyms include exertion games, exertainment, active-play videogames, and game-based technology-mediated physical activity. Popular exergaming platforms are Nintendo Wii and Microsoft Kinect.

Exergames are being used to facilitate physical exercise, balance training and rehabilitation in different settings.[8-10] There is a growing body of research on the health effects of exergames, including rehabilitation of motor impairments, fighting obesity, stroke rehabilitation, and balance training.[11-14] Chang et al.[15] tested the validity and reliability of WiiFit Balance board for the assessment of balance among young and older adults, and found the Wii balance board to have good reliability for older adults. Further, Graves et al.[16] compared the cardiorespiratory and enjoyment measurements among adolescents, young and older adults during inactive videogaming, Wii fit, and treadmill exercises. The study found Wiifit to be an enjoyable exergame for adolescents and adults, stimulating light-to-moderate intensity activity through the modification of typically sedentary behavior. Previous studies performed on both young and older age groups have focused largely on the validity of the technology and the physiological effects, rather than on the game design itself. Despite having a body of research focusing on the use of exergames and health effects,[8, 17, 18] there is still a need to gain more insight into how to design exergames for specific age groups. From a game design perspective, this raises the question as to what extent such games need to be designed for specific age groups. To answer this question, it is necessary to know what motivates different age groups to play exergames. To our knowledge, no studies have identified the underlying differences in motivational factors for young versus older age groups.

Assessing the motivational differences between young and older adults concerning exergames raises the need for a theoretical understanding of the term *motivation*. The term *motivation* originates from the Latin word *movere*, which means "to move". It generally refers to the forces that act on or within an individual and which cause the arousal, direction and persistence of goal-directed, voluntary effort. Most theories on motivation tend to consider motivation predominantly as a one-dimensional phenomenon, which means that the motivation to perform a certain activity can range from none or little to a considerable amount. Self-Determination Theory (SDT) [19] expanded this traditional view of motivation by also taking into account the orientation (or type) of motivation. In particular, SDT differentiates between reasons that give rise to an action. *Intrinsic motivation* refers to actions that are perceived as inherently interesting or enjoyable. *Extrinsic motivation*, on the other hand, refers to actions which are performed due to some external resource or reward. With respect to motivation for physical activity in general, Molanorouzi et al.[20] found that motivation for participation in physical activity among young and middle-aged adults differed across type of activity, age and gender. They reported that young adults had higher affiliation, mastery and enjoyment associated with participation in physical activities than middle-aged adults who considered psychological conditions and other expectations more important for participation. Furthermore, Kilpatrick et al.[21] found that among college students, motivation for sports participation was more related to intrinsic factors such as enjoyment and challenge, compared to more extrinsic motivation related to appearance and weight management for exercise behavior as such.

In this paper we compare motivational factors that influence healthy young and healthy older adults playing an exergame, by analyzing their assessments of the same game. Our research adds to the limited knowledge of designing goal-directed, interactive exergames for specific user groups. The main objective of the conducted study was to evaluate a balance training weight-shift exergame by these two age groups. The working hypothesis is that there are significant differences between the considered age groups, and that these differences have implications for designing motivating exergames. Both user groups played a balance training weight-shift exergame and filled out a questionnaire after playing the game. The results presented in this paper are based on a qualitative analysis of the participants' answers to the semi-structured text input questionnaire.

METHODS

Participants

The participants in this study consisted of 12 young adults between 23 to 28 years of age (25.3 ±1.6, 50% female), and 10 older adults between 65 to 85 years of age (74.5 ± 5.4, 80% female). The sample size was chosen to fit the aim of the study, i.e. to do an in-depth user experience assessment of the game. The participants were all healthy individuals and no additional medical information or medical data was collected for the study. The young adults were recruited from the University campus, and the older participants from senior groups. The overall inclusion criterion was to have overall good health for their age. Furthermore, older adults had to live independently and be able to stand and walk for at least 30 minutes. The exclusion criteria were any form of motor and/or cognitive impairment. The younger adults were regularly physically active for at least 60 minutes weekly. Three of the younger adults had previously played exergames, and seven of them indicated that they played videogames at least once a week. The older adults regularly performed some form of physical activity every week for at least 30 minutes. Two of the older adults indicated that they had previous exergame experience, and one indicated that she plays videogames daily.

Location and Equipment

The study was conducted in the University's usability laboratory equipped with roof-mounted, remotely controlled cameras (Sony EVI-D70) for video recording. For playing the game, we set up a PC with a Microsoft Kinect v2 connected to a wall-mounted 32" high definition LCD-TV with external speakers. The Kinect v2 motion recognition sensor was used as motion input device to play the game, not for data collection. Based on the sensor limit of the Kinect (1.2-3.5 meters), an appropriate physical gaming area (1.5 x 1.5 meters) was marked using colored tape.

The Exergame

The Celestial Shower is an age-neutral balance training exergame that was developed by the authors and used in the study. The game was designed within the Unity 3D game engine[1] using Microsoft Kinect.

[1] www.Unity3D.com

Figure 1: Screenshot of the Celestial shower exergame

Figure 1 shows a screenshot of the gaming environment. The gaming environment consisted of a main avatar, that mimicked the player's physical movements. The avatar was positioned within a dynamic environment that consisted of several approaching stars and asteroids. The main task of the players was to stretch out their arms and shift their weight from side to side to catch approaching stars and gain points. At the same time, the players were to avoid the impact of oncoming asteroids by similarly shifting their weight and leaning sideways. The players got one point for every star caught. At the start of the game, the players were provided with a 100 % full health bar and lost ten percent of health each time the avatar was hit by an asteroid. The game was designed to elicit simple weight-shifting movements as in general balance training exercise. Furthermore, the game was designed to be very simple with minimal game objects and multi-sensory feedback systems, such as audio and graphical visual feedback.

Study Procedure

The study was ethically approved by the Regional Committees for Medical and Health Research Ethics (REK) and carried out in accordance with the Norwegian Centre for Research Data (NSD) and the Helsinki Declaration.

The participants were given basic information about the goal of the game and its control mechanism. All the participants filled out a simple questionnaire with background-specific information about their age, gender, gaming experience, exercise routine and a consent form before starting the experiment. All the participants were filmed from behind during the experimental session.

The participants initially played a two minutes' demo to get acquainted with the game and learn about the basic game dynamics. Following the demo, the participants played the game for 20 minutes. After the gaming session, participants filled out a questionnaire asking specific questions about the participants' perception and acceptance of the exergame, as well as their individual feedback and preferences. The entire session lasted between 45-60 minutes, depending on the individual participants.

Data Collection and Analysis

The qualitative data consisted of answers to a semi-structured text input questionnaire, consisting of several questions about pros, cons and suggestions for improvements of the game without explicitly asking about motivation. Gender differences were not addressed in this study due to the limited sample size. The answers from both the young and older adults were segmented into meaningful expressions. An open coding approach was followed on the two sets of data (young and older adults). Corbin and Strauss [22] describe open coding as follows: "*In open coding, events/actions/interactions are compared with others for similarities and differences. They are also given conceptual labels. In this way, conceptually similar events/actions/interactions are grouped together to form categories and subcategories*" (ibid, p. 13). Open coding is an iterative data analysis process where categories are added until inductive thematic saturation[23] is established, and all data have been categorized.

For each of the two user groups, expressions relating to similar topics were clustered together through an open coding process, leading to one set of topics (categories) for each age group.

RESULTS

In the coding process, inductive thematic saturation was established for both age groups, leading to five topics (categories) for young adults and seven topics (categories) for older adults.

Feedback from young adults

Figure 2 shows a young study participant playing the game. The feedback from the young participants obtained through the questionnaire were related to five distinct topics: *Challenge, Complex gaming environment, Graphics and music, Enhanced reward system,* and *Personalization.*

Challenge: Many of the younger participants stated that they liked challenging themselves. The younger participants preferred being challenged both at a physical and a cognitive level while playing the game.
Py04 (Male; 28yrs): "Challenging yet doable"
Py10 (Male; 25yrs): "The difficulty level gradually increased, which kept me engaged and focused"

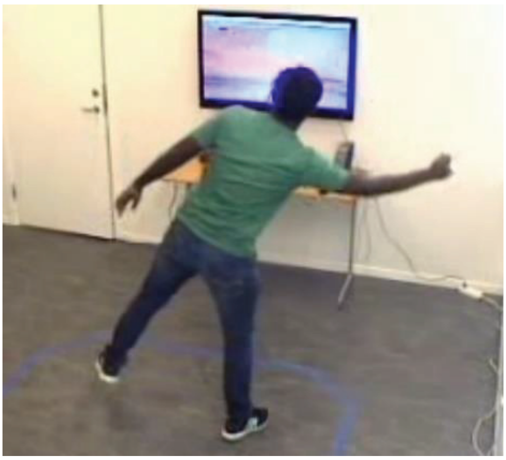

Figure 2: A young participant playing the game

Py07 (Male; 26yrs): "I liked it when I had to move quickly and do more things at the same time"
Py11 (Male; 23yrs): "I would like it to be more challenging"

Complex gaming environment: One participant indicated that he preferred a more complex gaming environment as compared to a simple environment.

Py07 (Male; 26yrs): "Add multiple elements within the game"

Graphics and music: Five of the young participants indicated that they liked the background and graphics in the game, including the visual feedback and the gaming environment.
Py12 (Female; 24yrs): "The graphics and music were pleasant"

Py11 (Male; 23yrs): “I liked both background and character graphics”
Py10 (Male; 25yrs): “The background music helped to be more active”
Py09 (Male; 23yrs): “I like the music”
Py01 (Male; 26yrs): “I like the background and game environment”

Enhanced reward system: Three of the young participants suggested improvements for the in-game reward system.
Py11 (Male; 23yrs): “Include a better reward system”
Py10 (Male; 25yrs): “Include different booster points”
Py05 (Female; 26yrs): “There should be ways to earn extra points”

Personalization: Two of the young adults wanted to personalize the game with respect to parameters such as the theme, music, avatar, etc.
Py12 (Female; 24yrs): “option for different background”
Py11 (Male; 23yrs): “change in graphics”

In sum, the young participants expressed their interest and ideas about having a challenging and rewarding game environment. They further emphasized visual and interaction design parameters such as graphics, music, and personalization.

Feedback from older adults

Figure 3 shows an older participant playing the game. The feedback from the older participants obtained through the questionnaire were related to seven distinct topics: *Physical and Cognitive training*, *Having fun*, *Prompt feedback*, *Negative feedback*, *Movement Variation*, *Technology*, and *Increased Training Time.*

Figure 3: An older participant during the study

Physical and Cognitive training: The older participants expressed that they felt good about practicing their balance and training their mind at the same time. Given below is the corresponding feedback:
Po03 (Female; 76yrs): “It would be nice to have more challenging foot balancing tasks”
Po04 (Female; 76yrs): “I liked having to concentrate and move my body the whole time.”
Po05 (Female; 71yrs): “I liked training my concentration and performing the simple movements.”

Po06 (Female; 75yrs): “I like using my head and my body simultaneously”
Po07 (Female; 76yrs): “I like that it was engaging and required my concentration”
Po10 (Female; 65yrs): “I like that I am training my reflexes”

Having fun: Several participants expressed that they had fun playing the game, and that it was engaging. The participants had different reasons for why they found it to be fun. Some participants did not mention why they found the experience to be fun, whereas other participants (e.g. Po05 and Po08) mentioned why they found playing the game to be fun.
Po01 (Female; 71yrs): “It was fun”
Po04 (Female; 76yrs): “It was very fun and a good training”
Po05 (Female; 71yrs): “It was more fun than being alone, knitting, or watching the TV”
Po08 (Female; 70yrs): “I liked concentrating on my movements, so I don’t get killed by the asteroids. For this reason, I found it to be fun.”

Prompt feedback: One participant particularly acknowledged the timely feedback provided in the game.
Po03 (Female; 76yrs): “I like the fast feedback.”

Negative feedback: One participant suggested providing more negative feedback.
Po04 (Female; 76yrs): “It would be nice if the game could provide more negative feedback for undesired movements such as stepping outside the gaming area”

Movement Variation: Two of the older participants expressed that they preferred more variation in physical movements while playing the game.
Po01 (Female; 71yrs): “I would like more movement variations”
Po02 (Male; 85yrs): “Would like more variation”

Technology: The older participants often needed to be reminded to position themselves in the center of the playing area. Another observation with respect to the sensor technology was that almost all the older participants initially reached forward to catch the stars instead of sideways. Four of the older participants commented on the motion recognition system as follows:
Po07 (Female; 76yrs): “The avatar wasn’t responding precisely”
Po09 (Male; 72yrs): “The reaction of the avatar was slow”
Po03 (Female; 76yrs): “I felt having little control over the avatar”
Po01 (Female; 71yrs): “I did not like the slight lag between my movement and the avatar’s movement”

Increased Training Time: It was observed that after the two minutes of demo, not all the older participants were sufficiently accustomed to the game. This sometimes resulted in participants repeating the demo or trying to learn the game during the actual gaming session as well. The need for increased demo time was both an observation and feedback that was received from one of the older participants.
Po08 (Female; 70yrs): “I like the second half better, because by then I understood the game better”

In sum, the older adults expressed their appreciation of the gaming experience in terms of having fun and for training their physical and cognitive skills. In addition, it was observed that this user group experienced slight difficulties with the technology and required more time to learn the game.

DISCUSSION

The purpose of the study was to compare motivational factors between healthy young and older adults by analyzing their assessments of the same balance training exergame. Results from a qualitative analysis of their answers to a semi-structured text input questionnaire indicate that when designing for older adults, in addition to making the games joyful to play, it is beneficial to give feedback on specific health effects and focus less on in-game rewards.

Relating to the Self-Determination Theory of motivation, both age groups show a combination of intrinsic and extrinsic motivation:

- ***The younger adults are intrinsically motivated by the game challenge, while the older adults are intrinsically motivated by the joy of playing.***
- ***The younger adults are externally motivated by the in-game rewards, while the older adults are externally motivated by the perceived health effects of playing.***

Although clear areas of concern emerged from the two different age groups, we do not claim that all younger adults are not motivated by health effects, nor that all older adults are not motivated by in-game rewards. We are only pointing to trends in motivational factors that should be considered when designing exergames for different age groups. A potential explanation for these differences could be that with age comes more self-reflection and less focus on competition. Another explanation could be that the perceived health effects of exergames were of more value to the older adults compared to the young adults, due to age-related decline in function and increased health problems, making it likely for older adults to be more aware of their health. However, this is generally not the case for healthy younger adults who might be less concerned about age-related functional decline. Furthermore, although the young and older participants framed their responses differently, certain responses conveyed similar meaning. For e.g. Py07 (Male; 26yrs): "I liked it when I had to move quickly and do more things at the same time" and Po06 (Female; 75yrs): "I like using my head and my body simultaneously". Both the participants conveyed that they enjoyed the challenge, although for older adults this seemed to be related to potential positive health effects. This is further supported by the responses provided by participants Po03, Po04, and Po05 with respect to physical and cognitive training, where they conveyed that they preferred and enjoyed the challenges for reasons of a positive health effect. However, as there are also older adults who participate in physical activities for competitive aspects, games should provide users with a choice for the amount of in-game rewards that they prefer to receive.

Although the sample of older adults (65 to 85 years of age) had a larger age spread than the younger adults, there were no differences between the youngest and oldest participants within the older adult group. Furthermore, as 80% of the older adults were females, this could have resulted in a gender bias. Though there were few males in the older adult group, their feedback was similar to that of the females within the group, which further supports the observed generational difference. An earlier study by Molanorouzi et al.[20] found that men were more motivated by mastery and competition, while females are more motivated by appearance and physical conditions. However, in this paper we only assessed the motivational differences between young and older adults, without assessing other factors such as gender. The women were spread evenly within the older adult sample, without clustering at either end of the age range.

The study provides specific feedback on aspects of the game that could be improved to better suit the different age groups, for example a more advanced reward system for the young participant and increased training time for the older users. This is of value as input to specific guidelines for designers of future exergames. What we found interesting in the results, however, are the implicit motivations behind the different areas of concern (topics) emerging from their answers. We did not ask the participants explicitly about what motivated them to play exergames, but it seems reasonable to assume that when a user answers "I like X", then X motivates him/her.

Following this line of reasoning, the motivational factors for the two age groups can be summarized as follows.

The young adults were motivated by:

- Exergames that allowed them to challenge themselves, both physically and cognitively.
- A complex gaming environment with visually appealing graphics and music that fits the game.
- An advanced reward system.
- The ability to personalize the game.

The older adults were motivated by:

- Exergames that can lead to positive physical and cognitive health effects on the player.
- Exergames that are fun to play (enjoyment).
- Feedback that help them do the desired movements.

Therefore, the implications of the above differences in motivational factors between young and older adults are that for older adults less effort can be put on designing the in-game reward system, and more on showing the player the potential health effects of their play. Furthermore, the competition aspect can be downplayed, and more focus placed on making the gaming experience itself as joyful as possible.

LIMITATIONS

As previously mentioned, we acknowledge several limitations in the current study. The limited number of participants precluded use of quantitative analysis and statistics. Furthermore, the group of older adults consisted of 80% women, which might have resulted in a gender bias. Despite these limitations, we believe that the results point to a real difference in motivational factors, especially given that we did not explicitly ask about motivation.

CONCLUSION

The current paper presents the evaluation of an age-neutral balance training exergame by healthy young and older adults, to assess differences in motivational factors between the two age groups. We found that the young adults tended to be intrinsically motivated by the game challenge and extrinsically motivated by the in-game reward system (scores). In contrast, the older adults were more intrinsically motivated by the joy of playing and extrinsically motivated by the perceived health effects (physical and cognitive), with less regard for the in-game rewards.

We conclude from this that when designing exergames for older adults, in addition to making the games joyful to play, it is beneficial to give feedback on specific health effects and focus less on in-game rewards and competition. While designing for specific user groups it is crucial to consider design preferences and influencing factors to achieve maximal adherence levels. We believe that the current results and insights could be of potential use for future design processes involving similar user groups. Further research is required to investigate the specific effects of age, gender and health status on motivation.

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AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist

REFERENCES

1. Alves AJ, Viana JL, Cavalcante SL, et al., *Physical activity in primary and secondary prevention of cardiovascular disease: overview updated.* World Journal of Cardiology, 2016; 8: 575-583.
2. Warburton DER, Nicol CW, and Bredin SSD, *Health benefits of physical activity: the evidence.* Canadian Medical Association Journal, 2006; 174: 801-809.
3. Gillespie LD, Robertson MC, Gillespie WJ, et al., *Interventions for preventing falls in older people living in the community.* Cochrane Database Syst Rev 2012;CD007146., 2012; 12:
4. Barenbrock A, Herrlich M, and Malaka R. *Design lessons from mainstream motion-based games for exergames for older adults.* in *2014 IEEE Games, Media, Entertainment (GEM) Conference, 22-24 Oct. 2014.* 2014. Piscataway, NJ, USA: IEEE.
5. Adam C and Senner V. *Which Motives are Predictors for Long-term Use of Exergames?* in *11th conference of the International Sports Engineering Association, ISEA 2016, July 11, 2016 - July 14, 2016.* 2016. Delft, Netherlands: Elsevier Ltd.
6. Ijaz K, Yifan W, Ahmadpour N, et al. *Physical activity enjoyment on an immersive VR exergaming platform.* in *2017 IEEE Life Sciences Conference (LSC), 13-15 Dec. 2017.* 2017. Piscataway, NJ, USA: IEEE.
7. Larsen LH, Schou L, Lund HH, et al., *The physical effect of exergames in healthy elderly—a systematic review.* Games for health journal, 2013; 2: 205-212.
8. Tanaka K, Parker JR, Baradoy G, et al., *A Comparison of Exergaming Interfaces for Use in Rehabilitation Programs and Research.* Canadian Game Studies Association, 2012; 6: 69-81.

9. Hausdorff J, Rios D, and Edelberg H, *Gait variability and fall risk in community-living older adults: a 1-year prospective study.* Arch Phys Med Rehabil, 2001; 82: 1050-1056.
10. Ellmers TJ, Young WR, and Paraskevopoulos IT. *Integratingfall-risk assessments within a simple balance exergame.* in *2017 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), 6-8 Sept. 2017.* 2017. Piscataway, NJ, USA: IEEE.
11. Feltz DL, Irwin B, and Kerr N, *Two-player partnered exergame for obesity prevention: using discrepancy in players' abilities as a strategy to motivate physical activity.* J Diabetes Sci Technol, 2012; 6: 820-827.
12. Ho SS, Lwin MO, Sng JRH, et al., *Escaping through exergames: Presence, enjoyment, and mood experience in predicting children's attitude toward exergames.* Computers in Human Behavior, 2017; 72: 381-390.
13. Baranyi R, Reisecker F, Lederer N, et al. *WristDroid - a serious game to support and motivate patients throughout their wrist rehabilitation.* in *2014 IEEE Conference on Biomedical Engineering and Sciences (IECBES), 8-10 Dec. 2014.* 2014. Piscataway, NJ, USA: IEEE.
14. Schwenk M, Grewal GS, Honarvar B, et al., *Interactive balance training integrating sensor-based visual feedback of movement performance: a pilot study in older adults.* Journal of NeuroEngineering and Rehabilitation, 2014; 11: 164 -177.
15. Chang W, Chang W, Lee C, et al., *Validity and reliability of Wii fit Balance board for the assessment of balance of healthy young and the elderly.* J Phys. Ther. Sci, 2013; 25: 1251-1252.
16. Graves L, Ridgers N, Williams K, et al., *The physiological cost and enjoyment of Wii fit in adolescents, young adults and older adults.* Journal of physical activity and health, 2010; 7: 393-401.
17. Thomas S, Fazakarley L, Thomas PW, et al., *Testing the feasibility and acceptability of using the Nintendo Wii in the home to increase activity levels, vitality and well-being in people with multiple sclerosis(Mii-vitaliSe): protocol.* BMJ Open, 2014; 4: 1-11.
18. Hanley CA, Arciero PJ, Brickman AM, et al., *Exergaming and Older Adults Cognition: A Cluster Randomized Clinical Trial.* American Journal of Preventive Medicine, 2012; 42: 109-119.
19. Deci EL and Ryan RM, *Self-determination theory: A macrotheory of human motivation, development, and health.* 2008; 49: 182-185.
20. Molanorouzi KK, Selina; Morris, Tony;, *Motives for adult participation in physical activity: type of activity, age, and gender.* BMC Public Health, 2015; 15:
21. Kilpatrick M, Hebert E, and Bartholomew J, *College Students' Motivation for PhysicalActivity: Differentiating Men's and Women'sMotives for Sport Participation and Exercise.* Journal of American College Health, 2003; 54: 87-94.
22. Corbin JM and Strauss A, *Grounded theory research: Procedures, canons, and evaluative criteria.* 1990; 13: 3-21.
23. Saunders BS, Julius; Kingstone, Tom; Baker, Shula; Waterfield, Jackie; Bartlam, Bernadette; Burroughs, Heather; Jinks, Clare;, *Saturation in qualitative research: exploring its conceptualization and operationalization.* Qual Quant, 2017; 52: 1893-1907.

Paper-III-Review

Systematic Review of Design Guidelines for Full-Body Interactive Games

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ABSTRACT

This paper provides a systematic review of research articles published between 2010 and mid 2018 that have offered design guidelines for full-body interactive games for recreational purposes and physical exercise. From an initial 3,562 retrieved database references, 22 articles were found to meet our predefined criteria and included in the final review. The review of 22 articles resulted in the extraction of 107 design guidelines, which were grouped in twelve different categories: *Movement elicitation, Mapping of movement, Explicit movement guidance, Player representation and game world, Attention, Feedback on player performance, Player agency and customization, Exertion, Safety, Universal design,* and *Social aspects*. While the current body of guidelines were found to cover multiple aspects pertaining to the design of full-body interactive games, the conducted review also revealed a number of overarching concerns regarding the present state. Specifically, these concerns relate to (1) the hedonic–utilitarian divide in movement-related design guidelines of relevant literature; (2) the lack of common structure for specifying guidelines; (3) the lack of systematic development of guidelines; (4) issues related to the validity of existing guidelines; and (5) the limited focus on tangible interfaces in the present state of the art. In conclusion, the current review paints a somewhat questionable picture of the present state of the corpus of design guidelines for full-body games, with relatively large differences in the quality of the guidelines proposed in the individual articles and a lack of reference to already existing guidelines. In the longer run, these quality issues risk watering out the original meaning of the term *design guideline* and reducing the potential value design guidelines can offer in development of full-body interactive games.

CCS CONCEPTS

• Human-Centered Computing → Human Computer Interaction (HCI) → HCI theory, concepts and models

KEYWORDS

Full-body games, Exergames, Design guidelines, Game design.

Research Highlights:

- There are a wide variety of design guidelines for full-body games. Existing guidelines generally aim to support design of full-body games for either entertainment or for rehabilitation/preventive training purposes.
- Most design guidelines for full-body games have been derived from studies of screen-based games.
- The lack of a common structure for design guidelines for full-body games and the apparent non-systematic development of existing guidelines make it particularly challenging to build a structured network of guidelines that can be easily extracted and navigated.

- The current literature review paints a somewhat questionable picture of the present state of the corpus of design guidelines for full-body games, with relatively large differences in quality and a lack of reference to already existing guidelines.

1 Introduction

The past two decades have given rise to entirely new gaming concepts where players are encouraged to use their entire body when playing. As such, movement-based or *full-body* interactive games stand in sharp contrast to traditional device-controlled computer games, where players' body largely remain idle during gameplay. This development was to a large extent propelled by commercial gaming consoles such as Microsoft Kinect®, Nintendo Wii®, and Sony PlayStation®.

By utilizing the body as a medium for interaction and putting the body at the center of the user experience, full-body games open up new and rich interactive possibilities. The fun and playfulness many associate with games and gaming, combined with the health benefits of physical activity, are making full-body games applicable for potentially multiple purposes, ranging from leisure (Nijholt et al., 2010) to more "serious" objectives such as improved mental, social, and physical health and well-being (Li et al., 2018; Rosenberg et al., 2019; Staiano and Calvert, 2011). However, full-body games present interaction, and game designers, with challenges where existing design knowledge falls short. For example, Höök (2018) proposes a shift in interaction design towards a more experiential, felt, and aesthetic stance that reincorporates body and movement into the design regime. Others, such as Bamparopoulos et al. (2016) and Plow et al. (2011), argue that realizing the potential health benefits of such games also requires extensive knowledge about the physical functioning of the body. The latter argument emphasizes that successful design of full-body applications often requires multi-disciplinary skills (Wiemeyer et al., 2015).

The Design and use of full-body games have gained increased attention in human–computer interaction (HCI) and other fields of computer science over the previous decade. Within HCI, this growing interest reflects in many ways the paradigm shift in the field towards embodied interaction (Dourish, 2001), and the increased focus on physical and bodily aspects of interaction this shift has entailed (Konrad et al., 2003; Mueller et al., 2019; Svanæs, 2013). A potentially important indication of a maturing body of knowledge on the design of full-body games is the increasing number of published works offering design guidelines or recommendations for best design practice. According to Nowack (1997), a design guideline is "*a prescriptive recommendation for a context sensitive course of action to address a design issue*". Fu et al. (2016) offer a similar definition also highlighting the basis on which design guidelines are derived: *[A design guideline is a]context-dependent directive, based on extensive experience and/or empirical evidence, which provides design process direction to increase the chance of reaching a successful solution*.

Drawing on the above definitions, then, a design guideline, as understood in the context of this work, is an explicit, experience-based or empirically grounded advice on how a designer can or should go about to accommodate factors that have been identified as important for a design solution to meet certain domain-specific goals or standards. As such, design guidelines can be considered to form an intermediary interface between the designer and user interface design knowledge (Huhn, 2010). Nowack (1997) suggests that a design guideline should contain the following parts: A description of the issue or issues addressed or impacted, links to design context, action recommendations, and rationale. Within HCI, Shneiderman's (1997) recommendation *Offer informative feedback* is an example of a well-known guideline for design of interactive user interfaces. Shneiderman (1997) elaborates his recommendation as follows: "*The user should know where they are at and what is going on at all times. For every action there should be appropriate, human-readable feedback within a reasonable amount of time. A good example of applying this would be to indicate to the user where they are at in the process when working through a multi-page questionnaire. A bad example we often see is when an error message shows an error-code instead of a human-readable and meaningful message*". While easily accessible and comprehensible descriptions of what-to-do and how-to-do are a key criteria of usable design guidelines (Cronholm, 2009), the format and elaborateness of design guidelines may vary considerably.

The primary value of design guidelines lies in their potential to provide empirically based directions for the design of future solutions by allowing practitioners to draw on the (sometimes hard-won) experience of others. As such, guidelines have played an important role in multiple design disciplines, including architecture and building design (Brittin et al., 2015), product design (Telenko and Seepersad, 2010), software architecture design (Robbins et al., 1998) and of course HCI. With respect to the lattermost, the guidelines offered by Nielsen (1993), Norman (2013), and Shneiderman (1997) are examples of well-established and highly acknowledged "rules of thumb" in the design of graphical user interfaces. These guidelines are part of the current HCI curriculum at most universities that offer an HCI program. Design guidelines continue to form one of the key contributions of HCI studies (Abascal and Nicolle, 2005; Benyon, 2013; Gong and Tarasewich, 2004; Stephanidis et al., 1998), including studies investigating the design and use of full-body games (Amershi et al., 2019; Rossmy and Wiethoff, 2019).

With the growing body of design guidelines for movement-based games, it is becoming increasingly challenging to have an overview of current design knowledge and what aspects of design the existing guidelines cover. The overall aim of this study is to synthesize and provide a systematic review of existing design guidelines for interactive games that require players to use their full body to achieve game objectives. In this review, we refer to this type of interactive games as *full-body* games. Our study has involved three main steps:

- *Mapping of relevant studies*: First, we mapped existing studies that have produced design guidelines of relevance for full-body games. This involved identifying and comparing key characteristics of the studies from which the guidelines were derived.
- *Grouping and review of design guidelines*: Second, we grouped the guidelines offered in the corpus of relevant studies according to what aspects of design the guidelines covered. An extensive description of each category and its associated guidelines are provided in the review.
- *Identification and discussion of key concerns*: Based on the mapped studies and the guidelines they proposed, the review identifies and discusses a set of key concerns regarding the status quo of design guidelines for full-body games.

The article is structured as follows. In Section 2, we describe what we mean by *full-body interactive game* as the term is understood in the context of this work. Section 3 accounts for the applied method, that is, how we conducted the literature review. Section 4 describes and characterizes the articles. Section 5 accounts for the results of the mapping and review process. In Section 6, five key concerns emerging from our review are presented. Section 7 presents the methodological considerations before conclusions are drawn in Section 8.

2 Defining Full-Body Games

This review focuses on design guidelines for *full-body interactive games* for recreational purposes and physical exercise. Before we continue, we first need to establish more precisely how the term is understood in this article. Addressing the latter part of the term first, we have adopted Salen and Zimmerman's (2004) definition of what a game is: *A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.* Our focus is on *interactive* (full-body) games, meaning that we take into consideration only games in which players interact with their bodies through computer technology.

The term *full-body*, or *whole-body* (Koštomaj and Boh, 2009), is ambiguous and has been used to denote a number of interactive games that encourage and/or respond to a range of body motions in players, often involving a combinations of multiple body parts (e.g., arms, hands, legs, feet, and torso). In the current work, we use the term to refer specifically to body movements that are *weight-bearing*. A medical definition of weight-bearing body movement was provided by MacKelvie et al. (2002). To be weight-bearing, according to the authors, motions must be part of a structured, force-generating activity that provides loading to skeletal regions above that provided by activities of daily living. We found this definition to be particularly helpful in deciding whether a movement-based or body-controlled game qualified as a full-body game. For example, a clapping game (Sheridan, 2010), which only encourages and responds to hand and finger movements of an otherwise immobile player, does not qualify as a full-body game, since such a game does not involve loading (of body weight) to skeletal regions. Similarly, serious games for hand rehabilitation (Elnaggar and Reichardt, 2016), and games played while being seated (Hernandez et al., 2012) do not qualify for the same reason. Moreover, interactive games that only provide very rough responses to a player's physical movements, and where the game design remains largely ignorant to the specific body movements that go into resolving the game challenge (e.g., *Into* (Ahtinen et al., 2010), *UbiFit garden* (Consolvo et al., 2008), *myFitnessCompanion* (Leijdekkers and Gay, 2013) and commercially available mobile games such as *Pokemon Go*® and *Zombies, Run!*®), also fall outside our definition. While a player may employ weight-bearing body movements while playing such games, the designer-intended goal of such applications is more toward promoting general physical activity, or exertion, in players rather than eliciting certain body movements.

While all full-body games use sensor technology to infer aspects of players' body movements, we do not consider full-body games to be restricted to any particular type of sensor technology. As such, full-body games may employ sensor technologies ranging from simple step pads (as in the stepping game *Dance-Dance Revolution*) to advanced 3D motion capturing cameras (e.g.(Schönauer et al., 2011)). Likewise, we do not consider full-body games to be limited to any particular output medium. While many full-body games provide visual output to players via a display such as a TV screen, there are also examples of full-body games that do not make use of screen-based output. The vertigo game *Balance Ninja* (Byrne and Marshall, 2016) is an example of these.

3 Methods

The volume of research on the design and use of full-body games is continuously growing. For the individual practitioner or researcher, this growth makes it increasingly challenging to remain updated or critically evaluate and synthesize the state of existing relevant knowledge. Within many scientific disciplines, literature reviews have become indispensable tools for anyone who wants to keep up with the research "frontier" and for identifying areas where existing evidence is insufficient. Due to the lacking scientific rigor of traditional narrative reviews there has been a significant increase in computer science over recent years, including HCI (Clark et al., 2019; Doherty and Doherty, 2019; Hornbæk and Hertzum, 2017; Nunes et al., 2015), in the number of published reviews that follow formal and structured methods, also known as *systematic literature reviews* (SLRs). The rigor associated with SLRs is reflected in their capability to produce explicitly formulated, reproducible, and state-of-the-art summaries of research relevant to a particular research question, area, or phenomenon of interest. In the context of full-body games, the SLR thus forms a key tool for providing an overview of "best practice" when it comes to design, as SLRs bring together and combine findings from multiple relevant studies.

3.1 Databases and Search Terms

The papers included in the review were collected on July 2, 2018 using five major databases: ACM, Scopus, Engineering Village, PubMed and Web of Science. As such, we collected data material from search engines indexing articles both within technically and medically oriented sciences. Our main rationale for including PubMed, a medical science database, was that initial queries revealed relevant work not been indexed by the other databases.

The query we used to collect data from the beforementioned databases were constructed iteratively, meaning that we used the results from initial queries, that is, specific terms used in the index articles and the studies they referenced, to expand our search string. Through the process, we learned that a relatively wide variety of terms are used in the literature to describe the applications which we understand as full-body games, for example movement-based game, motion-controlled game, exertion game, serious game, and different variations of the listed terms. Hence, we found it necessary to include a wide variety of synonyms for full-body game in our final search string. Similarly, we found a relatively wide range of synonyms used to describe guidelines in relevant literature, for example considerations, suggestions, and recommendations. These terms were often used in combination with design or development, for example design considerations or guidelines for development of movement-based games. Multiple keywords related to the three distinct categories *Game, Activity, and Design knowledge* were included in the search string. Since one of the key intentions with the review was to map as much as possible of the existing body of design guidelines for full-body games, we did not include any domain-specific terms in the search string. This has resulted in a broad range of design guidelines and different focal points of the corresponding studies included in the review. This issue is further discussed in later sections of the article. Table 1 shows the list of search terms that were used to construct the final query.

Table 1: Search Terms

Game	Activity	Design knowledge
Exergam*	design*	consideration*
Exertion gam*	develop*	recommend*
Multimodal gam*		guideline*
Exertion video gam*		suggestion*
serious gam*		strateg*
exercise gam*		lessons
movement-based gam*		
motion-control gam*		
motion-controlled gam*		
motion-based gam*		

Given the large variety in the nomenclatures used in relevant literature to describe design guidelines for full-body games, we ended up with a relatively extensive search string. The full final query, including Boolean operators (AND, OR) and truncations (denoted by an asterisk) can be found in Appendix 2.

The syntax of the query was adapted to the specific format of each database. Further, based on available search options, an advanced full-text search was performed in the ACM database, while an advanced title/keyword search was conducted in the PubMed database, and a title/abstract/keyword search was conducted in the Scopus, Engineering Village, and the Web of Science databases. The decision to use a relatively extensive search string meant that we increased the possibility of finding articles relevant to the topic of the review within the corpus of articles returned by the query.

3.2 Selection Process

To guide the selection of studies that were to be a part of the review, we used a protocol which, in addition to the search string, contained specific inclusion and exclusion criteria (see Table 2 for detailed description). The database search identified 3,562 studies of potential interest. As part of an initial screening process (conducted by the first author), duplicate records, non-peer reviewed studies, non-English articles, systematic reviews, books/dissertations, and articles with less than 5000 words such as extended abstracts (1,816 studies) were eliminated from the corpus. Next, the title, abstract and keywords of the remaining 1,746 articles were carefully examined independently by all three authors to identify articles offering design guidelines or recommendations for full-body games as a key scientific contribution which further eliminated 1,704 studies. A consequence of using such an inclusion criterion is that any article providing relevant design guidance in its body text, but whose abstracts does not explicitly state design guidelines (or recommendations or similar synonyms (see Table 1)) to be a scientific output from the described study, has been excluded from our review. Hence, the inclusion or exclusion in the final review was strongly dependent on the phrasing of the abstract of an article and whether or not design guidelines appeared to form a key contribution of the described study. For example, the phrase *"Based on our studies, we present seven guidelines for the design of full-body interaction in games",* which appears in the abstract of a study described by Gerling et al. (2012), clearly met our inclusion criteria. In comparison, Bianchi-Berthouze's article (2013), which proposes a model for player engagement in full-body games did not meet our criteria. The abstract of the article states "*Finally, I conclude by considering how the proposed model could lead to a more systematic and effective use of body movement for enhancing game experience*". While the phrase suggests that the article conveys design knowledge of potential relevance for development of full-body games the abstract does not suggest that this is in the form of prescribed recommendations. In cases where the abstract of an article raised uncertainty whether design guidelines formed a scientific output, the body of the article was examined.

Trade-offs resulting from selection processes such as the above are unavoidable in SLRs. Hence, and as further discussed in the *Methodological Consideration* in section 7, the current literature review should by no means be regarded as a *complete* summary of relevant guidance for design of full-body games produced in the period 2008–2010, but a review of central parts of that body.

Table 2: Inclusion/Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Articles *explicitly* offering design recommendations or guidelines for *full-body games* as a key scientific contribution of the described study or studies	Non-English articles Systematic reviews Articles with less than 5000 words (i.e., short-papers and extended abstracts) Overlap of identical guidelines described by the same authors in different articles (in such cases only the most extensive work was included) Books and dissertations Non-peer reviewed articles

Studies that provided only design methodological guidelines (for example, how to include people with Parkinson's disease in design activities; (McNaney et al., 2015)) were not included in the review. Disagreement about the eligibility of a study was resolved by full-text screening conducted by all three authors and resolution in a subsequent consensus meeting. As part of the title and abstract screening, 1,704 studies that did not comply with the inclusion criteria were excluded. The remaining 42 papers were then independently assessed in full text by two authors (the first author assessing all papers and the second and third authors assessing 21 different papers), yielding a total of 22 studies which were included in the review. In the final round of assessment, the study by Byrne and Marshall (2016) was excluded as the offered guidelines were not for the design of full-body games, but for the design of digital vertigo games. Furthermore, the conference paper by Mueller and Isbister (2014) was eliminated due to the overlap of identical guidelines with their journal paper (Isbister and Mueller, 2015) which was included in the review. Figure 1 illustrates the described selection process.

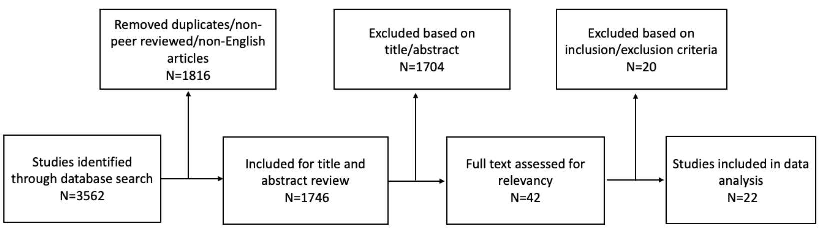

Figure 1: Flow chart over study selection through different phases of the review.

3.3 Analysis

The 22 articles included in the final review were read in full by the first and the second or third author. Data on aim, study design, participants, intervention, and game and game technologies were extracted from the included studies. Details regarding game and game technology included; game system and game objective; I/O technology and mapping of movements performed during game play; and design-intended movements. Details relating to study design included data collection and duration (see Table 5). The design guidelines and the rationale proposed in the individual articles were iteratively coded for themes. The set of papers in the final review were read again by all the authors and as new papers were added, new codes were created, renamed, removed, or rearranged, to match the categories suggested by all studies included up to that moment. In cases where we found different codes being used to describe the same feature, we selected the code providing the most precise description. Papers were read multiple times in order to ensure newer codes included all studies in the review. For example, the following design criteria provided by Gerling et al. (2010) "*Due to the target audience's lack of previous gaming experience, games should focus on simple interaction mechanisms and provide the player with constructive criticism to avoid frustration and foster an enjoyable player experience",* was coded as two design guidelines with corresponding rationales in two different themes *Mapping of movement* and *Feedback on player performance* (see Table 7 and 12). Comparative analysis was a driving principle in our analysis, forcing us to categorize the different studies, guidelines, and thereby leading us to reflect on what the data was telling us. As the classification of the studies and guidelines became clearer, they were iteratively discussed among all the three authors of the paper. The analysis was only complete as the final version of this article was ready for submission, as the categorization was further refined during the writing process.

4 Characterizing the Articles of the Review

The final corpus of papers in the review comprised of 22 studies (see Table 3 for an overview). The initial list of studies identified through the database search covered 22 years of research, with studies published since 1996. However, the earliest article included in the final review was published in 2010 (Gerling et al., 2010).

The included studies were published in a number of different venues. In total, there were thirteen conference papers, eight journal papers, and one book. The most common venues for the conference papers were ACM conferences, with eight papers, followed by IEEE conferences with two papers. The remaining three conferences (ITAP, WIS, REHAB), and a book published by Springer provided one study each. The most common venue for the journal papers was *Gerontology*, with two studies. The remaining studies were published in *Human-Computer Interaction*, *Games for Health*, *Pervasive and Mobile Computing, Entertainment Computing*, *JMIR Serious Games,* and *Journal of usability studies*. This also reflected in a broad range of study designs as illustrated in Table 3. Usability tests were opted by as many as twelve studies, while the other study designs were not used by more than two studies. The gaming interventions were carried out either in laboratory settings or at nursing homes with duration of gaming lasting from a few minutes only (e.g. Jensen and Grønbæk (2016)), to intervention studies with several weeks of gaming (e.g., Uzor and Baillie (2014)), or user centered design projects with years of follow up (e.g., Brox et al. (2017)) (see Table 5 for details).

In the 22 included studies the sample size ranged from 4 to 50, with a mean of 20 participants. Fourteen of the included studies focused on older adults, of which the aim of eleven studies (Barenbrock et al., 2014; Brox et al., 2017; Fernandez-Cervantes et al., 2018; Gerling et al., 2012; Gerling et al., 2010; Nawaz et al., 2014; Pyae et al., 2017; Pyae et al., 2016a; Pyae et al., 2016b; Velazquez et al., 2013; Velazquez et al., 2017) were to focus on understanding the exergaming experience among older adults and provide relevant guidelines for exergame design for the senior population. The other three studies, (Harrington et al., 2015; Skjaeret et al., 2014; Uzor and Baillie, 2014) focused on the usability of Kinect based games, movement characteristics, and the long-term use of exergames for older adults, respectively. Of the remaining eight studies, six focused on younger adults (Altimira et al., 2014; Jensen and Grønbæk, 2016; Jensen et al., 2015; Richards and Graham, 2016; Thin and Poole, 2010; Zaczynski and Whitehead, 2014), and the studies by Isbister and Mueller (2015); Wiemeyer et al. (2015) focused on providing age-neutral design guidelines for full-body games and recommendations for designing exergames for people with disabilities, respectively.

Table 3: Study Design of the Included Papers

Study design	No. of studies	Studies
User evaluation/ usability test	12	Thin and Poole (2010); Gerling et al. (2012); Skjæret et al. (2014); Zaczynski and Whitehead (2014); Harrington et al. (2015); Jensen et al. (2015); Wiemeyer et al. (2015); Jensen and Grønbæk (2016); Richards and Graham (2016); Pyae et al. (2016a; 2016b; 2017)
Action research	2	Velazquez et al. (2013; 2017)
Semi-structured interview	1	Isbister and Mueller (2015)
Group discussion	2	Brox et al. (2017); Wiemeyer et al. (2015)
Comparative study	1	Altimira et al. (2014)
Randomized control trial	1	Uzor and Baillie (2014)
Empirical feasibility study	1	Fernandez-Cervantes et al. (2018)
User-centered design	2	Brox et al. (2017); Nawaz et al. (2014)
Qualitative field study	1	Barenbrock et al. (2014)
Focus group tests	1	Gerling et al. (2010)
Brainstorming workshop	1	Jensen et al. (2015)

The intended exercise movements were not specifically mentioned in several of the studies. However, based on the games used in the studies, we were able to extract these details for most of the studies (see Table 5 for references). Of the 22 studies, two studies (Isbister and Mueller, 2015; Wiemeyer et al., 2015) were based on semi-structured interviews and group discussions with game design experts respectively. The remaining twenty studies provided design guidelines based on an evaluation of either one or more games. Of these 20 studies, 10 used commercially available games such as the Nintendo Wii games, *Silverfit games*, and *Dance Dance Revolution*, while the remaining studies designed their own games according to needs of their individual study. With the exception of three studies (Jensen and Grønbæk, 2016; Jensen et al., 2015; Uzor and Baillie, 2014), the remaining made use of commercially available gaming technology such as the Microsoft Kinect, webcam, or Nintendo Wii consoles. All the games used in the included studies were screen-based games that employed either a monitor or a TV screen. Table 4 provides an overview of games used in the twenty studies that have explicitly evaluated full-body games. The table illustrates details such as the overall purpose of the game(s) (i.e., entertainment or rehabilitation/preventive training), the type of sensor technology used, and the genre of the games corresponding to the individual studies. Table 5 further provides an elaborate overview of all the included studies.

Table 4: Overview of the games

	Purpose		Sensor technology						Game(s)
	Entertain-ment	Rehab./ Prevention	Pressure mat	Inertial sensors	Wii	Kinect	Webcam	N/P	
Gerling et al. (2010)		•			•				Customized balance game
Thin and Poole (2010)	•		•		•				Commercial dance and sport games
Gerling et al. (2012)		•				•			Customized gesture-based game
Velazquez et al. (2013)	•							•	Commercial sport games
Altimira et al. (2014)	•				•				Commercial sport game
Barenbrock et al. (2014)	•				•	•			Commercial sport, dancing, and virtual twister games
Nawaz et al. (2014)	•	•				•			Commercial sport, fitness, and balance games
Skjæret et al. (2014)	•	•	•			•			Commercial stepping games
Uzor and Baillie (2014)		•		•					Customized fantasy fall rehabilitation games
Zaczynski and Whitehead (2014)	•				•				Commercial yoga game
Harrington et al. (2015)		•				•			Commercial puzzle and fitness games
Jensen et al. (2015)	•			•					Customized handball game
Jensen and Grønbæk (2016)	•			•					Customized handball game
Pyae et al. (2016a)		•					•		Customized skiing game;
Pyae et al. (2016b)	•			•		•	•		Commercial sport games
Richards and Graham (2016)		•				•			Customized muscle strengthening game
Brox et al. (2017)		•				•			Customized fantasy game
Pyae et al. (2017)		•					•		Commercial skiing game
Velazquez et al. (2017)	•				•	•			Commercial sport games
Fernandez-Cervantes et al. (2018)		•				•			Customized gym game

N/P= not provided

Table 5: Overview of Included Studies

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Gerling et al. (2010)	To discuss chances and challenges of game design for an elderly audience	*SilverBalance* exertion game prototype with two balance tasks; Task 1: avoid falling obstacles. Task 2: avoid possible collisions	Screen; Balance board; Mapping of feet	Weight-shift movements	Focus group test at a nursing home in Germany; Observations; N/P	Older adults; N=9; A: 77–91; M= 84
Thin and Poole (2010)	To investigate the level of physical exertion required to play three different dance-based Exergames and assess the interaction between game play factors and exercise intensity on the level of enjoyment that players experience whilst playing the Exergames	G1: *Dancing Stage*: To step on defined areas of the mat and shake hands to a choreographed sequence shown on the screen G2: *Step Aerobics*: To perform stepping movements to a choreographed sequence G3: *Hula Hoop* : Requires players to rotate their hips in a coordinated manner as fast as possible to accumulate as many revolutions as possible in the time limit	Screen; Pressure mat, Wii's hand-held motion sensitive controllers, balance board; Mapping of feet	Arm and leg movements; stepping movements	User evaluation; Ambulatory gas analysis system, Questionnaires; N/P	University students; N=11; M=20±2
Gerling et al. (2012)	To develop game design guidelines for full-body motion controls for older adults experiencing age-related changes and impairments	"*Gardening game*": To stand on one leg or walk in place (to grow plants). If players are seated, plants automatically grow. Lift or wave one arm (to grow flowers). Extend one or both arms to the side or wave both arms (to make flower bloom). Move hand (to catch a bird).	Screen; Kinect; stick figure, mapping of arms and legs	Set of static and dynamic gestures	E1: User evaluation of gesture-based tutorial and E2: Gesture-based game in a nursing home; Questionnaires, sensor-based metrics, observations; N/P	Institutionalized older adults; E1: N = 15 (7 females, 8 males); A: 60–90; M = 73.72 ± 9.90 E2: N = 12 (5 females, 7 males); A: 60–91; M= 76.7 ±10.6

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Velazquez et al. (2013)	To develop insights for the design of full-body motion-control exergames for older adults experiencing age-related changes addressing problems raised by their motion capacity	Various movement-based games; N/P	Screen; N/P	Various movements (e.g., jog, walk, throw)	Action Research Study; Literature reviews, interviews, experiencing (field notes, observations, diaries, photographing), inquiring (focus groups, informal face-to-face, and questionnaires), and examining (attendance data, test scores, and encoding video files)"; 6 months	Specialists in aging; N=18 Healthy older adults; E: N=18; A: 63–82; M= 70
Altimira et al. (2014)	To measure player engagement after applying balancing adjustments to a digital table tennis game and the traditional table tennis game	Wii Tennis, Table tennis; N/P	Screen; Wii hand-held controller; N/P	Tennis movements (swing, sideward movement);	Comparative study; Questionnaires, interview; N/P	18+ that had previously played the traditional table tennis; N=46 (9 females, 37 males); A: 19–43 ; M= 26.7 ±4.9

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Barenbrock et al. (2014)	To discuss our qualitative findings and formulate design lessons to consider when developing games for older adults	G1: *Mario Kart:* To win the race and shoot opponents. G2: *Table Tilt:* To navigate marbles into a hole. G3: *Wii Bowling*: To throw bowling balls to knock pins. G4: *Wii Tennis:* To hit the tennis balls. G5: *Groove On*: To synchronize their motions with the beat of the music. G6: *Ski Jump*: By leaning forward at the right time and keeping the balance the player can control her avatar. G7: *Soccer Heading*: Standing on the Wii Balance Board, the player has to change her balance to keep the ball from the goal. G8: *Dance Central*: To imitate dancing moves as demonstrated by a virtual avatar G9: *20,000 Leaks:* The player tries to close virtual "holes" at different locations with hands, feet or other parts of the body	Screen; Kinect, Wii (Wiimote, nunchucks, balance board, steering wheel); N/P	N/P	Qualitative field study at home; Questionnaires, interviews; 3 days	Healthy older adults; N=4; A:71–86 (2 females, 2 males)

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Nawaz et al. (2014)	To design and evaluate an exergame concept developed to fit the need and preferences of elderly users	G1: Skiing and tennis in Kinect sports: N/P G2: YourShape: Fitness Evolved: N/P G3: *Fruit Ninja :* Players use their arms like a ninja to slice fruit that is thrown up into the air G4: *Out in Nature:* Different obstacles in the nature trail: (a) jump from rock to rock to get over the river, (b) walk over the log lying across the path, (c) duck under the branch hanging over the path, (d) get over the lake by rowing the boat, (e) balance on the log to get over the river, (f) walk on the rocks lying on the path.	Screen; Kinect; Simple avatar mapping	Challenge players' muscle strength and balance	User-centered design with elderly; Focus group interviews; N/P	Older adults; W1: N=7 W2: N=5; M= 70.6±7.9
Skjæret et al. (2014)	To investigates game elements and older players' movement characteristics during stepping exergames	G1: *DanceDanceRevolution:* Hitting targets (arrows) and avoiding obstacles (bombs) G2: *The mole from Silverfit:* Hitting targets (moles and mice) and avoiding obstacles (ladybug) G3: *LightRace in YourShape:* Hitting targets	Screen; G1: step pad; no avatar, no mapping, G2: Kinect; simple avatar, mapping of feet, G3: Kinect; humanoid avatar, mapping of player's body	Stepping exercises	Lab based user evaluation of 3 games; video observation; G1: 3 min, G2: 2 min, G3: 1 min	Older adults; N = 14 (9 females, 5 males); A: 65–85; M= 73 ±5.7

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Uzor and Baillie (2014)	To explore long term use of exergames for fall rehabilitation in homes	G1: *Pigeon Express Game:* Hit target (fruits falling out of the back of a moving van) G2: *River Gems Game*: Hit target (colored gems that comes towards the game character) G3: *Panda Peak Game*: March on the spot in optimal speed (making a panda walk across a log) G4: *Horse Hurdles Game* : The objective of the game is to jump over as many hurdles as possible	Screen; Inertial motion sensors; G1: Pigeon; mapping of sit-to-stand movements G2: Game character; mapping of side-stepping motions G3: Panda; mapping of on-the-spot marching G4: Horse; mapping of bending and standing up movements	Strength and balance exercises	Randomized controlled trial; Exercise diaries, functional walking, Questionnaires, interviews; 12 weeks	Older community-dwelling adults over the age of 65 years who had had at least one fall 12 months prior to taking part in the study; Group 1: N = 8 (7 females, 1 male); M= 75 Group 2: N = 8 (6 females, 2 males); M= 76
Zaczynski and Whitehead (2014)	To examines several issues including adapting for occlusion and lack of visibility; learning and orientation; and providing feedback to develop a set of design recommendations	*Wii Fit Yoga*: To repeat yoga poses demonstrated by the virtual yoga instructor	Screen; Wii balance board; Avatar with mapping of player movements	Yoga poses	User evaluation; feedback, interviews; N/P	Young adults; E1: N=20 (10 females, 10 males); M= 30±7 E2: N=20 (9 females,11 males); M= 29±5

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Harrington et al. (2015)	To evaluate the usability challenges of Kinect-based exergames for older adults	"Body and Brain Connection" and "Your Shape Fitness Evolved"; N/P	Screen; Kinect; complete avatar with mapping of full body movements	N/P	Usability test of two Kinect based games; Questionnaires, interviews; E: 1.5–3 hours	20 healthy older adults; N= 10 (5 females, 5 males) A: 60–69; M = 66.2 ±1.40 and N=10 (5 females, 5 males); A: 70–79; M = 74.6± 2.72
Isbister and Mueller (2015)	To collect design guidelines for movement-based games	N/A	N/A	N/A	Semi-structured interviews with movement-based game design experts in person/Skype; 1 hour	Movement-based game design experts; N=14
Jensen et al. (2015)	To investigate how game elements can affect the training experience	*The bouncer*: The Bouncer is similar to traditional handball training, where the players would run towards goal and shoot to score. The bouncer forces players to make decisions in air based on their perception	Screen; 3*3 meter rebounder frame mounted with 8 sensors to detect the impact of balls with an estimated 10 cm accuracy; no avatar, no mapping	Handball related movements (running, jumping, throwing);	Brainstorming workshop with students; User study with 3 games; semi-structured interviews, audio/video recordings; 60-90mins	Handball players and students; N=10 (2 females and 8 males); A: 24–27; M= 25

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Wiemeyer et al. (2015)	To develop recommendations for design, evaluation, and application of exergames in therapy, serving as potential guidelines for researchers, developers, and therapists	N/A	N/A	N/A	Group discussion with experts in exergame design; N/P	Individuals with expertise in the field of exergames in prevention and therapy (i.e., the authors of the article); N = 7
Jensen and Grønbæk (2016)	To compare three approaches of balancing the game: a physical, an explicit digital, an implicit digital balancing approach	*The bouncer*: Hitting virtual elements displayed on the physical rebounder	Screen; The 3*3 meter rebounder frame is mounted with 8 sensors to detect the impact of balls with an estimated 10 cm accuracy; no avatar, no mapping	Throwing	User study/evaluation; interviews, audio/video recordings; Each game lasted 1 minute and 40 seconds	Young adults; N= 24 (11 females, 13 males) divided in 12 pairs; A: 14 – 54; M= 27 ±11.5
Pyae et al. (2016a)	To investigate Japanese elderly participants' feedback towards the usability of the Skiing Game, and to investigate their game experiences during and after the gameplay.	*Skiing game*: To move both hands forward and backward to ski, while moving the body left and right to avoid obstacles	Screen; webcam; N/P	Double pole skiing movements	Usability test; Questionnaires, Interviews; 45 minutes	Older adults from nursing homes; N= 24; A: 60–85

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Pyae et al. (2016b)	To understand game design guidelines, the usability of Kinect, commercial, and non-commercial games	G1: *puuhas* sport wall game, G2: *Xbox* climbing game, G3: *Playstation* tennis game ; N/P	Screen; G1: webcam, G2: Kinect, G3: Handheld sensors; N/P	Side swaying, sit to stand, light jump	Usability test of three games in an Elderly service home in Finland; Questionnaires, feedbacks; E1:45 mins, E2: 1 hour	Healthy older adults residing/visiting service homes; E1: N=8; A: 64–78 E2: N=5; A: 60+
Richards and Graham (2016)	To investigate methods for enhancing agency in repetitive motion exergames while still meeting these rigid constraints	*Brains & Brawn–Strategy card game*: The player has a fixed number of turns to defeat their opponent by reducing all enemy characters' health to zero	Screen; Kinect; no avatar, no mapping of movements	Muscle strengthening exercises (bicep curl, shoulder press, squats)	Laboratory based user study; Questionnaires, semi-structured interviews; N/P	Students; N = 8 (2 females, 6 males); A 17–25; M=21
Brox et al. (2017)	To record lessons learned in 3 years of experience with exergames for older adults	GameUp-project developed games; N/P	Screen; Kinect; N/P	Balance, flexibility, strength	User Centered Design: interviews, semi-structured interviews, observations, group discussions; Gathered every second week for 3 years	Older adults from a senior center; N=16; A=66-95; M= 80

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Pyae et al. (2017)	To investigate the Finnish elderly people's user experiences in playing a digital game-based exercise called 'The Skiing Game'	*Skiing game*: To move both hands forward and backward to ski, while moving the body left and right to avoid obstacles	Screen; webcam; N/P	Double pole skiing movements	Usability test in an Elderly service home in Finland; Questionnaires, interviews, observations; 2 days (45 mins)	Older adults; N=21; M=76
Velazquez et al. (2017)	To understand how the exertion experience in commercial exergames can be personalized to the individual condition of each older adult	Various movement-based games (e.g., Kinect sports, Bowling, Tightrope, Walking out); N/P	Screen; Wii, Kinect; N/P	Customized movements for users based on their health	Action Research Study; experiencing (field notes, observations, diaries, photographing), inquiring (focus groups, informal face-to-face, and questionnaires), and examining (attendance data, test scores, and encoding video files); E1:32 weeks,E2: 24 weeks (Total=8 months)	Older adults; E1: N = 22 (12 females, 6 males); A: 63–82; M= 70 E2: N = 50 (37 females, 13 males); A: 58–92; M= 71

Table 5 (*Continued*)

Study	Aim	Game and Game Objective	I/O technology and Mapping of Movement	Design-Intended Movements	Study Design, Data Collection, and Duration	Sample Characteristics
Fernandez-Cervantes et al. (2018)	To provide set of practical guidelines relevant to design of Kinect based exergames for older adults	*VirtualGym*: Follow instructions and mimic the movements of a virtual coach avatar (standing in front of the user's translucent shadow avatar). Corrections are provided graphically	Screen; Kinect; Shadow avatar (partly transparent silhouette) seen from rear	Set of six different exercises:(1) Arms to the side (2) Arms to the Sky (3) Side Bends (4) Overhead Press (5) Waist Rotation (6) Standing on One Foot	Empirical feasibility study; questionnaires, interviews; 2x20 mins session. (separated by 3 weeks)	Older adults (with no mobility issues) from community dwelling & assisted living facilities); N = 10; A: 68–91; M = 79± 6.8

N/A = not applicable; N/P = not provided; N = number of participants; E = experiment; A = age range; M = mean age; G = game

5 Design Guidelines

Based on the iterative coding process explained in Section 3.3, the design guidelines were classified into twelve categories: *Movement elicitation, Mapping of movement, Explicit movement guidance, Player representation and game world, Attention, Game challenge, Feedback on player performance, Player agency and customization, Exertion, Safety, Universal design, and Social aspect*. Figure 2 shows the twelve categories divided into four overarching classes of design guidelines: *Movement facilitation*, *Cognitive and physical demand*, *Graphical user interface design (GUI design)* and *Other*.

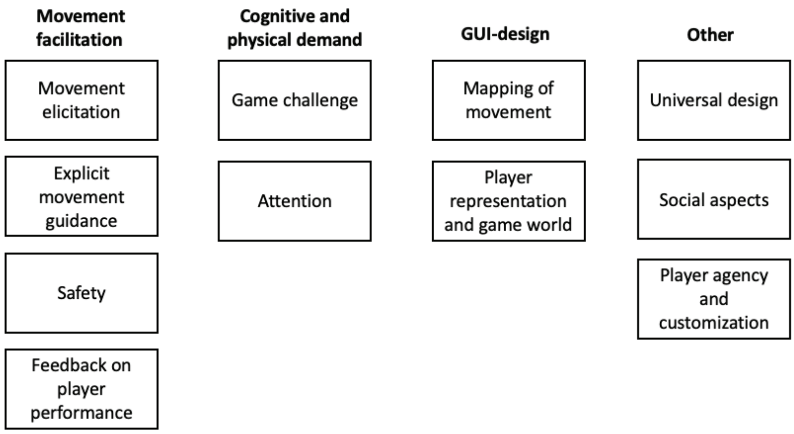

Figure 2: Categories of design guidelines grouped into four overarching classes.

Tables 6 to 17 present an overview of the categorization, describing relevant guidelines (with a unique identifier for later reference), their rationales, and the study context and the evaluated game (or games) from which the guidelines were derived. The phrasing of each design guideline is similar to the way the guidelines are presented in the original source, except for supplementary words [in brackets] added to present the guidelines in a clear and consistent manner.

This section presents the guidelines corresponding to the various categories in separate tables (6–17), followed by an explanation of the individual guidelines pertaining to each category.

5.1 Movement Elicitation

Table 6 presents the guidelines corresponding to *Movement elicitation*. This category includes guidelines describing movement characteristics that a full-body game, depending on its purpose, should promote, along with suggestions as to how desirable movement characteristics can be encouraged through the use of various game mechanics. Guidelines describing movements that should be avoided also fall under this category.

Table 6: Guidelines for Movement elicitation

1. Movement elicitation			
Guideline	Rationale	Study Context	Game(s)

1.1	[Provide] controller-free natural movements (Pyae et al., 2016a; 2016b)	Suitable for the elderly players because of its simplicity and ease-of-use	Usability test with healthy older adults in an elderly service home/health promotion center	Customized skiing game; Commercial sport games
1.2	[Provide] familiar game actions (Pyae et al., 2016b; 2017)	Participants enjoyed performing familiar game actions	Usability test with older adults in an elderly service home/health promotion center	Commercial sport games; Customized skiing game
1.3	Support players in expressing themselves using their bodies (Isbister and Mueller, 2015)	Playing a movement-based game is a form of self-expression	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users
1.4	Embrace ambiguity of movement, instead of fighting it (Isbister and Mueller, 2015)	Trying to force [movement] precision may only frustrate the player and make the limitations of the sensor obvious in a very un-fun way	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users
1.5	Help players identify rhythm in their movements (Isbister and Mueller, 2015)	Movement is rhythmic and becomes easier with a beat	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users
1.6	Elicit weight-shift (Skjæret et al., 2014)	Displacing center of mass is important for balance as a fall prevention exercise	Laboratory-based user evaluation with older adults	Commercial stepping games
1.7	Provide temporal variation (Skjæret et al., 2014)	Offering adaptive changes in speed is important for fall prevention	Laboratory-based user evaluation with older adults	Commercial stepping games
1.8	Promote step length variation (Skjæret et al., 2014)	Offering variation in task is a fall prevention exercise	Laboratory-based user evaluation with older adults	Commercial stepping games
1.9	Elicit variation in movement directions (Skjæret et al., 2014)	Stepping in different directions is a fall prevention exercise	Laboratory-based user evaluation with older adults	Commercial stepping games

1.10	[Provide] a model based on evidence-based therapy (Uzor and Baillie, 2014)	To promote ideal quality of movement for effective therapy	Randomized control trial with community dwelling older adults	Customized fantasy fall rehabilitation games
1.11	[Avoid] repetitive game action (Pyae et al., 2017)	Repetitive game action is less interesting	Usability test with older adults in an elderly service home	Customized skiing game
1.12	[Beware of] unsuitable physical actions (Pyae et al., 2016b)	Some physical actions are not suitable for the safety of elderly players	Usability test with healthy older adults in an elderly service home	Commercial sport games
1.13	[Beware of] unadvisable movements (Brox et al., 2017)	Various health issues may make some movements unadvisable	Usability test with older adults in a senior center	Customized fantasy game
1.14	Avoid sudden or extensive movements (Gerling et al., 2010)	To consider the age-related physical limitations in older adults	Focus group test with older adults in a nursing home	Customized balance game

The guidelines in Table 6 highlight the importance of unrestricted or non-choreographed player movements. Specifically, Isbister and Mueller (2015) recommended that movement-based games should support freedom in the way players chooses to use their body when playing (DG 1.3), as self-expression might increase the fun of gaming. Further, providing rhythm can be beneficial in supporting player movements (DG 1.5), as many players find it easier to move to a beat. Isbister and Mueller (2015) also argued that, rather than forcing players to perform movements with great precision, a movement-based game should be designed to embrace ambiguity of movement (DG 1.4), as employing sensor technology to detect fine-grained movements is likely to frustrate players and inhibit their gaming experience.

Studies that focused on games for older adults also found that the players preferred motion-based interactions that felt natural and easy to perform (Pyae et al., 2017; 2016a; 2016b). When designing for older adults, providing simplicity and familiar action to elicit movements is recommended (DG 1.1, 1.2). Typically, the types of physical activities most popular among older adults are of lower intensity, such as walking, gardening, golf, and other low-impact aerobic activities performed as part of their daily life activities in and around their home (Jørstad-Stein et al., 2005). However, having games that consist of repetitive movements (DG 1.11) might be less interesting as this might become monotonous (Pyae et al., 2017) and, hence, could demotivate further play.

Drawing on the above, design recommendations with regard to elicitation of movements appear uniform across all ages and should generally enhance natural movements and facilitate variation of movements through game play.

While some of the reviewed studies (Isbister and Mueller (2015) and Pyae et al., (2017; 2016a; 2016b)) have focused on promoting general activity through movement-based games, other studies have considered full-body games used in the context of therapy or specific exercise for older adults. Uzor and Baillie (2014) considered full-body games used in the context of therapy and recommended that designers pay specific attention to ways of promoting movement that are effective in such regard. The authors provided a general guideline advising designers to model games based on evidence-based therapy (DG 1.10), eliciting desirable movement characteristics such as range and pace of motion through an appropriate reward (scoring) system.

Similarly, Skjæret et al. (2014) offered four movement-specific guidelines specially intended to support the design of full-body stepping games for balance training in older adults. The study highlighted how promotion of weight-shift in players is important for balance training (DG 1.6), and that full-body games used in this context therefore should constantly urge players to transfer body weight from one foot to the other, for instance by employing stepping targets that players will intuitively attempt to press down rather than just touch or tap. Furthermore, Skjæret et al. (2014) recommended temporal variation in stepping games by offering adaptive changes in game speed based on either the players' movement abilities or the accuracy of their performance (DG 1.7). The authors also suggested that a stepping game should be designed to vary in step length (DG 1.8) and movement direction (DG 1.9) which can be achieved by providing stepping targets at different distances from the player and in different locations in the playing area.

Comparing the guidelines advocating freedom of movement (Isbister and Mueller, 2015; Pyae et al., 2016a; Pyae et al., 2016b) with guidelines for games aiming to serve specific health purposes (e.g., balance-training in older adults (Skjaeret et al., 2014)), one apparent distinction is the extent to which the latter tend to focus on promoting specific movement characteristics. This does not necessary mean that the health-oriented design guidelines require a strict choreography of player movements (thus conflicting with many of the guidelines proposed by Isbister and Mueller (2015) and Pyae et al., (2016a; 2016b)). Existing studies (Subramanian et al., 2019) suggest that the same movement characteristic may be achieved also by opening up for various ways to accomplish movement-related tasks in full-body games.

When designing specifically in the context of older adults, there are also recommendations regarding game-related movements that should be discouraged in a game. Even though several people are living longer and healthier lives, the number of disabilities increases considerably with age, and above the age of 65 years most people have more than one chronic condition that needs to be taken into consideration when designing games for this population (Wolff et al., 2002). For instance, Pyae et al. (2016b) and Brox et al. (2017) advised game designers to be mindful of unsuitable movements that can be harmful for the older players (DG 1.12, 1.13) as they often may have physical and cognitive challenges that will affect their possibility to move during gameplay. Similar concerns about potential negative effects that game-related movements can have on players' health were raised by Gerling et al. (2010). They advised game designers to avoid provoking sudden or extensive movements that may be unsuitable for the users (DG 1.14).

5.2 Mapping of Movement

Guidelines under the category *Mapping of movement* offer advice on how players' body movements should be represented within the game during gameplay. Table 7 presents the extracted guidelines corresponding to the mapping of movements. In most of the full-body games described in the reviewed studies, player movements are usually mimicked by means of a virtual representation of the player, that is, an *avatar* (Klevjer, 2006). The following guidelines address different concerns related to the mapping of player body movements.

Table 7: Guidelines for Mapping of movement

2. Mapping of movement				
Guideline		Rationale	Study Context	Game(s)
2.1	Map movements in imaginative ways (Isbister and Mueller, 2015)	To offer players fantasy-fueled opportunities that they do not otherwise have	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users

2.2	Decouple physical movement from avatar movement (Richards and Graham, 2016)	Such mapping can be unsafe or inappropriate for many exercises	Laboratory-based user study with University students	Customized muscle strengthening game
2.3	[Provide] easy gesture recall (natural mapping with clear instructions) (Gerling et al., 2012)	Many older adults have no previous gaming experience and are dependent on assistance while playing	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game
2.4	Focus on simple interaction mechanism (with respect to gameplay) (Gerling et al., 2010)	Older adults often lack previous gaming experience	Focus group test with older adults in a nursing home	Customized balance game
2.5	[Promote] simple but effective gameplay (Pyae et al., 2016a; 2016b)	To improve users' ability in exercising	Usability test with healthy older adults in an elderly service home	Customized skiing game; Commercial sport games
2.6	Classify gamers' motion capacities during gameplay (Velazquez et al., 2017)	The classification was demonstrated to be useful at programming exertion time	Exergaming interventions and focus groups with older adults in a hospital	Commercial sport games
2.7	Choose an appropriate level of sensing (Jensen et al., 2015)	The challenge when designing training games is choosing the appropriate level of sensing for game input, while ensuring sports relevance and allowing for engaging interactions	Brainstorming workshop and user study with students at a sporting resort	Customized handball game

Full-body interactive games allow movements to be mapped in a wide variety of ways. Isbister and Mueller (2015) suggested that game designers should take advantage of this opportunity and map movements imaginatively, including using ways that are not possible in real life (DG 2.1). Being creative in the mapping process is considered to provide players with fantasy-fueled opportunities. Likewise, Richards and Graham (2016) recommended decoupling physical movements from avatar movements, arguing that doing so opens space to various design possibilities (DG 2.2). However, decoupling movements might only be advisable while designing a fantasy game and not for a real-world sports experience. Jensen et al. (2015) emphasized that the challenge in designing training games is choosing an appropriate level of sensing as game input to facilitate interaction between players and the game (DG 2.7), while ensuring sports relevance and allowing for engaging interactions. They also underlined that designing training games where every movement is sensed and dictated by the system will affect players' engagement negatively and perhaps curtail players' opportunity to experiment with different strategies that is important in a sport setting.

In contrast, Gerling et al. (2012) state that when designing specifically for older adults, it is necessary to provide natural mappings and clear instructions that support gesture recall to empower players (DG 2.3). Games designed for older adults should also focus on simple interaction mechanisms to avoid frustration and to promote an enjoyable player experience (DG 2.4) (Gerling et al., 2012), and be simple but effective enough to improve players' ability to do exercises (DG 2.5) (Pyae et al., 2016a; 2016b).

Furthermore, Velazquez et al. (2017) suggested classifying gamers' motion capacities during gameplay, as it was demonstrated to be useful at programming exertion (DG 2.6). Though it is already known that motion capacity must be assessed before starting any physical exercise, the authors established an elaborate classification method that includes not only arcs assessment but also a simple test of strength and balance aimed at obtaining a more accurate profile of a gamer's motion capacity.

The differences in guidelines for how to represent players' body movements within the game during gameplay shows the importance of designing and adapting full-body games to the players at hand, being young adults gaming for specific sport exercise or institutionalized older adults. Decoupling movements (DG 2.2) and imaginatively mapping of movements (DG 2.1) may be motivating for younger adults or active and healthy older adults, however for adults with reduced physical and/or cognitive capacity, natural mappings (DG 2.3) may be preferable to motivate and activate the players.

5.3 Explicit Movement Guidance

Table 8 presents various guidelines for *Explicit movement guidance*. These guidelines are related to the use of explicit intended instructions informing players on *how* and/or *when* to move their bodies while playing full-body games. The guidelines consist mainly of how movement instructions should be provided during gameplay and include recommendations about what mode of delivery to use (e.g., visual or auditory).

Table 8: Guidelines for Explicit movement guidance

3. Explicit movement guidance				
Guideline		Rationale	Study Context	Game(s)
3.1	[Provide] in-game instructions (Pyae et al., 2017)	Participants stated that in-game instructions made the game easy to understand and play	Usability test with older adults in an elderly service home	Customized skiing game
3.2	Use animation instead of texts and figures (Uzor and Baillie, 2014)	Users got bored of reading text, and animated movements were more effective than static images	Randomized control trial with community dwelling older adults	Customized fantasy fall rehabilitation games
3.3	[Provide] multi-modal demonstration (Zaczynski and Whitehead, 2014)	Descriptive verbal delivery had a significant impact on players' understanding and pose accuracy	User evaluation with healthy young adults	Commercial yoga game
3.4	Provide verbal delivery as supplementary (Zaczynski and Whitehead, 2014)	The use of direction (i.e., left and right) in descriptions often caused confusion	User evaluation with healthy young adults	Commercial yoga game

Interestingly, both younger and older adults stated that movement guidance in full-body games should not be delivered by text on screen only. Zaczynski and Whitehead (2014) observed that the young adults participating in their study preferred verbal delivery about how and when to move their bodies during gameplay. The authors stated that descriptive verbal delivery had a significant impact on players' understanding and pose accuracy, whereas the absence of verbal delivery was considered inadequate by participants. Based on this rationale, the authors emphasized on providing multi-modal demonstrations that include providing accurate verbal delivery as a supplement (DG 3.3, 3.4) to textual guidance, as the latter often led to confusion.

Similarly, both Pyae et al. (2017) and Uzor and Baillie (2014) found that providing clear in-game instructions are important in games designed for older adults (DG 3.1, 3.2). Uzor and Baillie (2014) modelled their study by replacing heavy text-based instructions with image-based instructions, as the users felt that they became bored reading texts. Being bored might, however, not be the only reason for replacing text. As visual impairment is common in older adults, and the prevalence increases with age (Congdon et al., 2004), providing pictures might be a more beneficial way of proving instructions for this age group. Providing verbal delivery as a supplement might also be valuable for older adult (as suggested in Zaczynski and Whitehead (2014)), having in mind that approximately one-third of persons over 65 years are affected by disabling hearing loss (WHO, 2012).

5.4 Player Representation and Game World

This section describes guidelines concerning the design of the virtual game world, that is, the screen-based representation of the game setting, and how players are represented within this world (i.e., what the player *is* within the game world). Table 9 presents guidelines corresponding to this category of *Player representation and game world.*

Table 9: Guidelines for Player representation and game world

4. Player representation and game world				
Guideline		Rationale	Study Context	Game(s)
4.1	Avatars should be anthropomorphic, without much detail but with elements of an older appearance (Fernandez-Cervantes et al., 2018)	The senior participants involved in the study preferred simple humanoids	Empirical feasibility study with healthy older adults at home	Customized gym game
4.2	Provide effective visual cues (clear orientation environment) (Pyae et al., 2016b; 2017)	Visual cues are important for elderly players to pay closer attention to their gameplay and easily understand how to succeed in game tasks	Usability test with healthy older adults in an elderly service home	Commercial sport games; Customized skiing game
4.3	[Provide] clear orientation of the environment (Zaczynski and Whitehead, 2014)	Establishing a clear environment orientation to clarify the relationship between one's own body and the game is important with complicated poses	User evaluation with healthy young adults	Commercial yoga game

4.4	Maintain relevance when translating physical elements into digital representation (Jensen et al., 2015)	Designing poses a great challenge of extracting relevant elements from a sport and choosing an appropriate type of representation without reducing the sport relevance	Brainstorming workshop and user study with students at a sporting resort	Customized handball game
4.5	Utilize both physical and digital domains (Jensen and Grønbæk, 2016)	Design packages that suits different player pairs, as participants did not prefer one specific balance mechanism	User study with people aged 14–54 at a sporting resort	Customized handball game
4.6	[Provide] reality-based game mechanics/ideas (Barenbrock et al., 2014; Pyae et al., 2016a; Nawaz et al., 2014)	Participants preferred performing real-world activities that they had enjoyed in the past	Qualitative field study at home with healthy older adults; User centered design with older adults	Commercial sport, fitness, dancing, balance and virtual twister games; Customized skiing game

In game design, it is rather challenging to translate physical elements into a digital representation within the game world, and Jensen et al. (2015) stated that it is important to maintain relevance when doing so (DG 4.4). The authors stated that a literal translation, such as a simulated goalkeeper, poses several technical difficulties for the game to be perceived as a useful tool for training. Hence, the authors suggested choosing an abstract representation that provides designers with more freedom to utilize game mechanics and elements in the design. In contrast to Jensen et al. (2015), Fernandez-Cervantes et al. (2018) suggested designing more human-like avatars without much detail, but with elements of an older appearance, when designing for older adults (DG 4.1)**.** The authors recommended doing so based on findings of their empirical feasibility study, in which the older adults involved in the study did not appreciate fantasy or cartoon-like avatars but rather preferred more simply shaped humanoid avatars.

Providing visual demonstration and cues, however, seems to be important regardless of age. Zaczynski and Whitehead (2014) recommended that instructions should begin by establishing a clear orientation environment (DG 4.3). Based on a yoga game used in their study, the authors observed that several users missed an entire demonstration as they were too engaged in identifying which hand or foot to use. Hence, establishing a clear orientation environment, for example by facing the virtual instructor away or towards the user, or providing visual cues such as a yoga mat, would allow users to mentally clarify the relationship between their own body and the instructor, which is particularly important when performing complicated poses. Likewise, Pyae et al. (2016b) found that providing effective visual cues would enable elderly players to pay more attention to gameplay, which further enabled the players to easily understand and succeed with game tasks (DG 4.2) (Pyae et al., 2017).

Furthermore, the study performed by Barenbrock et al. (2014) and Pyae et al. (2016a) revealed that participants mainly enjoyed games that offered them the opportunity to do sports or other real-world activities that they enjoyed doing in the past (DG 4.6). Similarly, Nawaz et al. (2014) also recommended providing a game story that is close to the real-life activities of older adults as the senior participants in their studies suggested real-life activities for game design.

Another challenging aspect is balancing mechanisms within the game, for which Jensen and Grønbæk (2016) recommended utilizing both the digital and physical domain by fusing balance mechanisms and providing players with choices, since participants did not prefer a specific balancing mechanism (DG 4.5). The authors also recommended designers to design for different player pairs, such as brothers, father-daughter, and others.

Adding a social factor to a game is often perceived as one of the advantages with gaming, and promoting social interaction is an area in which full-body games can excel. As games are generally popular among all age groups, they can be used to encourage different generations to play together. Hence, DG.4.5 might be utilized across all ages, and with different constellations.

5.5 Attention

The reviewed articles provided several guidelines that concern players' attention and awareness during gameplay, as presented in Table 10. Many of the guidelines in the *Attention* category address how designers can deal with cognitive issues that full-body games may give rise to.

Table 10: Guidelines for Attention

5. Attention				
Guideline		Rationale	Study Context	Game(s)
5.1	Consider movement's cognitive load (Isbister and Mueller, 2015)	Moving can demand a lot of mental attention, creating high "cognitive load" especially when learning new movements	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users
5.2	[Consider/provide] appropriate reaction time (Barenbrock et al., 2014; Brox at al., 2017)	The game speed needs to be appropriate, so that players have enough time to react	Qualitative field study at home with healthy older adults; Usability test with older adults in a senior center	Commercial sport, dancing, and virtual twister games; Customized fantasy game
5.3	Provide visual independency (Skjæret et al., 2014)	Focus of player during gameplay should be on the exergame activity or task, and not on where to place feet to make a correct step	Laboratory- based user evaluations with older adults	Commercial stepping games
5.4	Simplicity is key (Fernandez-Cervantes et al., 2018)	Elements that serve only entertainment purposes can be distracting	Empirical feasibility study with healthy older adults at home	Customized gym game

5.5	Games should be developed with attractive and user-friendly interfaces that are not complex and are easy to interpret (Harrington et al., 2015)	Minimizing the amount of information presented on a single screen allows older adults to better perceive information	Laboratory-based usability test with healthy older adults;	Commercial puzzle and fitness games
5.6	Important information must come after gameplay (Brox at al., 2017)	Older adults have only one focus of attention	Usability test with older adults in a senior center	Commercial fantasy game
5.7	[Provide] simple and uncluttered user interface (Pyae et al., 2016a; 2016b; 2017; Nawaz et al., 2014; Wiemeyer et al., 2015)	Elderly people prefer simple and uncluttered user interfaces so that they can play the game without distractions	Usability test with healthy older adults in an elderly service home/health promotion center; Workshops with older adults in a senior center; Group discussion with experts in exergame design for persons with disabilities	Commercial sport, fitness, and balance games; Customized skiing game;
5.8	Focus attention on effective movements (Velazquez et al., 2013)	Older adults need to reduce intensity of motion to focus attention on effective movements	Action research study with specialists in aging and healthy older adults	Commercial sport games
5.9	The primary focus should be on movement quality without too much distraction (Nawaz et al., 2014)	Senior participants wanted to know why to do the different tasks and what kind of training benefits the games could give them beyond entertainment	Workshops with older adults in a senior center	Commercial sport, fitness, and balance games
5.10	Provide more audio and visual feedback with less text (Pyae et al., 2016b)	To ensure that elderly players pay attention	Usability test with healthy older adults in an elderly service home	Commercial sport games

When designing full-body games Isbister and Mueller (2015) recommended not overloading players with too much feedback during gameplay (DG 5.1) as moving can create a high cognitive load, particularly when learning new movements. As Table 10 shows, most papers that deal with players' attention and awareness during gameplay concern older adults.

Learning new movements requires a great deal of concentration and focus, which can compete with the attention needed to understand the provided feedback (Spelmezan et al., 2009). Fernandez-Cervantes et al. (2018) found that elements that only serve the purpose of "entertainment" can be distracting, and hence state that simplicity is key (DG 5.4). Based on their own guidelines, the authors modified their game "VirtualGym" from a fantasy setting into a simple, spacious, and minimalist yoga studio that proved to be more efficient.

Harrington et al. (2015) stated that games should be developed with attractive and user-friendly interfaces that are not complex but rather easy to interpret (DG 5.5). The authors stated that minimizing the amount of information presented on a single screen will allow older adults to better perceive information, thereby making instructions easier to follow. In addition, Brox et al. (2017) realized that none of the older adults were aware of information about the gameplay such as scores and time left while they were playing, irrespective of the size of the information, until the game stopped, and hence, recommended displaying important information after gameplay only (DG 5.6). Likewise, Pyae et. al., (2017; 2016a; 2016b); Nawaz et al. (2014) and Wiemeyer et al. (2015) stated that when designing games for physical rehabilitation, the game interface should be simple and uncluttered, as this was well received by the elderly players (DG 5.7). Pyae et al. (2016b) further recommended providing more audio and video feedback instead of text to ensure that the elderly players pay attention (DG 5.10)

Another important aspect to consider when designing for older adults is the decrease on reaction time. In the study by Barenbrock et al. (2014) participants identified games as hard to play when they were either too fast or did not allow enough time to react. Hence, the authors suggested providing appropriate time to react (DG 5.2). Similarly, Brox et al. (2017) stated that players need time to understand and process the information given to plan an appropriate movement reaction. Also, Velazquez et al. (2013) stated that older players require longer time to engage with games and be guided through game mechanics. They suggested that senior players instead should reduce the intensity of motion and focus their attention on effective movements (DG 5.8).

Nawaz et al. (2014) stated that the primary focus within game play should be on movement quality without too much distraction as senior participants wanted to know why they had to perform different tasks and the health benefits they would gain in addition to entertainment (DG 5.9). One thing to keep in mind then is the recommendation from Skjæret et al. (2014) which identified that it was necessary to help players maintain visual independency and focus their attention on the game activity or task rather than on how to control the game (DG 5.3). The authors stated that visual attention or the focus of the player during gameplay should be on the game activity, not on where to physically move. In addition, the authors stated that there should be no need for players to focus on the ground, thereby implying that all relevant information should be provided on the screen.

Even though most of the guidelines concerning players' attention and awareness during gameplay have been given in studies concerning older adults (DG 5.2–5.10), providing simple and relevant feedback that ensures movement quality is important disregarding who the game is designed for (as suggested by Isbister and Mueller (2015) (DG 5.1).

5.6 Game Challenge

The category *Game challenge* provide suggestions regarding tasks or actions that are to be performed by players in order to reach the goal of the game. In particular, the guidelines concern the difficulty of the game challenge and how to design for an appropriate level (see Table 11).

Table 11: Guidelines for Game challenge

6. Game challenge			
Guideline	Rationale	Study Context	Game(s)

6.1	Provide possibility of individually adjusting the level of difficulty (Gerling et al., 2010)	To challenge the experience of a broad audience and equally account for individual needs	Focus group test with older adults in a nursing home	Customized balance game
6.2	[Provide] dynamic game difficulty (Gerling et al., 2012)	Games need to adjust to large range in ability to keep more active players engaged while avoiding overstraining others	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game
6.3	Identify mobility capacity and adapt gameplay to it (Velazquez et al., 2013)	Motion capacities need to be taken into account, as reduced mobility requires reduced intensity and adequate feedback	Action research study with specialists in aging and healthy older adults	Commercial sport games
6.4	Games need to provide enough challenge, but at the same time they should not be too difficult (Barenbrock et al., 2014)	For players to be encouraged to play again	Qualitative field study at home with healthy older adults	Commercial sport, dancing, and virtual twister games
6.5	Adapt the pace of the game to match the respective speed of information processing (Wiemeyer et al., 2015)	Adapt to fit the condition of the target group	Group discussion with experts in exergame design for persons with disabilities	Not based on game evaluation with users
6.6	The difficulty of the tasks is adapted to the current state of the individual (Wiemeyer et al., 2015)	Self-adaptation can overload the patient and lead to demotivation	Group discussion with experts in exergame design for persons with disabilities	Not based on game evaluation with users
6.7	Assess and utilize players' absolute skills (Jensen and Grønbæk, 2016)	The game should provide new challenges at an appropriate pace and increase as the player progresses	User study with people aged 14–54 at a sporting resort	Customized handball game

6.8	Provide range of motion adaptability (Gerling et al., 2012)	Institutionalized older adults often suffer from a reduced range of motion that limits their ability to engage in full-body interaction	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game
6.9	[Avoid] unexpected physical challenges (Altimira et al., 2014)	Introducing an unexpected physical challenge led players to experience decreased sense of control, frustration, and disengagement	Laboratory-based comparative study with adults aged 19–43	Commercial sport game
6.10	[Avoid] unacceptable competitive advantage (Altimira et al., 2014)	More skilled players disengaged when playing with a score disadvantage	Laboratory-based comparative study with adults aged 19–43	Commercial sport game
6.11	[Provide] adaptability (Barenbrock et al., 2014)	Elderly persons have very different age-related issues	Qualitative field study at home with healthy older adults	Commercial sport, dancing, and virtual twister games
6.12	Understand and adapt for capability (Zaczynski and Whitehead, 2014)	To ensure that poses are performed accurately without injury	User evaluation with healthy young adults	Commercial yoga game
6.13	Fuse balancing mechanisms (Jensen and Grønbæk, 2016)	The participants in the study did not prefer one specific mechanism	User study with people aged 14–54 at a sporting resort	Customized handball game
6.14	Inform players about balancing (Jensen and Grønbæk, 2016)	Probing players about the presence of balancing mechanisms played an important part in their acceptance of them	User study with people aged 14–54 at a sporting resort	Customized handball game
6.15	Make balancing available for both players (Jensen and Grønbæk, 2016)	Players emphasized that knowing balancing could be applied for both players increased their acceptance of it and made them consider the game more fair	User study with people aged 14–54 at a sporting resort	Customized handball game

6.16	Reduce negative effects of competitiveness (Velazquez et al., 2017)	To recover the desire to play among gamers with low skills levels	Exergaming interventions and focus groups with older adults in a hospital	Commercial sport games
6.17	Provide a variety of games and different gameplay to make them more interesting (Pyae et al., 2017)	Participants stated that they would like to play a variety of digital games	Usability test with older adults in an elderly service home	Customized skiing game
6.18	Increase efficiency from first attempt at playing by privileging motion-tracking based on step-by-step decomposition of the game mechanics (Velazquez et al., 2017)	To increase self-efficiency and to reduce the time needed to control the game	Exergaming interventions and focus groups with older adults in a hospital	Commercial sport games
6.19	Elderly users should be able to choose and add difficulty elements in the game for confidence and better progress (Nawaz et al., 2014)	The participants expressed that they wanted a simple way to display progress and learning in their gameplay	Workshops with older adults in a senior center	Commercial sport, fitness, and balance games
6.20	Describe if the outcome of the game is a physical challenge, a cognitive challenge or both (Nawaz et al., 2014)	Some older adults were concerned that including cognitive tasks takes the focus away from the physical tasks to cognitive tasks	Workshops with older adults in a senior center	Commercial sport, fitness, and balance games
6.21	The exergame concept must make it clear what kinds of movements are required at different difficulty levels (Nawaz et al., 2014)	Senior participants wanted a clear description of what was required for different difficulty levels	Workshops with older adults in a senior center	Commercial sport, fitness and balance games
6.22	Exergames should be designed with very low initial skill demands (Thin and Poole, 2010)	to maximize the user's level of exertion and to realize and reward progress	User study with students	Commercial dance and sport games

Several studies recommended providing dynamic game difficulty when designing for full-body games. This involves automatically changing the difficulty parameters of a game in real time based on players' abilities to avoid making players either bored or frustrated, which can be caused if a game is either too easy or too difficult (Oppermann and Slussareff, 2016). Jensen and Grønbæk (2016) stated that a game should assess players' absolute skill level and utilize it to increase (or decrease) the challenge and suggested that designers create dynamic difficulty to not only balance between the players, but also balance the difficulty of the game for individual players (DG 6.7). They determined that in their game, when one player (or both players) was continuously hitting targets, the targets should begin to move or decrease in size in order to increase the challenge of the game. Contrarily, if a player (or both) was unable to hit any targets, they should grow in size. Thin and Poole (2010) also pointed to the importance of designing exergames with very low initially demand skills to maximize users' exertion and to realize and reward progress, thereby promoting an enjoyable exercise experience and in turn counterbalance any sense of exertional discomfort (DG 6.22). Similarly, Zaczynski and Whitehead (2014) stated that, particularly in training, the system's awareness of users' capabilities is essential to ensuring that poses are performed accurately without any injury (DG 6.12). The authors stated that the system must be aware of user ability and provide alternative actions that still address the benefit of the pose without overexerting or discouraging the user.

When designing for people with disabilities, Wiemeyer et al. (2015) stated that the pace of the game should match the respective speed of information processing (DG 6.5) and that the difficulty of the game must be adapted to the current state of the individual (e.g., size of target zones, distance of targets, or resistance) (DG 6.6). They also recommended that automatic adaption by appropriate algorithms or manual adaptation by a therapist would be feasible for this target group.

In addition to the above, Gerling et al. (2012; 2010); Velazquez et al. (2013), and Barenbrock et al. (2014) also recommended having dynamic game difficulty for games designed specifically for older adults. Gerling et al. (2010) pointed out that games need to adjust to a large range in functional ability from one institutionalized older adult to another to allow for an appropriate level of activity and challenge to keep more active players engaged while avoiding overstraining others. They stated that when designing for older adults, players should be provided the possibility of individually adjusting the level of difficulty**,** game speed, and sensitivity of the input device, so that games can be used by a wider range of audience and also support individual needs (DG 6.1). Similarly, Gerling et al. (2012) recommended offering difficulty adjustments between players and individually scaling challenges, as this will keep active players more engaged while not overstraining others (DG 6.2). To achieve better adaptability in games, Gerling et al. (2012) further recommended creating interaction paradigms that adapt to individual differences in player range of motion, as these adults need to be calibrated according to individual player abilities (DG 6.8)**.** In this regard, the authors suggested creating interaction paradigms that adapt to individual differences, as it is common for this user group to suffer from reduced range of motion that limits their ability to engage in full body interaction. Also Barenbrock et al. (2014) emphasized the need for a healthy balance between challenge and easy progress. As providing a clear and measurable account of players' progress is important for all audiences, games need to provide enough challenge for players to be encouraged to play again, but at the same time the challenge should not be too difficult (DG 6.4). The authors stated also stated that as older adults have different age-related issues, it would be advisable to make games and hardware adaptable for users (DG 6.11) and allowing players to directly select and switch between different stages of a game. Another initiative for achieving dynamic game difficulty was given by Velazquez et al. (2013), where the authors suggested identifying mobile capacity and adapting game play to it, and that measuring arcs of mobility provide good insight in this regard (DG 6.3). Velazquez et al. (2017) further proposed assisting older adults to increase their efficiency from the first time they play by privileging motion-tracking based on step-by-step decomposition of the game mechanics in contrast with fast and uncontrolled movements, as this was shown to increase self-efficiency and reduce the time needed to control the game (DG 6.18).

Another aspect that was raised as important when designing for older adults was the game content. In the study by Pyae et al. (2017) several of the older participants suggested that games should provide a variety of minigames as different gameplay makes playing more interesting to perform (DG 6.17). Also, Nawaz et al. (2014) suggested that elderly participants should be able to choose and add difficulty elements in the game for confidence and better progress as the participants expressed that they wanted a simple method of displaying progress and learning in the game play (DG 6.19). The authors recommend describing if the outcome of the game is a physical challenge, a cognitive challenge, or both as some older adults from their studies were concerned that including cognitive tasks may take the focus away from the physical tasks (DG 6.20). Nawaz et al. (2014) additionally suggest providing clear description of what type of movements are required to be performed at different difficulty levels as they state that senior participants wanted to have a clear description of what was required at various levels of difficulty (DG 6.21).

Interestingly, balancing mechanisms in games where described in studies with young adults only. For instance, Jensen and Grønbæk (2016) suggested fusing the balance mechanism, utilizing both the physical and digital, as the participants in their study did not prefer a specific balancing mechanism (DG 6.13). Furthermore, the authors suggested to informing players about balancing, as informing players had a large impact on player acceptance in their study (DG 6.14). Next, the authors suggested making balancing available for both players, since doing so would make the game more easily accepted and fair in that case (DG 6.15). Similarly, considering multiplayer games, Velazquez et al. (2017) stated that negative effects from competitiveness must be avoided to recover the desire to play among gamers with low skills (DG 6.16). They suggested implementing cooperative gameplay to avoid negative effects due to poor performance, pondering scores using motion classification aimed at leveling performance, and/or increasing social interaction by including observers in the playground area. To prevent disengagement among skilled players, Altimira et al. (2014) found that introducing an unexpected physical challenge (for e.g., playing traditional table tennis with a non-dominant hand) can lead to frustration and player disengagement and therefore suggested avoiding unexpected physical challenges (DG 6.9). Second, the authors stated that unacceptable competitive advantage should be avoided, as more skilled players disengaged when playing with a score disadvantage (DG 6.10). In this regard, the authors suggested that a lower score adjustment can be applied in games that require a lower skill level to play to avoid overbalancing the game and thereby increasing the chance of disengagement owing to an unacceptable competitive advantage.

5.7 Feedback on Player Performance

Feedback on player performance refers to the evaluative and/or corrective response a full-body game provides players about their movements during gameplay. Relevant guidelines, presented in Table 12, provide recommendations concerning both how and when feedback should be provided and which forms of feedback that should be avoided.

Table 12: Guidelines for Feedback on player performance

7. Feedback on player performance				
Guideline		Rationale	Study Context	Game(s)
7.1	Provide constructive criticism (Gerling et al., 2010)	To avoid frustration and to foster an enjoyable player experience	Focus group test with older adults in a nursing home	Customized balance game
7.2	Present rewarding feedback such as knowledge of results (Wiemeyer et al., 2015)	To support intrinsic motivation	Group discussion with experts in exergame design for persons with disabilities	Not based on game evaluation with users
7.3	[Provide] continuous player support (Gerling et al., 2012)	Extended tutorials are required to ensure that players are given time to learn the skills needed to play the game	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game

7.4	Communicate progress (Uzor and Baillie, 2014)	Providing an exergame score gives participants a motivational boost	Randomized control trial with community dwelling older adults	Customized fantasy fall rehabilitation games
7.5	[Provide] custom contextual feedback (Zaczynski and Whitehead, 2014)	Customized, contextual feedback offers a direct solution to inaccuracy rather than just demonstrating inaccuracy and allowing the user to determine a solution	User evaluation with healthy young adults	Commercial yoga game
7.6	Provide helpful information and feedback at appropriate time (Harrington et al., 2015)	Many participants were unsure of what action was supposed to take place at a particular time	Laboratory-based usability test with healthy older adults	Commercial puzzle and fitness games
7.7	Feedback must be timely and contextual (Fernandez-Cervantes et al., 2018)	Providing users with continuous feedback on their performance can be overwhelming and eventually ignored	Empirical feasibility study with healthy older adults at home	Customized gym game
7.8	Avoid feedback overloading (Isbister and Mueller, 2015)	Developing movement skill requires not only bodily but also cognitive attention, with attention being a limited resource	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users
7.9	Focus on the body and not the screen when designing player feedback (Isbister and Mueller, 2015)	In movement-based games, the body is a major focus of attention	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users
7.10	Celebrate movement articulation (Isbister and Mueller, 2015)	With movement-based games, it is not about just if and when, but also how movement is performed. Sometimes the movement can be enjoyable on its own	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users

7.11	Introduce points in training exercises without reducing sport relevance (Jensen et al., 2015)	Game elements hold great potential to motivate players to exert themselves in training sessions, but it also raises the challenge of avoiding influencing sport relevance in a negative way	Brainstorming workshop and user study with students at a sporting resort	Customized handball game
7.12	Negative feedback should be avoided (Wiemeyer et al., 2015)	Not provided	Group discussion with experts in exergame design for persons with disabilities	Not based on game evaluation with users
7.13	Schematic and generic positive feedback should be avoided (Wiemeyer et al., 2015)	Not provided	Group discussion with experts in exergame design for persons with disabilities	Not based on game evaluation with users
7.14	Progress in-game should be more simple and meaningful than using scores and points (Pyae et al., 2016b)	Not provided	Usability test with healthy older adults in an elderly service home	Commercial sport games
7.15	Provide clear indication of expected results and the health benefits achieved by playing (Nawaz et al., 2014)	Elderly participants wanted information regarding the specific effect and outcome of the exercises	Workshops with older adults in a senior center	Commercial sport, fitness, and balance games
7.16	Provide simple and effective audio feedback (Pyae et al., 2016a)	Excessive audio feedback could make the elderly distracted from the gameplay	Usability test with older adults at a health promotion center	Customized skiing game
7.17	Provide multimodal feedback (Zaczynski and Whitehead, 2014)	Feedback is suitable if it is provided in a modality that compliments the orientation of the action being performed	User evaluation with healthy young adults	Commercial yoga game

7.18	All important information must be communicated consistently and promptly (Fernandez-Cervantes et al., 2018)	Since many older adults' experience deteriorated peripheral vision, information around the edge of the screen or in many different places may be ignored	Empirical feasibility study with healthy older adults at home	Customized gym game
7.19	Multiple alternative information-communication channels must be supported (Fernandez-Cervantes et al., 2018)	Older adults may experience visual or auditory decline	Empirical feasibility study with healthy older adults at home	Customized gym game

Zaczynski and Whitehead (2014) stated that providing customized, contextual feedback offers a direct solution to inaccuracy rather than only demonstrating inaccuracy and allowing users to determine a solution. They suggested providing customized, contextual feedback to help resolve errors (DG 7.5). The authors stated that feedback including verbal and haptic, and a combination of these, were found to have an impact on pose performance, as they were highly preferred to commercially available feedback systems such as avatar mirroring. The authors further stated that multimodal feedback should be provided in a modality that compliments the orientation of the action being performed by the player (DG 7.17), as players are likely to be mid-action when feedback is provided. Therefore, the authors recommend that the system should adapt accordingly, by for instance providing haptic or verbal feedback if users' eyes are averted. Wiemeyer et al. (2015) further stated that providing rewarding feedback such as knowledge of results would support intrinsic motivation (DG 7.2), whiteout further ideas for practical implementation.

Isbister and Mueller (2015), however, prompted designers to think past screen-based feedback and to use audio and haptics to provide feedback. They recommended focusing on the body and not just on the screen when designing player feedback, as the body must be the main focus of attention, Further, they found that it was necessary to celebrate how well players articulate movements, and the movement of joy, by providing feedback on movement quality from moment to moment (DG 7.10). To practically implement these guidelines, Isbister and Mueller (2015) suggested highlighting players' articulation without judgement, so that the players may reflect and learn from it by themselves. Furthermore, Isbister and Mueller (2015) suggested avoiding feedback overload, as developing movement skills requires not only bodily but also cognitive attention (DG 7.8). Therefore, players initially need to focus on learning a new movement, and while getting better at the movement they can devote more cognitive attention toward more complex and nuanced forms of feedback. In this regard, the authors' ideas for practically implementing this guideline were to provide feedback on the movement itself, without much focus on the score, and to provide players with several forms of feedback with no requirement to engage with all of them.

To avoid frustration and to promote an enjoyable player experience among elderly players who lack previous gaming experience, Gerling et al. (2010) suggested providing constructive criticism (DG 7.1). However, they did not provide ideas for practical implementation. Harrington et al. (2015) and Fernandez-Cervantes et al. (2018) identified the importance of timing when providing feedback for older adults. Harrington et al. (2015) stated that in their study, several older participants were unsure of when to perform a specific action and claimed that this could have been addressed by providing on-screen instructional gestures during each activity to serve as a form of reinforcement. Based on this rationale, the authors suggested providing useful information and feedback at appropriate times throughout a program, as it will be beneficial to older adults (DG 7.6). On a similar note, Fernandez-Cervantes et al. (2018) stated that feedback must be timely and contextual, as continuous feedback on performance can be overwhelming and eventually ignored (DG 7.7). They further suggested that multiple alternative information-communication channels must be supported for older adults such as both written and spoken instructions (DG 7.19). Similarly, Nawaz et al. (2014) suggest providing a clear indication of expected results and health benefits that can be achieved by playing as the elderly participants were interested to know more information regarding specific health effects and outcome of the exercises (DG 7.15).

Gerling et al. (2012) stated that integrating continuous tutorials and player prompting facilitates gesture learning and interaction (DG 7.3). The authors suggested doing so by integrating continuous tutorials and player prompting. They stated that extended tutorials are necessary to ensure that players have enough time to learn the skills needed to play the game. In addition, they stated that some older adults suffer from reduced attention span and hence, to grasp their attention, games should visually and audibly prompt the user if no interaction is detected. The authors added that it should never be assumed that players are capable of knowing when actions are required, and hence continuous prompting for correct input is necessary. On a similar note, Fernandez-Cervantes et al. (2018) stated that because many older adults experience deteriorated peripheral vision, information around the edge of the screen, or in many different places may be ignored, and therefore recommended that all important information should be communicated consistently and promptly (DG 7.18).

Similarly, with respect to communicating to the players, Uzor and Baillie (2014) identified in their study that giving players a motivational boost encouraged them to maintain the exercise program, and that if exergames are tailored to rehabilitation exercises with progress modeled on exergame scores, then an improvement in score corresponds to improved physical functioning. Therefore, the authors suggested communicating progress to give participants a motivational boost (DG 7.4). The authors stated that this can be accomplished through scoring systems within the game. On the other hand, Pyae et al. (2016b) stated that progress in the game should be more simple and meaningful than scores, without offering any further explanation (DG 7.14). Pyae et al. (2016a) additionally suggests that simple and effective audio feedback must be provided as excessive audio feedback can distract older adults from their gameplay (DG 7.16).

With respect to designing specific sports-training games, Jensen et al. (2015) stated that introducing points in training exercises without reducing sport relevance can motivate players to exert themselves in training sessions without influencing the sport relevance in a negative way (DG 7.11). The study illustrated that introducing a competitive element caused players to perform detrimental movements, deviating from regular handball movements just to gain higher scores. The authors believed that one way of tackling this situation would be to frame the game as training and reward optimal performance, so that players remain in a training mindset and exert themselves as necessary without reducing movement specific to the sport.

Regarding the types of feedback that should be avoided, Wiemeyer et al. (2015) suggested that in full-body games, negative feedback should be avoided and that instead specific positive feedback should be provided (DG 7.12). Furthermore, the authors suggested that designers should avoid schematic and generic positive feedback, and instead to provide realistic, specific, and individually tailored feedback (DG 7.13). Though the authors provided specific feedback guidelines, they did not further provide any rationale for why or how the guidelines could be implemented.

5.8 Player Agency and Customization

Table 13 presents the guidelines related to *Player agency and customization*, which provide advice on how players can be given control over certain game aspects for the purpose of tailoring to individual needs and desires.

Table 13: Guidelines for Player agency and customization

8. Player agency and customization			
Guideline	Rationale	Study Context	Game(s)

8.1	Enable choices where necessary (Uzor and Baillie, 2014)	There were aspects of the exergame that users felt could benefit from customized options such as music, collectable objects and background	Randomized control trial with community dwelling older adults	Customized fantasy fall rehabilitation games
8.2	Provide players with choices (Jensen and Grønbæk, 2016)	Players can choose themselves whether they would like to balance the game and how skill level should influence gameplay	User study with people aged 14–54 at a sporting resort	Customized handball game
8.3	Consider timing for the type of agency provided (Richards and Graham, 2016)	Granting players strategic agency would be inappropriate while they are actively exercising, because they would have to divide their attention between strategizing and performing the exercise safely	Laboratory based user study with University students	Customized muscle strengthening game
8.4	Illusion of agency can be combined with real agency (Richards and Graham, 2016)	Seeing through the illusion can change the way a player interacts with a game	Laboratory based user study with University students	Customized muscle strengthening game
8.5	Exploit agency to improve form and prevent injury (Richards and Graham, 2016)	Games should go beyond simple extrinsic rewards for correct movements	Laboratory based user study with University students	Customized muscle strengthening game
8.6	Provide game calibration and customization (Pyae et al., 2017)	To meet the needs of elderly peoples' abilities in physical movements	Usability test with older adults in an elderly service home	Customized skiing game

Richards and Graham (2016) provided three guidelines with respect to *Player agency and customization.* First, the authors recommended considering timing for the types of agency provided, as it is difficult for people to perform cognitive tasks while actively exercising (DG 8.3). The authors rationalized this by stating that granting players strategic agency would be inappropriate while they are actively exercising, because they would have to divide their attention between strategizing and performing the exercise safely. Second, the authors stated that illusion of agency can be combined with real agency (DG 8.4). An illusion of agency may be provided to meet the exercise constraints, but they also warned designers that the guideline must be crafted carefully so that it does not diminish the game experience, and that seeing through the illusion can change the way players interact with the game. Finally, Richards and Graham suggested exploiting agency to improve form and safety (DG 8.5). The authors stated that people have real-world choice when it comes to exercise, namely gym settings, but many people choose to perform them poorly. The authors stated that a real-world agency can be exploited to have consequences in-game, with the dual benefit of increasing players' perception of control and encourage correct form. However, games should go beyond simple extrinsic rewards, such as simply being awarded points for correctly performed movements. Furthermore, Jensen and Grønbæk (2016) stated that providing players with choices during gameplay (DG 8.2) enables them to decide if they want to balance a game at all and if so, which kind of balancing they prefer based on their skill level.

With regards to designing for older adults, Uzor and Baillie (2014) stated that there are certain aspects of exergames that need to be static, such as the core mechanic, as this must emulate the exercise that the game is modelled upon. However, the authors stated that there are other aspects of exergames that their participants felt could benefit from customized options, such as music, collectible objects, and background elements. Hence, the authors stated that designers should enable choices where necessary while maintaining the core mechanics, since people have different tastes, and prevent users from losing interest in the game over time (DG 8.1). In this regard, Pyae et al. (2017) suggested providing game calibration and customization to meet the needs of elderly peoples' abilities in physical movements (DG 8.6).

5.9 Exertion

The following section describes the guidelines related to exertion, or the use of energy in players of full-body games. Table 14 presents the guidelines for *Exertion*. The majority of guidelines in this category were derived from studies performed with older adults (e.g., Gerling et al. (2012) , Barenbrock et al. (2014), and Velazquez et al. (2017)). Hence, the recommendations offered are particularly relevant when designing for this user segment.

Table 14: Guidelines for Exertion

9. Exertion				
Guideline		Rationale	Study Context	Game(s)
9.1	Provide exertion management by appropriate game pacing (Gerling et al., 2012)	Due to the prevalence of sedentary lifestyles, institutionalized older adults often have a reduced stamina level and are much more prone to movement-based injury and overexertion	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game
9.2	Prevent overexertion (Barenbrock et al., 2014)	Games that require a lot of concentration are exhausting for older adults	Qualitative field study at home with healthy older adults	Commercial sport, dancing, and virtual twister games
9.3	Control the perceived exertion according to gamers' motion capacities (Velazquez et al., 2017)	Studies show that using the classification of the motion capacity facilitates establishing a time-of-exercise aimed at avoiding excessive strain or risky situations	Exergaming interventions and focus groups with older adults in a hospital	Commercial sport games

9.4	[Utilize] motion benefit for perceiving exertion (Velazquez et al., 2013)	Fitness benefit can be changed to motion benefit for older adults; older adults' perceived exertion does not necessarily require a high intensity exercise	Action research study with specialists in aging and healthy older adults	Commercial sport games
9.5	Implement fatigue as an intentional game challenge (Isbister and Mueller, 2015)	Movement results in fatigue that can be both positive and negative for the player; intend fatigue if used as a game challenge, but avoid it if it is not part of the game	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users

Based on user evaluations with institutionalized older adults, Gerling et al. (2012) emphasized the importance of providing fatigue management and preventing overexertion by appropriate game pacing (DG 9.1) as older adults often have reduced endurance level and are prone to movement-based injury and overexertion. Hence, the authors stated that games need to manage player fatigue through appropriate pacing, example by alternating physically intense and less challenging game periods that allow players to relax and recover. Similarly, Barenbrock et al. (2014) also highlighted that motion-based games should prevent overexertion and not overstrain the player physically or mentally (DG 9.2). The study identified that games which require a lot of concentration are particularly exhausting for older adults and can lead to overexertion. Velazquez et al. (2017) recommended controlling perceived exertion according to gamers' motion capacity, as it was identified that correctly classifying gamers' mobility helped to gradually increase perception of exertion and health benefits without any health risks (DG 9.3). Velazquez et al. (2013) stated that fitness benefit can be changed to motion benefit for older adults, as perceived exertion does not necessarily require a high intensity exercise (DG 9.4). The study recommended using casual exergames to evaluate, warm up, and restrain older adults in more intense challenges. It is also stated that some signals of tiredness or loss of balance can be detected visually, for instance limb shaking or outbreak to fall, which should not be ignored.

Isbister and Mueller (2015) provided generic guidelines for designing movement-based games and suggested using fatigue intentionally as a game challenge rather than incidental (DG 9.5). As movements often result in fatigue, it can either be a welcomed challenge for players if wanting to manage it (e.g., in an endurance sport), or it can negatively affect engagement if the game gets too hard to play. Isbister and Mueller (2015) further identified that fatigue can be minimized by creating short game cycles, have variation in movements, or by distracting players from fatigue through for example the use of music.

The guidelines provided with respect to exertion provide recommendations to design for safe gameplay experience by taking into consideration and controlling the exertion of players (DG 9.1–9.4), as well as how exertion can be used to manipulate the game challenge (DG 9.5).

5.10 Safety

Table 15 presents the guidelines sorted under the category *Safety*. These guidelines describe measures that can be taken to ensure that an environment or a physical gaming area is suitable for physical activity to reduce the risk of physical injury during gameplay.

Table 15: Guidelines for Safety

10. Safety

Guideline		Rationale	Study Context	Game(s)
10.1	Prevent health risks and injuries (Barenbrock et al., 2014)	While most healthy people can assess risks quite well, supervision is valuable for the target group	Qualitative field study at home with healthy older adults	Commercial sport, dancing, and virtual twister games
10.2	Promote safety during gameplay (Pyae et al., 2017)	Many elderly participants expressed concern about falling during gameplay	Usability test with older adults in an elderly service home	Customized skiing game
10.3	[Provide] a secured game interface (Wiemeyer et al., 2015)	To adapt for persons with disabilities	Group discussion with experts in exergame design for persons with disabilities	Not based on game evaluation with users
10.4	Exploit physical risk sensibly (Isbister and Mueller, 2015)	Movement has an inherent sense of risk associated with it, and with risk also comes a sense of thrill, which can contribute positively to the game experience	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users

One of the potential benefits of full-body games is that they can be used as a mean to increase physical activity and exercise in a home environment. However, movement, especially in everyday indoor environments, has an inherent sense of risk associated with it such as risk of hitting furniture or other people that can lead to injury. However, Isbister and Mueller (2015) stated that with risk comes a sense of thrill, which can contribute positively to the game experience, and movement-based games should exploit this risk (DG 10.4). It is, however, important to inform players of the risk involved in a gaming activity and consider the environment while exploiting the potential physical risk. They also recommended to let players' movements interfere with each other to facilitate body contact, always having the safety of the players in mind.

Similarly, playing with others or having a supervised gameplay was identified to be valuable for the senior user group. Based on studies with healthy older adults, Barenbrock et al. (2014) advised designers to take measures to prevent health risk and injuries in players during gameplay, particularly when motion-based games are used unsupervised (DG 10.1). Barenbrock et al. (2014) further stated that sensor technology can be used to facilitate gaming (e.g., biometric measures, camera observation) and help trigger for instance an emergency call in the case of a fall. Pyae et al. (2017) stated that safety in gameplay is highly important as most of the participants expressed concerns about falling during gameplay (DG 10.2). In addition, Wiemeyer et al. (2015), who based their guidelines on a group discussion with experts working in the field of exergaming and rehabilitation, recommended securing the game interface, for example by providing a handrail around a balance board (DG 10.3).

Even though risk might enhance movement in some populations, ensuring safety during gameplay is crucial if full-body games is to be used in a home setting, especially with older adults or people with an acquired disease. When using these games, one must anticipate potential risks with reference to established best practice including risk assessment, health and safety, and legal liability guidelines to ensure movement quality and quantity of activity.

5.11 Universal Design

Table 16 presents various guidelines for *Universal design*. These guidelines provide advice on how to design full-body games so that they can be accessed, understood, and played by a number of user segments, including older adults and groups that have little or no experience with interactive technology.

Table 16: Guidelines for Universal design

11. Universal design				
Guideline		Rationale	Study Context	Game(s)
11.1	Design with good colors and contrast (Brox at al., 2017)	Eyesight naturally deteriorates with age	Usability test with older adults in a senior center	Commercial fantasy game
11.2	Provide large menu buttons with distance between each other (Brox at al., 2017)	Eyesight naturally deteriorates with age	Usability test with older adults in a senior center	Commercial fantasy game
11.3	Volume should be the same for all sounds (Brox at al., 2017)	Sound was in some cases disturbing during the study	Usability test with older adults in a senior center	Commercial fantasy game
11.4	Provide thick, clear font (Brox at al., 2017)	Eyesight naturally deteriorates with age	Usability test with older adults in a senior center	Commercial fantasy game
11.5	[Provide] simple setup routines (Gerling et al., 2012)	Technical knowledge cannot be assumed for either institutionalized older adults or nursing staff	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game
11.6	Allow for navigation while sitting or standing (Gerling et al., 2010)	Players must be able to choose an adequate interaction scenario	Focus group test with older adults in a nursing home	Customized balance game
11.7	[Promote] age-inclusive design (Gerling et al., (2012)	Embrace age-related physical and cognitive impairments that is common for institutionalized older adults	User evaluations with institutionalized older adults in a nursing home	Customized gesture-based game
11.8	Provide age-appropriate music for elderly users, and the music should fit the aim of the game or the movements performed (Nawaz et al., 2014)	The elderly did not like the music and background noise in the three game systems	Workshops with older adults in a senior center	Commercial sport, fitness, and balance games

11.9	Avoid small details (Brox at al., 2017)	Small details are lost on people who do not see well.	Usability test with older adults in a senior center	Commercial fantasy game

Promoting an age-inclusive design was identified as a common base line among all the guidelines within this category as the guidelines were all extracted from studies performed with older adults. Having age-inclusive designs were highly emphasized by Gerling et al. (2012), Harrington et al. (2015), and Brox et al. (2017). Both physical and cognitive decline is common for institutionalized older adults which can strongly influences game interaction. Therefore, Gerling et al. (2012) recommended having systems that account for this decline by offering simple game structures to accommodate cognitive changes and offering gestures that adapt to each player's individual impairments (DG 11.7). They also suggested promoting easy menus, and simplified startup and shutdown routines to encourage independent gameplay among older adults (DG 11.5) as technical knowledge cannot be assumed among either institutionalized older adults or nursing staff. In Gerling et al. (2010), the authors recommended having interaction mechanisms that allow for navigation while sitting or standing, so that players can choose an adequate interaction scenario (DG 11.6). Additionally, they suggested that along with foot-based input, using the players' hand and arms may be appropriate to reduce access barriers for persons using wheelchairs.

With regard to colors and contrast, Brox et al. (2017) recommended that as eyesight deteriorates with age, more light is needed with a reduced variety of colors, and that graphics should be bright with good contrast (DG 11.1). Further, the authors stated that large menu buttons should be provided, with enough distance between them (DG 11.2) and that small details are lost on people who do not see well and hence suggested avoiding small details (DG 11.9). They further recommended using big, thick, and clear text (DG 11.4), that less text is better, and that the placement of the text on the screen plays an important role.

Brox et al. (2017) also stated that sound was identified to be disturbing by older adults in some cases during their study, and hence the authors suggested providing uniform volume for all sounds in the game (DG 11.3). Similarly, Nawaz et al. (2014) recommended providing age appropriate music for elderly users such that the music also fits the aim of the game and the movements performed (DG 11.8).

The above guidelines indicate the importance of diverse factors such as interface design, interaction mechanisms and communication in promoting an age inclusive design.

5.12 Social Aspects

Interestingly, Table 17 presents a single guideline corresponding to *Social aspects*. The guideline is related to the social factor and offers a suggestion concerning the social environment in which gameplay occurs.

Table 17: Guidelines for Social aspects

12. Social aspects				
Guideline		Rationale	Study Context	Game(s)
12.1	Facilitate social fun (Isbister and Mueller, 2015)	Moving with others is fun	Semi-structured interviews with movement-based game design experts	Not based on game evaluation with users

Even though the social aspect of a game, e.g., the ability to play, interact, and compete with others, is a major attraction for all gamers, Isbister and Mueller (2015) is the only paper presenting a guideline with the social aspect in mind. They suggested facilitating social fun by making movement a social experience, as moving with others can be perceived as fun (DG 12.1). Hence, the authors suggested a multiplayer design that includes other players and audience by making the game easy to learn by observation, and potentially turning bystanders into players.

However, in section 5.6 “Game Challenge” balancing mechanisms in games have been recommended as a way to increase game challenge (DG 6.9, 6.19, 6.13, 6.14, 6.15). These guidelines might also be a way to increase social aspects as balancing of games often deals with a multiplayer feature.

6 Emerging Concerns

Having systematically categorized and reviewed existing guidelines for the design of full-body interactive games, we now turn our attention to what we see as overarching concerns given the state of the art.

- The Hedonic–Utilitarian Divide in Movement-Related Guidelines
- The Lack of a Common Structure for Specifying Design Guidelines
- The Lack of Systematic Development of Design Guidelines
- Validity
- The Limited Focus on Tangible User Interfaces

6.1 The Hedonic–Utilitarian Divide in Movement-Related Guidelines

During the last decade, a new form of interactive gaming that requires physical body movements to play computer games has emerged, often referred to as full-body games or exergames. One of the main advantages of full-body games is the potential to provide both fun and utility for the users to engage in physical activity. Therefore, full-body games can be used for hedonic reasons, such as entertainment or fun, or for utilitarian reasons, such as rehabilitation and exercise, or for both.

If we take a closer look at the categories in the current review that offer guidelines for how a full-body game can influence the way players use their bodies during gameplay (i.e., *Movement elicitation*, *Mapping of movement* and *Explicit movement guidance*), we find that the relevant guidelines tend to address these two different objectives: (1) how to utilize body movements to promote positive player experiences (Isbister and Mueller, 2015) and (2) how to design with the intention of helping players achieve desirable health-specific effects from gameplay (Nawaz et al., 2014; Skjæret et al., 2014). These two objectives correspond to the *hedonic* and *utilitarian* aspects of game design (Kari, 2017). Below, we elaborate the two groups of guidelines further and discuss concerns related to imbalances and contradictions that may exist between them.

Many of the guidelines listed under the category *Movement elicitation* in Table 6 (i.e., DG 1.1–1.5 and 1.11) give suggestions for hedonic gameplay and how one can design for positive player experiences in full-body games. In general, these guidelines appear to point toward the importance of encouraging movements that are perceived by the player as unrestrictive and “natural” during gameplay, thereby encouraging explorative rather than strictly choreographed gameplay. For instance, Pyae et al. (2017) recommended that players should be able to interact with a game using movements that they are likely to already be familiar with through activities such as sports and daily life (DG 1.2). The suggestion to embrace the natural expression of movements and not to curtail individual self-expression in movements was also emphasized by Isbister and Mueller (2015) (DG 1.3 and 1.4), who stated that embracing ambiguity of movement is necessary, as forcing precision may only frustrate the players. Interestingly, these two articles are based on entirely different study contexts. As Pyae and colleagues (2017) based their studies with healthy older adults, Isbister and Mueller (2015) are presenting findings from long-term collaboration with design experts. This highlights the importance of enjoyment behind the usage intentions and the actual use of full-body games as an exercise tool, disregarding age and function of the intended users.

While most of the movement-related guidelines in the reviewed articles gave advice on how to design for enhanced player experiences *during* gameplay, the guidelines offered by Skjæret et al. (2014); Uzor and Baillie (2014) provided (utilitarian) recommendations for how full-body games can be designed to elicit player movements associated with health-specific effects. Interestingly, these guidelines derive from work with older adults specifically. However, even though several studies have found positive health effects of full-body usage, few games have been designed exclusively for specific physical functions or movement characteristics with utilitarian reasons in mind. Gaining long-term exercise adherence is difficult for persons of all ages, and adherence to exercise programs is generally low, with estimates suggesting that as many as 50% drop out in the first 3–6 months (Dishman, 1988). Enjoyment or interest in exercise benefits (White et al., 2005), as well as intrinsic motivation and satisfaction of basic needs (Duncan et al., 2010) are predictors of adherence to exercise. Previous research also pointed out that hedonic enjoyment perceptions have a stronger effect on attitude towards using full-body games compared to utilitarian perceptions of physical fitness promotion (Kari and Makkonen, 2014; Lin et al., 2012), which in turn might be the reason most guidelines focus on this aspect.

Other movement-related design guidelines that concern the health effects of gameplay include more safety-oriented guidelines, such as DG 1.12, 1.13, and 1.14. These guidelines draw attention to how game-related movements, in some cases, may present a safety hazard for players (with specific reference to older adults) and hence should be avoided. As there is limited evidence to assess where the use of full-body games is a safe tool of activity for older adults, measures to ensure safety during game play should be of high priority when designing these games.

Given the two "silos" that current design guidelines fall under, we see two main concerns. First, if we take the envisioned health benefits of full-body games into regard (e.g., (Li et al., 2018; Rosenberg et al., 2019; Staiano and Calvert, 2011)), the status quo suggests that there are currently few design guidelines that focus on health effects and that consequently can help realize these visions. Consequently, it can be argued that the existing body of design guidelines for full-body games suffer from a lack of specific clinical relevance for health and rehabilitation interventions.

Second, we see potential contradictions between the utilitarian and hedonic design guidelines, particularly when applied to the design of health interventions. While many of the guidelines addressing hedonic aspects of game design can be considered relevant for ensuring user acceptance and, hence, contribute indirectly to fulfilling a utilitarian (health) purposes, one should be aware of possible tensions. For example, by offering freedom of movement (DGs 1.1, 1.3, and 1.4) in a full-body game, with the intention of enhancing a player's immediate game experience, one also risks opening up for movements that are inefficient in terms of yielding desirable health effects—if the goal is to design for balance training, then movements that do not produce weight-shift in players during gameplay might be undesirable (DG 1.6). Similarly, there may be contradictions between freedom of movement and safety-oriented guidelines (DG 1.12, 1.13, and 1.14). The exemplified contradictions may be seen as a consequence of guidelines having been derived from different contexts, for example a physical rehabilitation context with older adults (Skjæret et al., 2014) versus a recreational context with young adults (Jensen and Grønbæk, 2016). Based on the above, we recommend that designers and developers of full-body games be mindful about potential conflicts between guidelines serving hedonic and utilitarian purposes, as well as designing for different generations.

For HCI and design of full-body games, we consider the two concerns raised above to represent new and interesting research possibilities. The lack of guidelines for how to design for specific movement qualities that can yield positive health effects is one (interdisciplinary) area of opportunity in this regard. Another research opportunity lies in bridging the hedonic–utilitarian divide that characterizes the existing body of design guidelines, that is, designing both for positive long-lasting player experiences and desired health effects from gameplay.

6.2 The Lack of a Common Structure for Specifying Design Guidelines

The conducted review revealed that the way design guidelines for full-body games are specified in the literature varies considerably. Some guidelines, such as those proposed by Isbister and Mueller (2015) (DGs 1.3, 1.4, 1.5, 2.1, 5.3, 7.8, 7.9, 7.10, 9.5, and 10.4), are presented in a structured format, with rich descriptions that specify elements such rationale, examples of use, strategies for designers, "do's and don'ts", references, and HCI relevance. The majority of reviewed guidelines, however, are presented in a more unstructured manner, often without the provision of a clear rationale, examples of practical implementation, or a description of how a specific guideline relates to others. We consider such "thin" specifications to reduce the credibility of a guideline and also to have practical consequences due to the limited advice provided on how it can be implemented. As such, the lack of consensus in the relevant literature on how to specify design guidelines for full-body games risks watering out the main purpose of design guidelines, that is, to clearly communicate recommendations for good practices in design (Interaction Design Foundation, 2019).

The way inconsistent structures and other format issues can reduce the usability of design guidelines have been discussed in earlier HCI research (Cronholm, 2009; Huhn, 2010). Given the focus of the current study, we find it relevant to specifically call attention to consequences inconsistent guidelines structures can have with respect to design of full-body games. Below, we highlight three relevant issues.

First, and as elaborated further in Section 6.3, we consider the lack of a common specification format a key barrier that prevents the *systematic* development of design guidelines for full-body games. This in turn may explain why several guidelines for full-body games appear to replicate guidelines that have existed for years.

Second, we consider the absence of a common structure to reduce the likelihood that central aspects pertaining to a specific guideline, for example information about the context from it has been derived, is sufficiently communicated. With respect to design guidelines for full-body games, context information is particularly relevant as design knowledge derived from one context is not automatically transferable to another. For example, recommendations that advocate freedom of movement and which typically have been derived from studies involving recreational full-body games, may have to be applied more cautiously in full-body games design for rehabilitation contexts. Naïve application of guidelines derived from other context may have undesirable effects.

Third, inconsistency in the structure of design guidelines for full-body games is also problematic in light of the to the complexity of factors that designers are likely to have to deal with. In the current review, we identified a large variety of issues pertaining to different aspects of the game and the game experience (cf. Tables 6–17). Compared to the more well-defined and usability-oriented sets of guidelines and principles proposed by Norman (2013), Nielsen (1993), and Shneiderman (1997), design guidelines for full-body games form a relatively large and highly unstructured network of design insights. The inconsistency in the format of design guidelines arguably makes this network less accessible and more challenging to navigate.

While identifying an ideal format the specification of full-body game design guidelines is beyond the scope of this work, we consider the pattern-inspired format adopted by Isbister and Mueller (2015) to be more in line with earlier definitions of what design guidelines are and what they should contain (Fu et al., 2016; Nowack, 1997). However, to benefit designers we argue that it is important to understand full-body game designers' needs and behavior in dealing with design guidelines. This argument is very much in line with the motivation underlying Huhn's (2010) observational study of designers' behaviors when developing online shopping sites. The study was conducted with the intention of informing the organization of relevant guidelines. To our knowledge, no similar studies addressing the organization of design guidelines for full-body games have been conducted.

6.3 The Lack of Systematic Development of Guidelines

As described earlier, full-body games are first and foremost characterized by the way the body is both a medium of interaction and also at the heart of the user or player experience. However, we found that the majority of the reviewed guidelines (i.e., categories 4–12) were neither concerned with movement as a design element nor strictly limited to movement-based applications (such as full-body games). For example, most guidelines listed under the category *Universal design* (e.g., DGs 11.1, 11.2, and 11.8) are highly generic, and hence potentially applicable to several other types of applications. Similarly, the larger portion of guidelines listed under the category *Feedback on player performance* (e.g., DGs 7.1–7.8, 7.12, 7.13, and 7.14, 7.16, 7.17, 7.18, 7.19) can be considered relevant for motivating not only players of full-body games, but also users of, for example, behavior change technologies. The same generalizability also applies to many of the guidelines grouped under the category *Game challenge* (e.g., DGs 6.1, 6.2, 6.4, 6.5, 6.6, 6.10, and 6.11).

While a generic and varied set of design guidelines (addressing many aspects of design) may initially be considered to form a rich "toolbox" for designers of full-body games, we were surprised to find that many of the guidelines related to the three categories mentioned above are to a large extent repeating the essence of guidelines published in earlier work. For example, the guidelines listed under the categories *Universal design,* *Feedback on player performance,* and *Attention* are to a large extent covered by the seven principles of universal design and work by Honeywell (1992); Story (1998). We also found large overlaps between several guidelines reviewed as part of the current study. Examples of such overlaps can be found between DGs 9.1 *Provide exertion management*, 9.2 *Prevent overexertion*, and 9.3 *Control perceived exertion* which essentially convey the same message. Similarly, DGs 10.1 *Prevent health risks and injuries,* 10.2 *Promote safety during gameplay,* and 10.4 *Exploit physical risk sensibly* convey similar meaning.

We see two main problems related to the relatively large number of "replicated" guidelines in the reviewed studies. First, the observation arguably questions the novelty of some of the insights the corresponding studies contribute. This is *not* to say that reproducing research result on which existing design guidelines are based is without value—As further discussed in the next subsection, the limited evidence that many design guidelines for full-body games appear to be based on is a considerable validity problem. From such a perspective, it can even be considered highly beneficial to see similar design lessons arise from comparable studies. In addition, we recognize that the application of design guidelines in various contexts may potentially create opportunities for new interpretations, which again may complement existing guidelines. When we question the research value of studies that close to replicate existing guidelines, we mean first and foremost the problem that the study that originally produced the guideline often is not discussed in the "replicating" study.

Second, and perhaps more dire, the replication of guidelines strongly suggests that there is a lack of systematic development of design guidelines for full-body games. The absence of a common guideline format (see above), can in many ways be seen as a key barrier preventing such a development, as it makes it more challenging to identify, compare, and relate guidelines found in the literature. This situation makes it particularly challenging to build a structured network of guidelines that can be easily extracted and navigated, and seriously compromises the quality of the corpus of relevant design guidelines as a whole. However, while a common guideline format might help the situation, we consider it equally important that review processes of work that offer new design guidelines thoroughly scrutinize how proposed recommendations fit into the network of existing ones described in related work. For the design of full-body interactive games, this means that the quality of the evolving body of design guidelines is in part a responsibility of the associated design community.

6.4 Validity

The reviewed design guidelines were derived from studies that employed different research methods (Table 3) and which were highly diverse, for example, in terms of number of conducted assessments, duration per assessment and number of participants (Table 5). The variations described above raise an interesting issue concerning what is required in the context of full-body games for a design recommendation to qualify as a guideline. As long as there is no formal definition of the quality requirements of a guideline for the design of Human–Computer interfaces in general, the validity of existing design guidelines for full-body games is likely to be highly ambiguous. Given these concerns, we consider the majority of guidelines presented in the reviewed articles to form candidate guidelines rather than proven best practices in design. As a consequence, the guidelines should be used with caution.

6.5 The Limited Focus on Tangible User Interface

Another noteworthy finding from the literature review is that the vast majority of identified guidelines were derived from studies of full-body games where large displays (e.g., TV-screens and projected screens) played a central role in player–game interaction. The high representation of screen-based solutions raises issues concerning the practical use value of some of the produced guidelines. First, many of the guidelines, for example those concerning the use of animations, avatars, and text (DGs 2.2, 3.2, 4.1, 4.2, 4.3, 5.10, 11.4, and 11.9) will only be applicable in the design of games that actually make use of large displays as the primary output channel.

Second, and more importantly, the limited attention paid to non-screen-based full-body games indicates that there is a potential gap in the existing body of design guidelines. While design guidelines derived from screen-based full-body games (e.g., DGs 5.5, 5.6, 5.7, and 5.8) in many cases can also be applicable also in the design of games that employ tangible user interfaces, new generalizable design knowledge might also be derived from studying non-screen-based games. Isbister and Mueller's (2015) recommendation to *Focus on the body and not the screen when designing player feedback* (DG 7.9) is an example of a design guideline, which was derived in part from studies involving the use of a non-screen-based game, *i-dentity* (Garner et al., 2014; 2013). Other recommendations Isbister and Mueller (2015) offer, which partly build on insights from studying players interacting with non-screen-based games are *Support players in expressing themselves using their bodies* (DG 1.3) and *Exploit physical risk sensibly* (DG 10.4). For both these design guidelines, the game *JS Joust* (Fabrik) is given as an example of implementation. In both *i-dentity* and *JS* joust, Sony Move controllers are used as I/O technology (Mueller and Isbister, 2014). Moreover, Isbister and Mueller's guideline *Help players identify rhythm in their movements* (DG 1.5) appears to draw on lessons learned from the face-to-face interaction clapping game *Mary Mack 5000* (Abe). In the game, sound (rhythm) plays an important complementary role to screen-based (visual) output by helping two collaborative players synchronizing hand clapping (Mueller and Isbister, 2014). The examples provided above illustrate how studies of full-body games employing alternative or additional output media to large displays may offer novel design insights.

7 Methodological Considerations

In the current study, we have synthesized and provided a systematic review of existing design guidelines for full-body games. As with all structured SLRs, the picture that is painted of the topic in focus is colored by aspects pertaining to the applied method. Hence, we find it relevant call into attention some methodological considerations that has influenced the status the current work gives of full-body games and relevant design guidelines.

First, inclusion of an article in the SLR was dependent on the abstract of that article specifying that design guidelines (or equivalent terms) for body-controlled games was a main scientific outcome. As mentioned earlier in the paper, this means that papers providing other forms of design knowledge or *guidance*, have not been included. Hence, it is important to understand that the current review does not present a status of all available design knowledge relevant for full-body games, but only reports on the body of research literature providing explicit recommendation for design of such applications. Using a relatively complex search string to gather relevant articles also meant that we retrieved a broad range of design guidelines that had been derived from studies with different focal points and designs targeting different user (player) groups. It is also worthwhile to note that while we focused on reviewing research articles explicitly offering design guidelines as the main outcome of the described study, we did not distinguish between the variety and quality in the formatting of the guidelines, i.e., the structure used in the individual papers to describe the guidelines.

Second, it is important to note that the categorization of identified guidelines (Tables 6–17) was based on our (the authors') interpretation of the guidelines. While we attempted to ensure consistency in our grouping through internal discussions and constant reassessments of the categories as they were expanded with new guidelines, the final result should not be regarded as a "blueprint" or an attempt to standardize categorization of design guidelines for full-body games. The categories are in other words a result of the authors' sense-making of the existing corpus of relevant recommendations.

Third, we recognize that our relatively broad coverage of design guidelines and the way we categorized them may to some extent also have affected the concerns we identified and discussed in Section 6. For example, the hedonic–utilitarian divide in movement-related guidelines (Section 6.1) can be seen as a result of this comprehensive coverage. The lack of systematic development of guidelines (Section 6.2), again, is to some degree an issue that emerged as a result of our interpretation and grouping of design guidelines, i.e. we became gradually aware of the issue through the grouping process. Thus, the emerging list of concerns is neither exhaustive nor complete, but rather a consequential result of the aspects pointed out above.

8 Conclusions

In light of the increasing attention that the design and use of full-body interactive games have gained in HCI and game design research in recent years, we assessed the present state of design guidelines for such applications through a systematic review of existing literature. A total of 22 articles were included from an initial 3,562 retrieved references. The review resulted in the extraction of 107 design guidelines, which were further sorted into twelve different categories and accounted for. The twelve categories were: *Movement elicitation, Mapping of movement, Explicit movement guidance, Player representation and game world, Attention, Game challenge, Feedback on player performance, Player agency and customization, Exertion, Safety, Universal design,* and *Social aspects*.

The broad range of categories suggests that the existing body of design guidelines for full-body interactive games cover many relevant design aspects. As such, the current work offers a comprehensive overview of both challenges related to design of full-body games and possible ways to cope with the same challenges. At the same time, the review revealed a number of overarching concerns regarding the present state of the same body. These concerns were related to (1) the hedonic–utilitarian divide in movement-related design guidelines relevant literature; (2) the lack of common structure for specifying guidelines; (3) the lack of systematic development of guidelines; (4) issues related to the validity of existing guidelines; and (5) the limited focus on tangible interfaces in the present state of the art.

In conclusion, the current review paints a somewhat questionable picture of the present state of the corpus of design guidelines for full-body games, with relatively large differences in the quality of the guidelines proposed in the individual articles and a lack of reference to already existing guidelines. In the longer run, these quality issues risk watering out the original meaning of the term *design guideline*. Rather than communicating best practices in design—if we understand “best practices” as simple-to-follow, exemplified, justified, structured, validated, and well-explained recommendations—there is a danger that the concept of *design guideline* will be reduced to nothing more than a simple hypothesis about design, thereby losing its potential value in design of full-body interactive games. To counter such prospects, we encourage designers of full-body games, including both users and developers of design recommendations, to engage in the discourse on how we can ensure the usability and value of design guidelines.

Appendix 1

Search string used in the ACM Digital Library focusing on CHI proceedings over the last decade:
(Exergam* OR “Exertion gam*” OR “Multimodal gam*” OR “Exertion video gam*” OR “serious gam*” OR “exercise gam*” OR “movement-based gam*” OR “motion-control gam*” OR “motion-controlled gam*” OR “motion-based gam*”)

Appendix 2

The full query used to extract relevant studies for the review:
((Exergam* OR “Exertion gam*” OR “Multimodal gam*” OR “Exertion video gam*” OR “serious gam*” OR “exercise gam*” OR “movement-based gam*” OR “motion-control gam*” OR “motion-controlled gam*” OR “motion-based gam*”) AND (design* OR develop*) AND (consideration* OR recommend* OR guideline* OR suggestion* OR strateg* OR lessons))

REFERENCES

Abascal, J., and Nicolle, C. (2005). Moving towards inclusive design guidelines for socially and ethically aware HCI. *Interacting with Computers, 17*(5), 19.

Abe, K. Mary Mack 5000. Retrieved from http://kahoabe.net/?portfolio=mary-mack- 5000

Ahtinen, A., Huuskonen, P., and Häkkilä, J. (2010). *Let's all get up and walk to the North Pole: design and evaluation of a mobile wellness application.* Paper presented at the NordiCHI'10 Reykjavik, Iceland.

Altimira, D., Mueller, F. F., Lee, G., Clarke, J., and Billinghurst, M. (2014). *Towards understanding balancing in exertion games*. Paper presented at the Proceedings of the 11th Conference on Advances in Computer Entertainment Technology, Funchal, Portugal.

Amershi, S., Weld, D., Vorvoreanu, M., Fourney, A., Nushi, B., Collisson, P., Suh, J., Iqbal, S., Bennett, N. P., Inkpen, K., Teevan, J., Gil, K. R., and Horvitz, E. (2019). *Guidelines for Human-AI Interaction.* Paper presented at the Human Factors in Computing Systems, Glasgow, Scotland UK.

Bamparopoulos, G., Konstantinidis, E., Bratsas, C., and Bamidis, P. D. (2016). Towards exergaming commons: composing the exergame ontology for publishing open game data. *Journal of Biomedical Semantics, 7*(1), 15.

Barenbrock, A., Herrlich, M., and Malaka, R. (2014). *Design lessons from mainstream motion-based games for exergames for older adults.* Paper presented at the 2014 IEEE Games, Media, Entertainment (GEM) Conference, 22-24 Oct. 2014, Piscataway, NJ, USA.

Benyon, D. (2013). *Designing Interactive Systems: A comprehensive guide to HCI, UX and interaction design*: Pearson.

Berkovsky, S., Coombe, M., Freyne, J., Bhandari, D., and Baghaei, N. (2010). *Physical activity motivating games: virual rewards for real activity.* Paper presented at the Conference on Human Factors in Computing Systems, Atlanta, Georgia, USA.

Bianchi-Berthouze, N. (2013). Understanding the Role of Body Movement in Player Engagement. *Human-Computer Interaction, 28*(1), 40-75.

Brittin, J., Sorensen, D., Trowbridge, M., Lee, K. K., Breithecker, D., Frerichs, L., and Huang, T. (2015). Physical Activity Design Guidelines for School Architecture. *PLoS One, 10*(7).

Brox, E., Konstantinidis, S. T., and Evertsen, G. (2017). User-Centered Design of Serious Games for Older Adults Following 3 Years of Experience With Exergames for Seniors: A Study Design. *JMIR Serious Games, 5*(1), e2. doi:10.2196/games.6254

Byrne, R., and Marshall, J. (2016). *Balance Ninja: Towards the design of Digital Vertigo Games via Galvanic Vestibular.* Paper presented at the CHI PLAY'16 Annual Symposium on Computer-Human Ineraction in Play, Austin, Texas, USA.

Clark, L., Doyle, P., Garaialde, D., Gilmartin, E., Schlögl, S., Edlund, J., Aylett, M., Cabral, J., Munteanu, C., Edwards, J., and Cowan, B. R. (2019). The state of speech in HCI: Trends, Themes and Challenges. *Interacting with Computers, 31*(4), 349-371.

Congdon, N., O'Colmain, B., Klaver, C., Klein, R., Munoz, B., Friedman, D. S., Kempen, J., Taylor, H. R., Mitchell, P., and Hyman, L. (2004). Causes and prevalance of visual impairment among adults in the United States. *Archives of Ophthamology, 122*(4), 477-485.

Consolvo, S., McDonald, D. W., Toscos, T., Chen, M. Y., Froehlich, J., Harrison, B., Klasnja, P., LaMarca, A., LeGrand, L., Libby, R., Smith, I., and Landay, J. A. (2008). *Activity sensing in the wild: a field trial of ubifit garden.* Paper presented at the CHI'08 Conference on Human Factors in Computing Systems, Florence, Italy.

Cronholm, S. (2009). *The usability of usability guidelines: a proposal for meta-guidelines.* Paper presented at the OZCHI: Australian Conference on Human-Computer Interaction (HCI), Melbourne, Australia.

Dishman, R. K. (1988). *Exercise Adherence: Its impact on Public Health*: Human kinetics books.

Doherty, K., and Doherty, G. (2019). Engagement in HCI: Conception, Theory and Measurement. *ACM Computing Surveys (CSUR), 51*(5), 39.

Dourish, P. (2001). *Where the acion is : the foundations of embodied interaction* Cambridge, MA, USA: MIT Press.

Duncan, L. R., Hall, C. R., Wilson, P. M., and Jenny, O. (2010). Exercise motivation: a cross sectional analysis examining its relationships with frequency, intensity and duration of exercise. *International Journal of Behavioral Nutrition and Physical Activity, 7*(1), 7.

Elnaggar, A., and Reichardt, D. (2016). *Digitizing The Hand Rehabilitation Using the Serious Games Methodology With a User-Centered Design Approach.* Paper presented at the 2016 International Conference on Computational Science and Computational Intelligence.

Fabrik, D. G. Johann Sebastian Joust. Retrieved from http://jsjoust.com

Fernandez-Cervantes, V., Neubauer, N., Hunter, B., Stroulia, E., and Liu, L. (2018). VirtualGym: A kinect-based system for seniors exercising at home. *27*, 60-72. doi:10.1016/j.entcom.2018.04.001

Fu, K. K., Yang, M. C., and Wood, K. L. (2016). Design Principles: Literature Review, Analysis, and Future Directions. *Journal of mechanical design, 138*.

Garner, J., Wood, G., Pijnappel, S., Murer, M., and Mueller, F. (2014). *i-dentity: innominate movement representation as engaging game element.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Canada.

Garner, J., Wood, G., Pijnappel, S., Murer, M., and Mueller, F. F. (2013). *Combining moving bodies with digital elements: design space between players and screens.* Paper presented at the Australian Conference on Interactive Entertainment: Matters of Life and Death, Melbourne, Australia.

Gerling, K., Livingston, I., Nacke, L., and Mandryk, R. (2012). *Full-body motion-based game interaction for older adults*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

Gerling, K. M., Schild, J., and Masuch, M. (2010). *Exergame design for elderly users: the case study of SilverBalance*. Paper presented at the Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology, Taipei, Taiwan.

Gong, J., and Tarasewich, P. (2004). *Guidelines for Handheld Mobile Device Interface Design* Paper presented at the DSI Annual Meeting.

Harrington, C. N., Hartley, J. Q., Mitzner, T. L., and Rogers, W. A. (2015). *Assessing older adults usability challenges using Kinect-based exergames.* Paper presented at the 1st International Conference on Human Aspects of IT for the Aged Population, ITAP 2015 Held as Part of 17th International Conference on Human-Computer Interaction, HCI International 2015, August 2, 2015 - August 7, 2015, Los Angeles, CA, United states.

Hawley-Hague, H., Boulton, E., Hall, A., Pfeiffer, K., and Todd, C. (2014). Older adults' perceptions of technologies aimed at falls prevention, detection or monitoring: A systematic review. *Int J Med Inform, 83*(6), 416-426.

Heinz, M., Martin, P., Margrett, J. A., Yearns, M., Franke, W., Yang, H. I., Wong, J., and Chang, C. K. (2013). Perceptions of technology among older adults. *Journal of Gerontological Nursing, 39*(1), 42-51.

Hernandez, H. A., Graham, N. T. C., Fehlings, D., Switzer, L., Ye, Z., Bellay, Q., Hamza, M. A., Savery, C., and Stach, T. (2012). *Design of an Exergaming Station for Children with Cerebral Palsy.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

Honeywell. (1992). Human Factors Design Guidelines for the Elderly and People with Disabilities*Revision 3*. Retrieved from

Höök, K. (2018). *Designing with the Body: Somaesthetic Interaction Design*.

Hornbæk, K., and Hertzum, M. (2017). Technology Acceptance and User Experience: A Review of the Experiential Component in HCI. *ACM Transactions on Computer-Human Interaction (TOCHI), 24*(5), 30.

Huhn, K. (2010). Effective organization of design guidelines reflecting designer's design strategies. *International jounal of industrial ergonomics, 40*(6), 669-688.

Interaction Design Foundation. (2019). Design Guidelines. Retrieved from https://www.interaction-design.org/literature/topics/design-guidelines

Isbister, K., and Mueller, F. (2015). Guidelines for the Design of Movement-Based Games and Their Relevance to HCI. *Hum.-Comput. Interact., 30*(3-4), 366-399. doi:10.1080/07370024.2014.996647

Jensen, M., and Grønbæk, K. (2016). *Design Strategies for Balancing Exertion Games: A Study of Three Approaches*. Paper presented at the Proceedings of the 2016 ACM Conference on Designing Interactive Systems, Brisbane, QLD, Australia.

Jensen, M. M., Rasmussen, M. K., Mueller, F. F., and Grønbæk, K. (2015). *Keepin' it Real: Challenges when Designing Sports-Training Games*. Paper presented at the Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, Seoul, Republic of Korea.

Jorgensen, M. G., Laessoe, U., Hendriksen, C., Nielsen, O. B., and Aagaard, P. (2013). Efficacy of Nintendo Wii training on mechanical leg muscle function and postural balance in community-dwelling older adults: a randomized controlled trial. *The Journals of Gerontology: Series A, Biological Sciences and medical sciences, 68*(7), 845-852.

Jørstad-Stein, E. C., Hauer, K., Becker, C., Bonnefoy, M., Nakesh, R. A., Skelton, D. A., and Lamb, S. E. (2005). Suitability of physical activity questionnaires for older adults in fall-prevention trials: a systematic review. *Journal of Aging and Physical Activity, 13*(4), 461-481.

Kari, T. (2017). *Exergaming Usage: Hedonic and Utilitarian Aspects.* (Doctoral Dissertation), University of Jyväskylä,

Kari, T., and Makkonen, M. (2014). *Explaining the usage intentions of exergames*. Paper presented at the Thirty Fifth International conference on Information Systems, Auckland.

Klevjer, R. (2006). *What is the Avatar? Fiction and Embodiment in Avatar-Based Single player Computer games.* (PhD), University of Bergen,

Konrad, T., Demirdjian, D., and Darrell, T. (2003). *Gesture + play : full-body interaction for virtual environments.* Paper presented at the CHI'03 Extended Abstracts on Human Factors in Computing Systems.

Koštomaj, M., and Boh, B. (2009). *Evaluation of User's Physical Experience in Full Body Interacive Games.* Paper presented at the International Conference on Haptic and Audio Interaction Design.

Leijdekkers, P., and Gay, V. (2013). Personalised mobile health and fitness apps: Lessons learned from myFitnessCompanion. *Health and Technology, 3*(2), 7.

Li, J., Erdt, M., Chen, L., Cao, Y., Lee, S., and Theng, Y. (2018). The Social Effects of Exergames on Older Adults: Systematic Review and Metric Analysis. *Journal of Medical Internet Research, 20*(6).

Lin, H. H., Wang, Y. S., and Chou, C., H. (2012). Hedonic and utilitarian motivations for physical game systems use behavior. *International Journal of Human-Computer Interaction, 28*(7), 445-455.

MacKelvie, K. J., Khan, K. M., and McKay, H. A. (2002). Is there a critical period for bone response to weight-bearing exercise in children and adolescents? a systematic review. *British Journal of Sports Medicine, 36*(4), 7.

Maillot, P., Perrot, A., and Hartley, A. (2012). Effects of interactive physical-activity video-game training on physical and cognitive function in older adults. *Psychology and Aging, 27*(3), 589-600.

McNaney, R., Balaam, M., Holden, A., Schofield, G., Jackson, D., Webster, M., Galna, B., Barry, G., Rochester, L., and Olivier, P. (2015). *Designing for and with People with Parkinson's: A Focus on Exergaming.* Paper presented at the Conference on Human Factors in Computing Systems.

Mueller, F., and Isbister, K. (2014). *Movement-based game guidelines*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada.

Mueller, F. F., Li, Z., Byrne, R., and Mehta, Y. D. (2019). *A 2nd Person Social Perspective on Bodily Play.* Paper presented at the CHI Conference on Human Factors in Computing Systems, Glasgow, Scotland, UK.

Nawaz, A., Waerstad, M., Omholt, K., Helbostad, J. L., Vereijken, B., Skjæret, N., and Kristiansen, L. (2014). *An Exergame Concept for Improving Balance in Elderly People*. Paper presented at the REHAB 2014: ICTs for Improving Patients Rehabilitation Research Techniques, Oldenburg, Germany.

Nielsen, J. (1993). Guidelines and Heuristic evaluation. In *Usability Engineing*. Mountain View, California: SunSoft.

Nijholt, A., Reidsma, D., and Poppe, R. (2010). Games and Entertainment in Ambient Intelligence Environment. In *Human-Centric Interfaces for Ambient Intelligence*. Burlington, MA, USA: Academic Press.

Norman, D. (2013). Design Thinking. In *The Design Of Everday Things*. New York: Basic Books.

Nowack, M. L. (1997). *Design guideline support for manufacturability.* (Doctor of Philosophy (PhD)), University of Cambridge,

Nunes, F., Verdezoto, N., Fitzpatrick, G., Kyng, M., Grönvall, E., and Storni, C. (2015). Self-care Technologies in HCI: Trends, Tensions, and Opportunities. *ACM Transactions on Computer-Human Interaction (TOCHI), 22*(6), 45.

Oppermann, L., and Slussareff, M. (2016). *Pervasive games.* Paper presented at the International GI-Dagstuhl Seminar on Entertainment Computing and Serious Games, GI 2015, July 5, 2015 - July 10, 2015, Dagstuhl Castle, Germany.

Osorio, G., Moffat, D. C., and Sykes, J. (2012). Exergaming, exercise, and gaming: Sharing motivations. *Games Health J, 1*(3), 205-210.

Plow, M. A., McDaniel, C., Linder, S., and Alberts, J. L. (2011). A Scoping Review of Exergaming for Adults with Systemic Disabling Conditions. *Journal of Bioengineering & Biomedical Science, 1*, 11.

Pyae, A., Liukkonen, T. N., Mika, L., Kattimeri, C., and Smed, J. (2017). Investigating the Finnish elderly people's user experiences in playing digital game-based skiing exercise: A usability study. *Gerontechnology, 16*(2), 65-80. doi:10.4017/gt.2017.16.2.002.00

Pyae, A., Liukkonen, T. N., Saarenpää, T., Luimula, M., Granholm, P., and Smed, J. (2016). When Japanese Elderly People Play a Finnish Physical Exercise Game: A Usability Study. *Journal of Usability Studies, 11*(4), 131-152.

Pyae, A., Luimula, M., and Smed, J. (2016). *Pre-studies on using digital games for the elderlys physical activities.* Paper presented at the 6th International Conference on Well-Being in the Information Society, WIS 2016, September 16, 2016 - September 18, 2016, Tampere, Finland.

Rendon, A. A., Lohman, E. B., Thorpe, D., Johnson, E. G., Medina, E., and Bradley, B. (2012). The effect of virtual reality gaming on dynamic balance in older adults. *Age and aging, 41*(4), 549-552.

Richards, C., and Graham, T. C. N. (2016). *Developing Compelling Repetitive-Motion Exergames by Balancing Player Agency with the Constraints of Exercise*. Paper presented at the Proceedings of the 2016 ACM Conference on Designing Interactive Systems, Brisbane, QLD, Australia.

Robbins, J. E., Hilbert, D. M., and Redmiles, D. F. (1998). Extending Design Environments to Software Architecture Design. *Automated Software Engineering, 5*(3), 29.

Rosenberg, D., Depp, C. A., Vahia, I. V., Reichstadt, J., Palmer, b. W., Kerr, J., Norman, G., and Jeste, D. V. (2019). Exergames for Subsyndromal Depression in Older Adults: A Pilot Study of a Novel Intervention. *The American Journal of Geriatric Psychiatry, 18*(3).

Rossmy, B., and Wiethoff, A. (2019). *StringTouch: A Scalable Low-Cost Concept for Deformable Interfaces.* Paper presented at the Conference on Human Factors in Computing Systems, Glasgow, Scotland UK.

Salen, K., and Zimmerman, E. (2004). *Rules of Play: Game design Fundamentals*. Cambridge, Massachusetts: The MIT Press.

Schoene, D., Valenzuela, T., Toson, B., Delbaere, K., Severino, C., Garcia, J., Davies, T. A., Russell, F., Smith, S. T., and Lord, S. R. (2015). Interactive cognitive-motor step training improves cognitive risk factors of falling in older adults–a randomized controlled trial. . *PLoS ONE, 10*(12).

Schönauer, C., Pintaric, T., and Kaufmann, H. (2011). *Full body interaction for serious games in motor rehabilitation.* Paper presented at the Augmented Human International Conference.

Sheridan, J. G. (2010). *When clapping data speaks to Wii: physical creativity and performative interaction in playground games and songs*. Paper presented at the Proceedings of the 24th BCS Interaction Specialist Group Conference, Dundee, United Kingdom.

Shneiderman, B. (1997). *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. Boston, MA, United States: Addison-Wesley Longman Publishing Co., Inc.,.

Skjaeret, N., Nawaz, A., Morat, T., Schoene, D., Helbostad, J. L., and Vereijken, B. (2016). Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy. *Int J Med Inform, 85*(1), 1-16. doi:10.1016/j.ijmedinf.2015.10.008

Skjaeret, N., Nawaz, A., Ystmark, K., Dahl, Y., Helbostad, J. L., Svanaes, D., and Vereijken, B. (2014). Designing for movement quality in exergames: lessons learned from observing senior citizens playing stepping games. *Gerontology, 61*(2), 186-194. doi:10.1159/000365755

Spelmezan, D., Jacobs, M., Hilgers, A., and Borchers, J. (2009). *Tactile motion instructions for physical activities.* Paper presented at the Conference on Human Factors in Computing Systems.

Staiano, A. E., and Calvert, S. L. (2011). The promise of exergames as tools to measure physical health. *Entertainment Computing, 2*(1), 5.

Stephanidis, C., Akoumianakis, D., Sfyrakis, M., and Paramythis, A. (1998). *Universal accessibility in HCI: Process-oriented design guidelines and tool requirements*. Paper presented at the 4th ERCIM Workshop "User Interfaces for All", Stockholm, Sweden.

Story, M. F. (1998). Maximizing Usability: The principles of Universal Design. *Assistive Technology, 10*(1), 8.

Subramanian, S., Dahl, Y., Skjaeret-Maroni, N., Vereijken, B., and Svanaes, D. (2019). *Twelve ways to reach for a star: Player movement strategies in a whole-body exergame.* Paper presented at the IEEE International Conference on Serious Games and Applications for Health (SeGAH), Kyoto, Japan.

Svanæs, D. (2013). Interaction design for and with the lived body: Some implications of merleau-ponty's phenomenology. *ACM Transactions on Computer-Human Interaction (TOCHI), 20*(1).

Telenko, C., and Seepersad, C. C. (2010). A Methodology for Identifying Environmentally Conscious Guidelines for Product Design. *Journal of Mechanical Design, 132*(9), 9.

Thin, A. G., and Poole, N. (2010). Dance-Based ExerGaming: User Experience Design Implications for Maximizing Health Benefits Based on Exercise Intensity and Perceived Enjoyment In *Transactions on Edutainment IV.* (Vol. 6250): Springer, Berlin, Heidelberg.

Uzor, S., and Baillie, L. (2014). *Investigating the long-term use of exergames in the home with elderly fallers*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada.

Van Hooren, S., Valentijn, A., Bosma, H., Ponds, R., Van Boxtel, M., and Jolles, J. (2007). Cognitive functioning in healthy older adults aged 64-81: a cohort study into effects of age, sex and education. *Aging Neuropsychology and Cognition, 14*, 40-54.

Velazquez, A., Martinez-Garcia, A. I., Favela, J., Hernandez, A., and Ochoa, S. F. (2013). *Design of exergames with the collaborative participation of older adults.* Paper presented at the 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2013, June 27, 2013 - June 29, 2013, Whistler, BC, Canada.

Velazquez, A., Martinez-Garcia, A. I., Favela, J., and Ochoa, S. F. (2017). Adaptive exergames to support active aging: An action research study. *Pervasive and Mobile Computing, 34*, 60-78. doi:10.1016/j.pmcj.2016.09.002

White, J. L., Ransdell, L. B., Vener, J., and Flohr, J. A. (2005). Factors related to physical activity adherence in women: Review and suggestions for future research. *Women Health, 41*(4), 123-148.

WHO. (2012). Mortality and burden of diseases and prevention of blindness and deafness. Retrieved from https://www.who.int/pbd/deafness/news/GE_65years.pdf

Wiemeyer, J., Deutsch, J., Malone, L. A., Rowland, J. L., Swartz, M. C., Xiong, J., and Zhang, F. F. (2015). Recommendations for the Optimal Design of Exergame Interventions for Persons with Disabilities: Challenges, Best Practices, and Future Research. *Games Health J, 4*(1), 58-62. doi:10.1089/g4h.2014.0078

Wolff, J. L., Starfield, B., and Anderson, G. (2002). Prevalence, expenditures, and complications of multiple chronic conditions in the elderly. *Archives of internal medicine, 162*(20), 2269-2276.

Zaczynski, M., and Whitehead, A. D. (2014). *Establishing design guidelines in interactive exercise gaming: preliminary data from two posing studies*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada.

Paper-IV-Framework

Svanæs, Dag; Lyngby, Andreas Scharvet; Bärnhold, Magnus; Subramanian, Sruti. "UNITY-Things: An Internet-of-Things software framework integrating Arduinoenabled remote devices with the UNITY game engine," Accepted for publication in HCI International, 2021.

This article is awaiting publication and is therefore not included.

Paper-V-Tangibles

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