Multidisciplinary Iterative Design of Exergames (MIDE): A Framework for Supporting the Design, Development, and Evaluation of Exergames for Health

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Abstract. Exercise video games (exergames) are increasingly being employed as a complementary intervention to promote physical activity engagement in response to the need for creating sustainable strategies for supporting health. While exergames have shown that they can have comparable effects to conventional human-guided training programs in certain situations, its adoption in healthcare applications are still limited. This is in part because of a disconnection between the technology/content producers, healthcare providers, and end-users. Many design frameworks have been proposed to guide the process of creating games for health, however, what is missing is an integrated and multifaceted approach that includes the preliminary research and evaluation stages that are needed to create plausible solutions for exergames. Furthermore, relevant stakeholders are often not included throughout the entire process, neglecting the importance of transdisciplinary collaborations when creating exergames for health. This paper presents the Multidisciplinary Iterative Design of Exergames (MIDE) framework as a comprehensive, integrative, and specific framework for exergame design, development, and evaluation following different research methods, techniques and tools. The MIDE framework is intended to support researchers, healthcare professionals, and industrial experts in identifying the stages, processes, techniques, and key roles needed to create novel exergames for exercise promotion. As older adults are a key user group, applicability of the framework is illustrated using considerations for older adults and immersive experiences (e.g., virtual reality). A specific use case is presented at the end of the paper to illustrate the use of the MIDE framework in the context of a project of using virtual reality exergames for promoting exercise in people living with dementia.

Keywords: Exergames · Framework · Game design · Game evaluation · Multidisciplinary · Iterative · Older adults · Virtual reality (VR)

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1 Introduction

Research has shown that physical activity (exercise) is associated with better health outcomes and have been recognized as valuable part of preventative and therapeutic strategies for healthy living [5,37]. While playing video games has been considered a sedentary activity in the past [38,40], many commercial video games exist that require players to be physically active by encouraging them get up and move. Recent research has shown that interactive video games, in which human movements are integrated as the main interface to elicit physical activity similar to exercise (also known as exergames), are able to motivate people engage in physical activity by offering an appealing and fun game experience, compelling game challenges, and novel ways to meet and interact with others [29]. In fact, exergames have been used to provide long-term motivation to support physical activity engagement in different populations for different purposes including education [48], rehabilitation [27], and physical/cognitive training [26].

While there are several interventions under development, an area of rapid growth is virtual reality (VR) exergames for older adults. VR is showing promise as a way to provide a realistic, novel, and immersive environment that encourages game players to exercise [32,39,41]. Access to conventional exercise can become more difficult as people age. Exergames have shown potential to benefit older adults' functional fitness, improve older adults' mental health [8,39], increase social connections and encourage interactions with peers [12,39], and being mentally stimulating [19,43]. Even though Conventional screen-displayed VR exergames (e.g., Nintendo Wii, Microsoft Kinect) have been widely adopted to support aerobic, balance, and strength training in older adults to increase physical activity and promote health [17,26,44,52], head-mounted display (HMD) VR exergames are increasingly gaining attention as they present fully immersive 3-dimensional (3D) environments in a format that can be accessible and intuitive for older adults to use, which means they can provide more realistic and engaging gaming experience for the participants compared to the other mediums.

Exergames have shown comparable effects to conventional human-guided exercise programs [44,51], however, the rate of adopting both commercially available and customized exergames in rehabilitation settings is still low. Based on a survey carried out across Canada [28], this may in part be due to poor compatibility of the technology with end-user preferences. While exergaming frameworks exist (e.g., geronotoludic design [9], DDE framework [50]), they are mainly focused on specific game design elements, often neglecting other important stages/stakeholders required to elicit design requirements. Further evaluation of the exergames concerning end-users and healthcare professionals are also generally missed in these frameworks. In addition, the design of meaningful and playable experiences within exergames has remained a major challenge when targeting older adults considering variations in motor and cognitive abilities within the population. Although a number of frameworks for designing exergames targeting older adults [9,21] have been proposed, novel immersive HMD-VR exergames pose new challenges regarding interaction paradigms, game design elements, and human factors that are associated with the use of HMD-VR headsets (e.g., motion and simulation sickness). Therefore, a special considerations for both older adults and HMD-VR exergames are needed to foster an informed adoption of this technology for exercise promotion.

This paper outlines the Multidisciplinary and Iterative Design for Exergames (MIDE) framework, an exergaming framework that includes three stages: i) contextual research, ii) game design and development, and iii) system evaluation. The MIDE framework takes a generalizable approach that considers general research and evaluation phases, guides information transfer between different stages (inputs and outputs), integrates contributions from relevant stakeholders, and recommends research methods (e.g, user-centered design).

1.1 Existing Guidelines for Designing Accessible Games and VR for Older Adults

A review of the existing guidelines starts with guidelines for developing accessible games.

Specific considerations addressing accessibility pros and cons of using virtual environments have been proposed [2,25]. From a *mobility* perspective, advantages of using VR environments are: i) possibilities to overcome real world physical barriers, ii) fully immersed and stimulating environments, and iii) avatar's customization to fight stigma; on the other hand disadvantages can be listed as: i) players with mobility impairments may have difficulty using controllers, ii) interaction in virtual environments often requires precise click targets, iii) hygiene issues due to aroused physiological responses, iv) players with severe mobility impairments may find movements, such as reaching and grasping, or sensations, like haptic cues, are difficult to perform or interpret, and v) movements in lower limbs (i.e., walking, stepping, standing, etc.) are usually hard to include/track in VR environment. Also, the use of virtual environments poses advantages for players with *cognitive* limitations such as: i) after training, players can become proficient in virtual environments, ii) the vividness and synchronous interaction in VR can allow players to focus their attention more effectively, iii) VR can be designed to support error-free training, which can help alter the environment complexity into cognitive abilities, iv) the distraction provided in the virtual environments has been found to diminish pain perception in hospitalized patients [45]. However, disadvantages can be: i) the user interface can be difficult to learn, ii) input devices such as motion controllers can be difficult to master, iii) players may experience motion sickness, due partially conflicts between sensory cues, and iv) flashing or excessive moving objects may cause seizures or migraines.

With respect specifically to for physical activity promotion for older adults using HMD-VR, design guidelines that consider accessibility issues for games can be used to address some of the aforementioned disadvantages of VR. According to existing accessibility guidelines for game design [1,2], physical and cognitive changes of the population should be carefully considered when designing games for people with impairments or disabilities. Considerations for exergames design targeting older adults regarding *mobility* issues may include: i) allow controls or input devices to be reconfigured and adapted, ii) ensure interactive elements are large enough and well spaced with appropriate color contract, iii) provide alternatives to buttons that are required to be held down, iv) do not rely on motion tracking of specific body types, and v) do not make precise timing essentials to gameplay. Similar considerations from a *cognitive* perspective are: i) allow the game to start without the need of menus, ii) use simple, clear, readable text and language, iii) include contextual in-game guidance, iv) reinforce essential information through text, visual, and speech feedback, and v) avoid any sudden or unexpected movement or events.

1.2 Frameworks for Exergame Design

In this section, a brief review of the existing frameworks for designing exergames is presented, looking at elucidating important previous research carried out to better understand how exergames for health should be designed. Knowledge gaps and opportunities to create more complete and comprehensive frameworks are identified in order to facilitate the positioning of our MIDE framework.

In order to bridge the gap between relevant fields within game research and game development, the Mechanics, Dynamics, Aesthetics (MDA) framework [23] provides a structural approach to understand games and to facilitate discussion and knowledge translations amongst all different disciplines. The framework describes different layers of abstractions in the dynamics of a gaming system to better infer the design and development considerations of a user-centred experience-driven game. The framework, however, focuses on the game mechanisms and fails to provide a coherent approach for game design that is suitable for all types of games.

The gerontoludic design framework [9] extends the generic MDA framework by providing guidance in designing attractive digital entertaining games specifically for older adults. In addition to adapt the specific design interpretations for seniors using fundamental game elements such as mechanics and aesthetics, the gerontoludic framework emphasizes the importance of user-centered (more specifically player-centered) design approach towards the goal of meaningful play. Similar to MDA, geronotoludic design provide necessary considerations and suggestions when designing for older populations but lacks details on implementations during actual game design and development process.

In response to some criticisms and challenges about the MDA framework mentioned above, the Design, Dynamics, Experience (DDE) framework [50] aims to provide a more comprehensive guidance in the game design and development process. Transforming the three main components, DDE framework provides clarifications regarding each categories and their subcategories. Instead of connecting different game layers to formulate either player's perspective or designer's perspective, both parties have distinct relationships within each layer of the game in DDE framework. While DDE framework has provided more clear picture of different components of game layers and considers the experience of players in each game layer, players are not involved in the framework as part of the design process/component.

Inspired by the successful examples in serious games, or games for health, that are developed according to the best-practices in rehabilitation, an adaptive exergames design framework [21] has been proposed for elderly population to address the specific needs that are not considered in the commercial exergames. Additional to the generic architecture framework for rehabilitation games develop process, the detailed adaptive layer illustrates the relationships between user and sensors for adapting exergames training session according to individual performance and preferences. The conceptual architecture, however, fails to consider necessary stakeholders and their contribution to the system.

To guide the design of a gamified system for rehabilitation settings, the People, Aesthetics, Context, Technology (PACT) framework [7] presents a set of considerations for an inclusive rehabilitation game design. In particular, the framework emphasizes on involvement of all necessary stakeholders in addition to users and developers. By tailoring the game design to the specific context and technologies and incorporating stakeholders' suggestions, the developed product of the framework will better suit the need of healthcare system for larger scale deployments. Although the paper presents an example of using the framework in the process of gamifying a rehabilitation system, the framework only presents key components to be considered in the four areas.

Table 1 summarizes the exergames design discussed frameworks above, describing their target audience, game categories, design stages that are discussed, and whether VR considerations are discussed. Existing frameworks have focused on game elements or game development considerations but none have proposed a systematic process to guide other relevant stages, such as contextual research and system evaluation.

Table 1. Exergames design frameworks.

Framework	Target audience	Game category	Stages covered	VR considerations
Geronotoludic design [9]	Older adults	Entertainment games	Game design	No
DDE framework [50]	Not specified	Entertainment games	Game design	No
Adaptive exergames [21]	Older adults	Exergames	Game design	No
PACT framework [7]	Not specified	Games for health	Game design, game development	No
MIDE framework	Older adults	HMD-VR exergames	Game design, game development, system evaluation	Yes

2 MIDE Framework

This section introduces the MIDE framework (Fig. 1), which is intended to provide guidance in the design, development, and evaluation of HMD-VR exergames for promoting physical activity participation among older adults. The framework

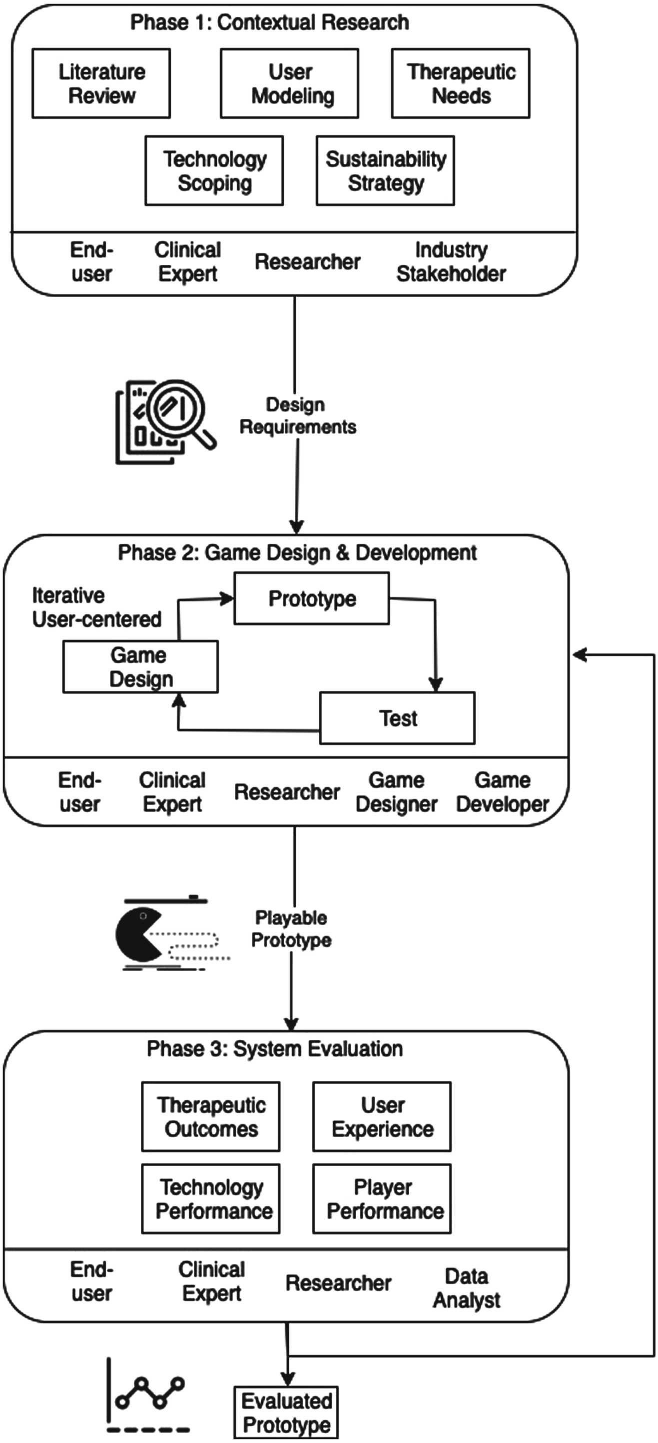

Fig. 1. The MIDE framework

is divided into three phases: contextual research, game design and development, and system evaluation. Key stakeholders are shown in the bottom portion of each Phase. While the framework can be used in exergames designed for health in general, specific elements that should be considered regarding HMD-VR and older adults have been described in the paper and should be used in part with the framework. While the framework is presented in sequential Phases, the developers should be aware of and planning for future stages and tasks to ensure activities performed in each Phase feed into the next.

2.1 Phase 1: Contextual Research

To develop appropriate exergaming solutions for the target user group, researchers need to be aware of the potential challenges and possible solutions by observing and interacting with older adults, healthcare professionals (such as physiotherapists, kinesiologists, clinical experts, nurses, etc.), industry stakeholders, and other possible parties (e.g., informal caregivers, family members, technicians, etc.) that can provide relevant information. In particular, researchers should carry out holistic reviews to define the problem and gaps, specify user preferences through user modeling, understand expected outcomes from therapeutic needs, understand the existing solutions and interventions via technology scoping, and manage distribution/deployment of the proposed exergaming solutions with sustainability strategies. The output of this phase is a set of design requirements that includes design considerations, accessibility recommendations, user modeling elements, and technological reflections to be followed in the design and development phase. Some of the aspects needed to carry out a contextually-informed model of end-users and exergames are:

Literature Review. A literature review is needed to understand the current knowledge about the proposed problem space from both research and industry perspectives as they usually complement each other by providing information from different aspects. In specific, there is a need for conducting reliable comprehensive literature reviews to understand the current theoretical and methodological contributions to the technology advancements, research methodologies, design considerations, and intervention evaluations. Examples of specialized academic conferences and journals include: Games for health (journal of Liebert), JMIR Serious Games (journal of JMIR), Serious Games and Applications for Health (conference of IEEE) and International Conference of Virtual Rehabilitation (conference of IEEE). It can be useful to explore non-academic information sources or grey literature (e.g., patents, industry networks) to better understand opportunities to create exergames that can transition from academic findings to potential marketable and accessible commercialized products. An example of a business to business (B2B) platform that showcase games for fitness promotion is https://www.fitness-gaming.com.

User Modeling. User models [18] should reflect the preferences and needs of the targeted user group from a multi-discipline perspective in order to optimize the exergaming experience. In addition to general aspects such as demographic, capability, characteristics, hobbies, and motivators for playing, exergames-specific user models should also include other attributes like the facilitators and barriers to physical activity engagement [49]. All these aspects help shape the game design elements such as mechanics and narrative. It has been shown that more familiar and plausible exergaming experience (e.g., prior experience, positive emotions) might be more effective in engaging older adults in physical activity. The detailed attributes in each aspect can be summarized from information-finding activities such as interviews, observations, and literature reviews. For example, hobbies and demographic information such as age, sex, and culture will highly influence the theme of the game [10]. Players with different characteristics, age, and backgrounds may prefer one game mode over another like enjoying cooperative games better than competitive games [24]. Specific physical and cognitive abilities should be considered to create more realistic player models capable to represent real users' capabilities. Finally, the user models can help to better categorize potential users into different player types [4] that can help in creating user archetypes (also called personas) that will facilitate the process of empathizing with the end-users [35].

Therapeutic Needs. The specific therapeutic needs of the population interacting with the exergames should be reviewed through existing evidence in exercise/exergames from the field and closely consulted with healthcare professionals in order to complement the existing training programs. The VR exergames will be adjusted based on individual needs and progress within the large scope of therapeutic requirement and best practice for the specific population. In conventional human-guided exercise training interventions, prescribed exercises are ideally tailored to the individual's unique health status, physical capability, interests, and exercise program goals. In this regard, exercise specialists are required to determine the core components of the training plan (e.g., type of exercise, target outcomes, based on FITT-VP: Frequency, Intensity, Type, Time, Volume, and Progression model) [20]. Periodic assessments are essential to adjust the exercise intervention according to the individual's training responses, progress and corresponding therapeutic needs. Following the same principles, in the exergames design and development process, researchers need to specify the users' fitness goals, training settings, and outcome measures beforehand. Individual clinical profiles and periodic assessments should also be considered in order to properly adjust the exergames training program in accordance with the individual's goals and progress. Taking the existing scientific evidence and best practice in exercise into consideration and acknowledging challenges and strengths of the exergames system are of prime importance when developing an individually tailored exercise regimen.

Technology Scoping. To deliver the solution with appropriate artifacts and equipment, the capacity of existing gaming technologies should be researched and scoped. By using techniques such as trend analysis and SWOT (Strength, Weakness, Opportunities, and Threats) matrix, appropriate technology interventions for the exergames should be identified by carefully comparing the existing technologies in the market. In consultation with industrial experts, hardware and software requirements for developing and deploying the exergames should be discussed and finalized especially for planning and budgeting purposes. For instance, the integration of existing fitness equipment, such as stationary bikes and treadmills, has been explored as a beneficial (e.g., engagement, user experience) technology integration approach for exergames [33]. Particularly in immersive VR, more sophisticated setups such as CAVE (Cave Virtual Environment) can be used to avoid hygiene issues (e.g., sweating by using the HMD) as well as to provide a more embodied experience which has boost the player experience [31]; however, this must be balanced against cost and the practicalities regarding implementation. Detailed strength and limitations of the VR system will come out from the stage to guide design process considering the needs of users and the capability of the system.

Sustainability Strategy. A shortcoming of the exergames for health that are designed and developed under research projects is their limited availability. Despite publishing scientific evidence of their impact, the majority of the final applications cannot be accessed or are not available beyond the duration of the project [30]. To tackle this issue, the technologies and games developed in academic contexts should consider strategies to be distributed/maintained outside of the research period so that they are available more widely and for longer-term by end-users and healthcare institutions. Examples of efforts towards creating digital libraries to facilitate the access to validated games for health can be found at: https://openrehab.org and https://seriousgames-portal.org.

2.2 Phase 2: Game Design & Development

To support appropriate development of exergames that meet expectations, older adults, healthcare professionals, and other stakeholders should be included in the game design process. This will enable meaningful and participatory contribution towards positively influencing the game design and development process. At the end of this phase, a fully functional prototype should be ready to playtest.

Design and Development Cycle. Following user-centered design approaches [47], the design and development cycle of the game should iterate until a qualified playable prototype is developed. In general, the cycle should start with a process, such as brainstorming as a multi-stakeholder group, to better understand the goal of the exergames and related training programs. Consequently, design sessions, where game concepts are discussed in light of the healthcare requirements and technological feasibility, should be carried out to establish a mutual exergames design expectation. The initial game elements such as game story and game mechanics should be discussed and analyzed on an ongoing basis by bringing examples from already existing exergames or other inspiring sources. Specific game concepts should then be evaluated and investigated through focus groups and individual interview sessions, with participation of older adults and healthcare professionals, later in the iterative cycle. Following the game design concepts, an iterative prototyping and playtesting process can be used to help estimate if the proposed game concepts (e.g., game mechanics, game theme) are suitable for the target population. When possible, the game content should be created with the interfacing hardware, allowing an early identification of possible modifications that have to be done in order to facilitate the interaction (e.g., removing the need of pressing buttons). The developed prototype should then be evaluated during test (or playtesting) sessions with both healthcare professionals and older adults. Through multiple playtesting and informal feedback sessions, specific game preferences and game elements will be modified based on the feedback from older adults and healthcare professionals during their one-on-one interactions with the prototype. The feedback and suggestions should be integrated in a new game design concept to improve existing limitations in the prototypes and the cycle starts again as many times as possible until a qualified prototype appears as suggested in conventional game design literature [42].

2.3 Phase 3: System Evaluation

The playable prototypes from game design and development phase are not the end product as they must be systematically evaluated with a representative sample of users to ensure the exergames meet their intended goals. The output of Phase 3 can be used in an iterative fashion as input into a continuation of Phase 2 as a part of a larger iterative cycle, supporting more extensive revisions and refinement. In particular, we propose four different domains to be evaluated for VR exergames.

Therapeutic Outcomes. Depending on the goals of the system, defined a priori, the exergames can be evaluated to better understand the targeted therapeutic outcomes and assess whether the individual therapeutic needs and goals are met. In this regard, physical, cognitive, and psychosocial aspects of the exergame can be some of the possible outcome areas:

– **Physical Aspect (Functional Fitness):** As a novel form of exercise, the impact of exergames on improving general fitness, and eliciting pre-specified physical outcomes can be evaluated. Increased cardiorespiratory fitness, range of motion, strength, and balance are of such physical outcomes depending on the training regimes (i.e., type of exercise, intensity, duration), fitness domain, and target muscle group. As a complementary and alternative training approach, evaluating the resulting energy expenditure and the exergames capacity in increasing exercise level can be important, in particular for those at higher risk of being sedentary, reluctant to exercise, or concerned about possible

adverse events associated with physical activity [6,41]. Evaluating the system with respect to physical outcomes will help to adjust exergames parameters according to the individual therapeutic goals/needs and commodities to avoid physical overexertion as well as reducing the likelihood of unwanted or detrimental effects.
- **Cognitive Aspect:** Considering the existing evidence supporting exercise as a promising means to enhance cognition in aging adults or tackle some of the age-related cognitive declines [22,36], the impact of the exergames on cognition and the extent to which they can induce change in cognitive function among elderly can be assessed as an outcome of interest. The focus can be on global cognitive ability or domain-specific areas. Evaluation of the exercise-induced cognitive outcomes in relation to the physical load and cognitive demand during exergaming can help to further explore the effect of different training programs and exergames modalities on specific cognitive domains.
- **Psychosocial Aspect:** In addition to physical function and cognitive performance, psychosocial effects of the exergames, including psychological changes and social well-being, can be possible outcomes of the system. Concerning the psychosocial impacts of the exergames, changes in mood, depressive symptoms, and enjoyment can be assessed. Additionally, motivation level, perceived quality of life, and self-efficacy influenced by exergaming can be other outcomes to be evaluated. With social isolation being one of the major concerns for older adults, it can be beneficial to evaluate the social effects of exergames on this population, in particular its impact on reducing loneliness, improving socialization as well as bonding with peers and grandchildren. Considering lack of motivation is one of the main barriers to uptake exercise among the older population, opportunities of the social connection provided by exergaming may increase exercise participation and adherence among this population.

User Experience. To understand the usability and acceptability of the VR exergames, the perceptions of the game and technology will be evaluated from both players' and healthcare professionals' perspectives. For example, simulator sickness, specifically motion sickness, of the players during the exergames sessions should be investigated through specific questionnaires. To understand the feasibility of adopting VR exergames system for longer period of time in long term care facilities, both players' and healthcare professionals' perceptions/acceptance of the technology should be well documented. In addition, the game user experience and players perceptions of virtual environments are extremely helpful to improve the game design.

Technology Performance. In addition to the user experience, the technology intervention should also be evaluated on its intended behavior once compared with resulted behavior. The elicited physical and physiological responses during the exergames session should be monitored and compared against the recommended guidelines [46] for older adults as the exergames are intended to provide incentives for physical activity through gamified contents. For example, when a certain heart rate zone is a target outcome of a exergames as a key indicator of physical activity intensity, the exergames is a failure if it cannot elicit the target heart rate of the player during the gameplay sessions. On the other hand, the interactions of the exergames should be documented and compared to intended user behaviors to understand if the technology meets its expectations. For example, the technology controllers fail to meet the purpose and may need to be altered if the player cannot use it properly; the technology configuration when the audio instructions provide additional confusion to users rather than guiding them through the games at proper time.

Player Performance. Player performance can be evaluated at two levels: physical sensing and game data. Game data, including game interactions, game progress, game score, and game event, will be combined and interpreted to present player performance in a reasonable and easy-to-understand manner. VR sensors, physical activity monitors, and physiological sensors will be used in physical sensing part. The sensors in the VR system (e.g., acceleration, 3D position) can be used on their own to track the physical activities of the user or can be augmented by external physical activity tracking sensors can provide more accurate and validated information about the exergames sessions, such as physical intensity level and energy expenditure.

2.4 Other Key Considerations

In addition to the general process described above, many tools and concepts can be used to facilitate the design process for better adaptive VR exergames for health.

Intelligent Software Layer. Intelligent software layers based on computer algorithms (i.e., machine learning, data management, etc.) can significantly improve the way exergames impact people's health. Such layers can be created with a diversity of functionalities and objectives, but generally speaking they aim to maximize the healthcare benefits by configuring aspects of the software to provide customised and personalised support for people using the exergames or data from it as either the primary end-users or secondary users (such as healthcare professionals). This can be done by taking advantage of the data that can be captured during exergaming sessions as well as providing strategies for real-time adaptation based on physiological metrics. For example, adaptive modules such as kinematic adaptation layers [34] can be implemented to facilitate personalizing and adapting in-game difficulty to provide longer engagement with the exergames and elicit higher physical activity level. Data management modules can be included for in game-data logging purpose but additional connection blocks to external clinical electronic health record system or data visualization blocks are possibly necessary depending on the application of the exergames [11]. Efforts towards unifying the exergames ontology for publishing open game data are being created to facilitate the collaboration and to replicate results [3].

Rapid Prototyping Tools. Considering its emerging and disrupting nature, VR technologies are constantly evolving and staying updated with the knowledge is a challenging but necessary task for developing VR exergames. The most popular game engines (e.g., Unity3D, Unreal) are frequently releasing tutorials and software tools to facilitate the creation of content for VR. However, to be able to use these game engines, some specific technical skills may be required, thus limiting the creation of virtual environments and games to people with knowledge in 3D modeling, programming, and game design. Therefore, with the aim to aid a rapid adoption of VR in different ecosystems (e.g., education, training, healthcare), tools for rapid prototyping have been created to allow the development of low-fidelity prototypes by only investing a couple of hours of work without requiring specialized knowledge/skill for VR development. Some of the most useful tools for prototyping VR include:

- **Paper Prototyping:** From workshops and ideation/brainstorming sessions to game jams, the use of pencil and paper sketches and drawings is always highly recommended to rapidly show concepts and initial designs. VR is not an exception either. Sketching concepts by using distorted and spherical paper-based templates can help to materialize ideas in a quick and elegant fashion. Tools such as templates, perspective techniques and available prototypes can be found at: https://blog.prototypr.io.
- **Google Blocks:** Empowered by a diverse and extensive library of 3D objects that use computationally low-cost models (low-poly), Google Blocks allows people to create virtual environments by dragging-and-dropping pre-established objects into a scene. Google Blocks allows users to either to import already existent models or to create their own, but one of its most interesting characteristics is that it allows users to create models even when they are immersed in the virtual environments. Thus, spatial features of the scene and object positioning can be used to aid establishing realistic simulated environments since users act as architects in the virtual space in real-time. The tool is freely available to be used with state-of-the-art VR headsets.
- **BrioVR:** This online platform allows users to create visually compelling and interactive VR prototypes without professional training. Virtual scenes can be created using a drag-and-drop workflow that integrates a library of 3D objects, text edition tools, geometric primitives, and an entire library of tolls for interaction such as triggers and object behaviors. Results can be previewed in commercially available VR systems (e.g., HTC Vive, Oculus Rift) as well as mobile systems powered by mobile phones. BrioVR is freely available and runs in web explorers.
- **Varwin:** Powered by the most popular game engine, Unity3D, Varwin offers a middleware that is able to be integrated with professional VR projects. Varwin integrates a block-based visual programming language that simplifies the creation of interactions within the virtual environment. Varwin has a freely available version that can be used to create multiple VR projects.

3 Summary of MIDE Framework Contribution

The MIDE framework is different from other exergames design frameworks as it is:

- **Integrative:** In order to reach a holistic understanding of the complete process, all three stages (contextual research, game design and development, and evaluation) are required to truly establish the exergames product as a feasible and effective complement of the existing exercise training programs. The MIDE framework includes key representative stakeholders throughout each stage, reinforcing the idea that a multidisciplinary team is required to ensure that diverse, yet complementary, perspectives of various stakeholders (e.g., industry partners, data analysts, healthcare professionals) are considered in the process of designing and developing exergames.
- **Specific:** The MIDE framework includes specific information about research methods, game design practices and considerations, VR prototyping tools, and evaluation approaches to create novel customizable immersive HMD-VR exergames for older adults.
- **Comprehensive:** The MIDE is intended to support the process of planning and executing research in exergames, VR games, and serious games for health by illustrating both an overall picture of the process as well as individual strategies and considerations for each stage, specifying inputs and outputs of each stage, providing design tools, well-established techniques and protocols, and references for further research.

4 Illustrative Use Case of the MIDE Framework

To illustrate the application of the MIDE framework, we present a sample use case related to the authors' current work: the design, development, and evaluation of HMD-VR exergames to promote physical activity in older adults with mild cognitive impairment (MCI) or dementia. As it is a project in progress, we are currently at the game design & development phase. The proposed system evaluation study is structured and will be conducted in the near future. Aspects of the model from Fig. 1 are indicated by the use of *italics*.

During the contextual research period, we conducted multiple *literature reviews* to understand exergames for older adults with MCI/dementia, current HMD-VR technologies for exercise and well-being, as well as some specific design considerations in motion based technologies and games for older adults with dementia from both academic and industry perspectives. Observations were made through shadowing exercise therapists in our long term care facility partner (Schlegel Villages) to collect information that informed our *user modeling*. In our previous pilot research [13–16], we found out that using farm related activities in the exergames allow players complete the tasks in an intuitive fashion as they recognised the environment and tasks they were expected to do. Simple audio instructions were given in a narrative, story-telling fashion, which was found to be extremely important in supporting game players in understanding what they were expected to do. Together with existing literature about older adults with dementia, a user model was constructed to understand the preferred game design concepts. Key considerations in *therapeutic needs* around target exercise outcomes, intervention practice, and system capability were concluded through literature reviews on existing evidence of exergames/exercise for older adults with MCI/dementia and discussions with healthcare professionals within the research team. Based on literature reviews, our user model, and discussions with healthcare professionals at long term care facilities as well as within the research team, we decided the exergames should promote upper limb exercises (and, by proxy, core strength) in a seated position to ensure safety and the instructions of the game should be straight forward. The length of the games is restricted to a maximum of 20 min (including warm up and cool down) and the intensity of the exercise does not exceed 80% of users' target heart rate. The current suite of games are being created in collaboration with a VR game development company (VR Vision), as a *sustainability strategy*, to support the deployment of commercially exergames to market after *technology scoping*. Together with experts from the industry partner, demonstration sessions have been arranged with Schlegel Villages to collaboratively explore the design expectations and requirements on the actual device by explaining the technology and the design concept to therapists (Fig. 2).

Fig. 2. Working in collaboration: Demonstration sessions for HMD-VR exergames development with our industry partner (VR Vision) and our long-term care partner (Schlegel Villages)

We are currently in the design & development phase, where we have designed and developed an initial playable prototype (Fig. 3), in collaboration with VR Vision, based on our design expectations from contextual research stage. With the initial prototype, we will investigate the validity of initial design concepts by conducting focus groups and demonstrating the initial prototype to older adults with MCI/dementia from Schlegel Villages as well as their therapists. The conclusions from the focus group sessions will be sent to VR Vision to adjust the inital prototype. Following some fast iterative play-development cycles with playtesting sessions and informal feedback sessions, we will demonstrate the final prototype to older adults with MCI/dementia and their therapists to understand their perception and acceptance about the technology.

Fig. 3. HMD-VR exergames initial prototype. Rowing activity.

Future work involves a six-week long feasibility study of the developed final prototype from the design and development stage to be carried out in long term care facilities. The goal of the feasibility study is to explore the potential of proposed intervention for a future larger scale trial in understanding the efficacy of HMD-VR exergames in older adults with MCI/dementia. In specific, we look into the adherence of the proposed exergames program and the feasibility of the assessment methods. Pre-post assessments on participants' functional fitness, cognitive function, and wellbeing will be collected and compared to reveal the *therapeutic outcomes* of exergames program. The proposed exergames is also evaluated on its *user experience* and *technology performance* through focus groups with participants and therapists from Schlegel Villages, observations of participants during exergames sessions, and a shot survey at the end of each exergaming session probing participant's VR exergaming experience during the session. Lastly, we will validate the potential of HMD-VR exergames as a stand along system to provide accurate information about the exercise sessions and *player performance*. To reach this goal, we first compare the validity of raw data information collected in VR sensor with the physical activity tracking sensor for movement measurements. Then, we investigate possible algorithms to provide objective measures such as energy expenditure and physical activity intensity from VR sensors by correlating the referencing values of derived objective measures from both physical activity tracking sensor and heart rate sensor with VR sensor data. Lastly, we also investigate novel metrics to reflect useful information about the exergames sessions and player status. Through discussions with therapists, we will identify several novel metrics to represent the VR exergaming sessions using the game data and movement measurements data from VR sensors, which will presented as the example information shown in Fig. 3.

5 Conclusions

The MIDE framework aims to provide guidelines and considerations related to the process of designing, developing, and evaluating exergames. While we focus on the creation of exergames for supporting older adults using VR applications, the general process and principles can be applied to any possible type of serious games for health and rehabilitation. The MIDE framework integrates a multidisciplinary approach and that seeks to involve relevant stakeholders by acknowledging and capturing the unique and valuable contributions of each role in different phases. It emphasizes the necessity of a amalgamation of different phases and perspectives in order to produce exergames systems that are complement the contexts and populations they are intended to support. As the MIDE is a new guideline, further research and testing in real-world development situations needs to be done to validate and improve it.

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