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An Exergame Solution for Personalized Multicomponent Training in Older Adults

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Abstract: In addition to contributing to increased training motivation, exergames are a promising approach to counteract age-related impairments. Mobility limitations, cognitive impairment, and urinary incontinence are very common in older adults. To optimally address these conditions, exergames should include interventions for strength, balance, cognition, and pelvic floor muscle training. In this study, we develop a personalized multicomponent exergame solution for the geriatric rehabilitation of age-related impairments. The exergame can provide interventions for balance, strength, cognition, and urinary incontinence in one single session, accommodating the needs of older adults with multiple disabilities. For its development, we involved a multidisciplinary team that helped us to specify the structure and contents of the exergame considering training requirements, game design principles, and end-user characteristics. In addition to allowing the customization of the training components, the exergame includes automatic adaptation of difficulty/load, in line with player progress over time. The game mechanics ensures the fulfilment of training needs as defined by the therapist. The exergame is cross-platform compatible (web-based) and includes novel means of interaction with wearable sensors.

Keywords: exergames; personalized exergames; multicomponent training; wearable sensors; older adults; game design; interaction design

1. Introduction

Ageing is associated with a gradual decline in physical and cognitive abilities. Mobility limitations, cognitive impairment, and urinary incontinence are particularly common in older adults [1], having a negative impact on their lives. Moreover, these conditions are associated with gait impairments, increased risk of falling, and all-cause mortality [2–4].

Mobility and cognitive impairments share common underlying mechanics of decline, and often coexist in older adults [5]. Results from several studies also suggest that mobility decline and cognitive impairment are associated—and frequently coexist—with urinary incontinence [4,6–8]. According to [4] improving functional independence reduces urinary incontinence, and improves cognitive function in older adults.

Multicomponent exercises—including aerobic, strength, endurance, and balance training—were shown to improve physical performance and health [9], reduce falls, urinary incontinence, and risk of injuries [10–12], while improving cognitive functions [13–15], quality of life [16], and self-efficacy [17] in older adults. Cognitive training showed positive effects in specific cognitive functions and dual-task activities in older adults with or without cognitive impairment [18–21]. Additionally, pelvic floor muscle training is recommended for women with geriatric incontinence [22,23]. Still, lack of motivation and low adherence to physical activity constitute a barrier to the implementation of conventional training programs [24].

Exergames can be used to encourage physical activity in older adults [25,26]. Besides being widely available, leveraging autonomous use, and providing performance monitoring and individual adaptation capabilities [27,28], exergames can be used as an alternative to conventional training [29]. Exergames showed promising results to improve motor and cognitive functions in older adults [30–33], reduce the risk of falling [34], improve quality of life and enjoyment [30], improve balance and mobility [35], improve strength [36], and minimize urinary incontinence [37].

If, on one hand, we cannot deny the potential value of exergames in geriatric rehabilitation, on the other hand, practical implementation at clinics or at home is far from being ideal [28]: older adults may have difficulties following fast paced games; they may be afraid of falling or being injured; they may feel low confidence; and they may feel anxious or insecure working with technology [38]. These difficulties are aggravated by the fact that most exergames—especially those available commercially, such as Nintendo Wii^{TM} or Xbox Kinect^{TM}—were not developed specifically for older adults, neglecting their characteristics and preferences [39–41]. In contrast, very basic game design and game mechanics may end up compromising usability, enjoyment, and motivation [42].

Gamification refers to the use of game design elements (e.g., scores, feedback, and progression) to improve user experience and motivation [43]. Gamified concepts were applied to approach motor and cognitive training in older adults with or without cognitive impairment [31,44–47], and pelvic floor muscle training in older women [37,48]. To improve training variety, current solutions usually integrate several games that target different components of the training. However, individual training times (of each individual component) cannot be personalized, being training times usually controlled by the user according to the verbal or written guidelines provided by the clinician [48–50]. Current exergames also do not offer solutions for the multicomponent training of the three conditions—i.e., mobility limitations, cognitive impairment, and urinary incontinence—simultaneously, even though they are frequently associated and occur simultaneously in an older person.

In view of the above, the project VITAAL (funded by the European Commission through the Active Assisted Living Program) proposed the development of a personalized multicomponent exergame solution for mobility limitations, cognitive impairment, and/or urinary incontinence in older adults [51]. In this study, we propose an exergame design and mechanics targeting the three age-related disabilities, which allows the customization of the training components. The game mechanics ensures the implementation of training requirements, so that the training needs—as defined by the therapist—can be fulfilled in each training session. Gamification techniques and usability guidelines are incorporated for better user experience and motivation.

This study aims to describe the development and the theoretical foundations of the new exergame solution. We discuss how the proposed game mechanics adapts to the training needs of older adults with different age-related impairments and, simultaneously, how it answers to the needs of personalization and multicomponent progressive training in older adults. Finally, we discuss the challenges of the game design process and summarize a set of considerations for interaction design and implementation.

2. Related Work

Several exergames have been proposed to target mobility limitations, cognitive impairment, or urinary incontinence (Table 1). In 2015, the iStopFalls consortium proposed the development of an innovative home-based solution for fall prevention, comprising exergames for balance and cognition provided by a Kinect-based solution [46]. In more recent studies, Kinect continues to be the first choice when it comes to tracking and evaluating full-body movements [31,44,47]. However, according to [52], more than one Kinect sensor should be used to accurately track complex human movement sequences, which may compromise application in real scenarios.

Inertial sensors have been used by [45] in a previous project, Active@Home, to track the movements of the upper and lower limbs. To interact with the game, users had to point to the screen (like a cursor), or perform multidirectional steps (to interact with motor-cognitive games). Older adults had some difficulties alternating interaction with the cursor and the with the feet. The usability study also revealed some difficulties in visualizing movement feedback elements (while following an avatar), although these elements were placed as close as possible to the main action of the game [45]. The movements of the avatar were very clear and easy to understand. Due to the position of the sensor at the ankle, multidirectional steps could not always be correctly evaluated, which caused some frustration. The usability study recommended the inclusion of in-game design strategies to support interaction and autonomous use [45].

A freeware dance program, StepMania, was combined with pelvic floor muscle training, achieving some promising results [48,53]. The game required users to step in the direction of the arrows that reached the top of the screen; pelvic floor muscle contractions were represented by a red dot incorporated in the sequence of arrows [53]. The study did not include any gamification or game design concerns [48,53]. In [37], the pelvic floor muscle training was provided resorting to an adaptation of a Wii Fit Plus™ exergame. Women would sit on the Wii Balance Board, and interact with the exergame resorting to pelvic movements. This intervention promoted a decrease in urinary symptoms; however, usability and game experience were not evaluated [37].

In [44] an augmented reality exergame was developed that combines a representation of the user body with a virtual environment. In [31], a virtual reality approach is employed, in which participants are required to wear virtual reality glasses. Although virtual and augmented reality promises many benefits for older adults, the use of these tools is still challenging due to lack of access and digital skills [54].

When designing exergames for older adults, the contents, mechanics, and interface of the exergames need to be tailored to the target group, considering their specific characteristics. Exergames designed specifically for older adults (as is the case of some of those presented in Table 1) incorporate some of the best practices for designing for older adults. Feedback, progression, time constraints and scores are considered particularly relevant for older persons' perceived performance while holding a training session [43]. Training principles such as feedback, optimal challenge and progression, and variety are also required for an effective training [23,38,49].

To improve training variety, studies usually integrate multiple exergames that target different components of the training. However, individual training times (of each training component) cannot be personalized, leaving it up the player to control training times as instructed by the clinician or researcher [48–50]. Current exergames offer no solutions for the simultaneous (multicomponent) training of mobility limitations, cognitive impairment, and urinary incontinence, even though these impairments frequently coexist in older adults.

Table 1. Exergames for motor-cognitive and pelvic floor muscle training in older adults.

Lead Author (Year)	Description	Technology	Limitations
Chen (2020) [44]	Three augmented reality exergames for simultaneous motor (strength and balance) and cognitive (attention, memory, and executive functions) training.	Kinect	Individual training times cannot be personalized. Training times are not ensured by the game.
Zhang (2021) [47]	The exergame combines cognitive and physical tasks to improve older adults' cognitive inhibition. The theme of the game (table tennis) is chosen considering the local popularity of this sport.	Kinect	Lack of progression mechanisms. Only cognitive inhibition and one type of physical exercise are targeted by the exergame.
Guimarães (2018) [45]	An exergame solution comprising dance (for balance), Tai Chi-inspired exercises (for strength) and motor-cognitive training. Dance and Tai Chi exercises are provided by a virtual instructor (3D Avatar).	Inertial sensors	Individual training times cannot be personalized. Training times are not ensured by the game.
Marston (2015) [46]	Three exergames for dynamic balance and stability based on weight shifting, knee bending and stepping. In addition, each exergame contains a cognitive component: memory, inhibition, and selective attention.	Kinect	Individual training times cannot be personalized. Training times are not ensured by the game.
Liao (2019) [31]	Two virtual reality-based physical training games and three virtual reality-based cognitive training games for people with mild cognitive impairment.	Kinect	Lack of progression mechanisms. Individual training times cannot be personalized.
Fraser (2014) [48]	A dancing (stepping) exergame combined with stimuli for pelvic floor muscle contractions.	Dance pad	Lack of progression mechanisms.
Botelho (2015) [37]	An exergame for the training of pelvic floor muscles. Women would sit on a pressure platform, and command the game through their pelvic movements.	Wii Balance Board	Not designed specifically for older adults.

3. Materials and Methods

The project VITAAL aimed at creating a technological solution—an exergame—to support personalized and multicomponent clinical interventions for older adults with mobility limitations, cognitive impairment, and/or urinary incontinence, while catering for individual capabilities and progress. Motivating the person through fun and entertainment was also an important goal of the project.

VITAAL was structured in three phases: investigation, development, and trials [51]. The investigation phase aimed at understanding user needs and expectations, for which partners in the project conducted a survey with end-users and a focus group with clinicians, whose results are reported elsewhere [51]. The development phase comprised the actual development of the solution using the methods thoroughly documented and discussed in this work. Following the development phase, the project foresees two evaluation loops that will assess (i) the acceptability and game experience of the users, and (ii) the feasibility of the intervention. In this study, we focus on the design and development of the VITAAL exergame solution.

The design and development of the VITAAL exergame considered inputs from older adults (resulting from the investigation phase of the project [51], and from the feedback obtained in a previous study [45]) and from a multidisciplinary team, including game designers, developers, user experience/user interface (UX/UI) designers, movement scientists, end-users, and clinicians. Through a set of meetings, and following an iterative design process, they helped us to specify the structure and contents of the exergame, ensuring its adequacy concerning training requirements, game design principles, and end-user characteristics.

In this section, we specify (i) the training requirements, (ii) the game mechanics, (iii) the game design, (iv) the minigames, (v) the evaluation and automatic progression adaptation, and (vi) the implementation details.

3.1. Training Requirements

Training requirements were identified with the help of clinicians—physiotherapists—and movement scientists with experience in geriatric rehabilitation. They all agreed that an exergame mostly based on the execution of multidirectional steps would fit the needs of the target population. Plus, multidirectional steps could be performed while answering to specific cognitive tasks, or contracting the pelvic floor muscles, which could largely improve the outcomes of the training [48,55]. Considering that most daily life activities require simultaneous performance of physical and cognitive functions, combining physical and cognitive exercises in a single exergame solution would potentially boost the benefits of both exercises [55].

According to the team, balance training should focus on the execution of multidirectional steps which have been previously recommended to prevent falls in older adults [56]. For optimal progression, the sequence and speed of steps should become increasingly challenging [57].

For strength training, exercises could be inspired by Tai Chi movements and focus on the hip, knee, ankle, and trunk muscles, as in a previous project Active@Home [45,49]. These exercises are mainly based on narrow and wide squats and should become increasingly challenging for optimal progression [49,58]. The team was responsible for defining the exercises, the number of repetitions and sets, and the progression within the exergame.

Cognitive training should focus on attention and executive functions (e.g., memory, reaction time, mental flexibility, and inhibition control) which are critical to control gait and walk safely [59]. For optimal load, the difficulty of the tasks must adapt to the person's abilities [38].

Exercises targeting urinary incontinence should involve strength (maximal contraction), endurance (repetitive or sustained contraction), and coordination (contraction prior to effort, e.g., prior to cough) training of the pelvic floor muscles [60]. For progression, pelvic floor muscle training should occur with multidirectional steps, following the challenges of the game [48]. The progressive training should increase the intensity and number of pelvic floor muscle contractions in line with patient performance [23,60]. The progression was defined by physiotherapists with experience on the treatment of urinary incontinence.

Studies recommend regular motor-cognitive training (targeting balance, strength, and cognition) in all three disabilities—mobility limitations, cognitive impairment, and urinary incontinence [48,61–63]. Additionally, women with geriatric incontinence should perform exercises for the training of the pelvic floor muscles [22]. The exergame should allow the training of the four training components, i.e., strength, balance, cognitive, and pelvic floor muscle training, in one single session. By personalizing the training times of each component, and adjusting its load, individual training needs should be optimally addressed [64].

3.2. Game Mechanics

To allow the integration of multiple training components within the game, we have structured it in a set of themes. The game mechanics was inspired on the SIMS (Electronic Arts Inc. (EA)) series of games, in which players take care of their virtual entities. In VITAAL exergame, the player should "take care" of each theme, ensuring that progress bars—associated with each theme—should be full by the end of the training session. Game mechanics was defined by game designers, together with a UX/UI designer, and considering the feedback from clinicians and movement scientists, to answer to the training requirements defined in Section 3.1.

Each training component (i.e., balance, strength, cognitive, and pelvic floor muscle training) was associated with one or more themes within the game. The themes were identified to target older adult preferences and interests—important to ensure adherence to the game [40]. The selected themes—nature, library, kitchen, farm, and supermarket—are related to the hobbies that were most commonly reported by older adults during the investigation phase [51]. Each theme includes two minigames targeting a single training component. Training components, themes, and minigames are depicted in Figure 1.

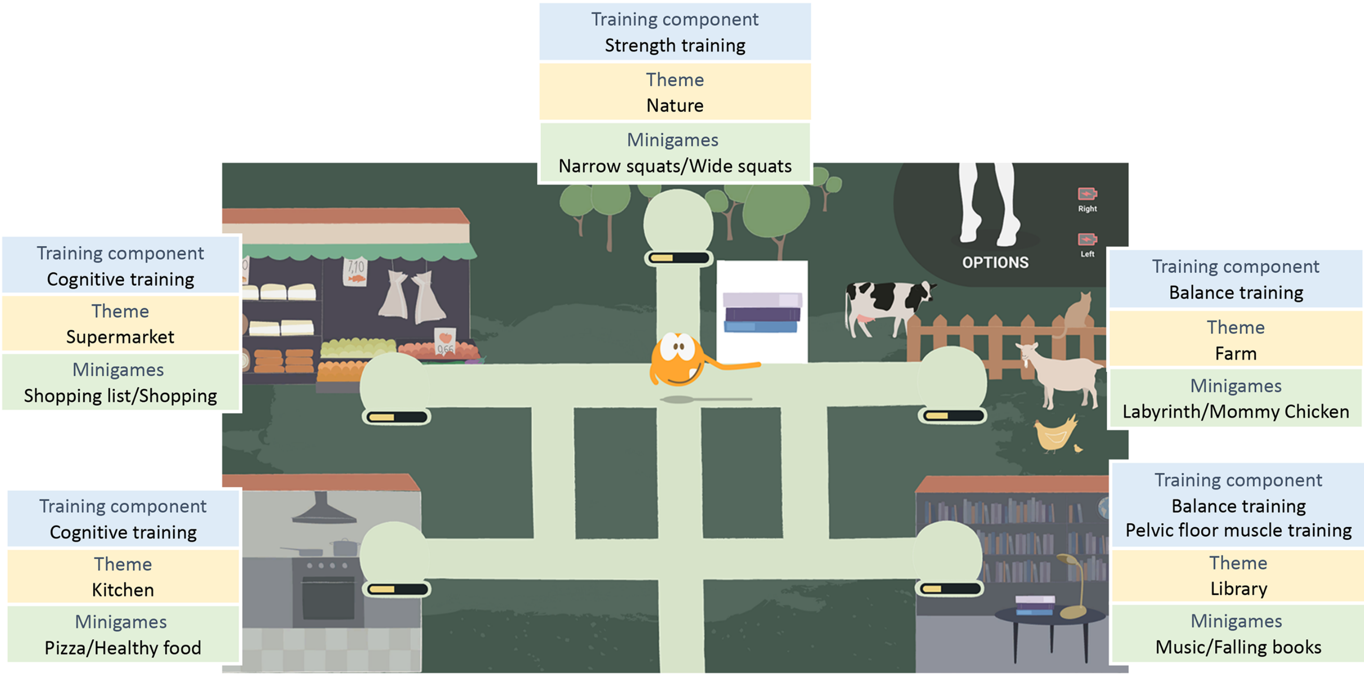

Figure 1. Main board: Training components, themes and minigames.

The game mechanics is illustrated in Figure 2 using a machinations diagram—a type of diagram used to describe game mechanics and its emerging gameplay dynamics [65]. Each progress bar has an initial state that is proportional to the prescribed training time (*b*)—defined by the therapist for a specific training component—within the total session time (*a*)—the total time of the session is the sum of the individual times prescribed for each training component. To update the status of the progress bar, the player should perform certain tasks (play minigames). The total time played (*c*) is used to update the status of the bar, which should increase proportionally to the percentage of time played (*e*). Progress bars provide information on training completion, and are used to guide the player through the themes and ensure the fulfilment of training needs—as defined by the therapist.

To ensure that recommended training times are not exceeded, the game engine also manipulates the duration of the minigames. This calculation is performed once when the player starts a new training session. The player is always able to repeat a minigame, even if the progress bars indicate 100% completion; when 100% is reached, the training times—as prescribed by the therapist—have been fulfilled.

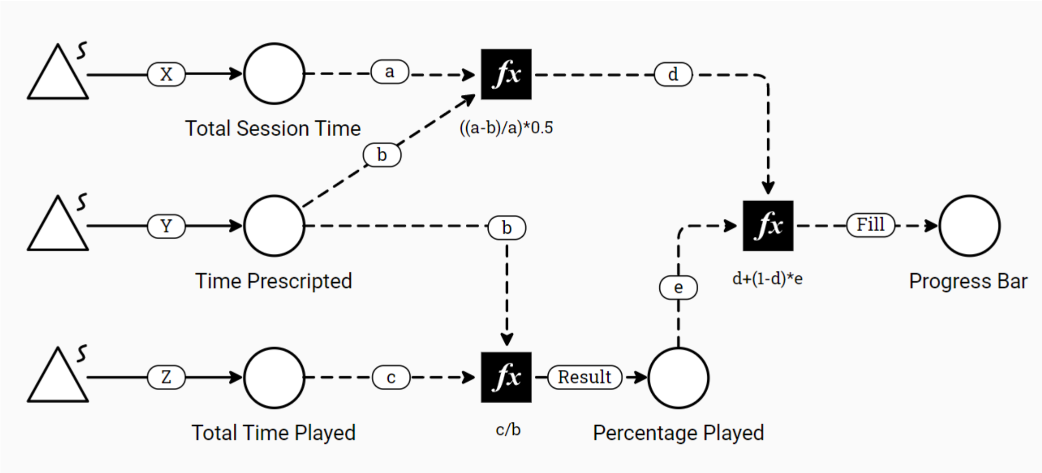

Figure 2. Game mechanics: initializing and updating the status of a progress bar.

3.3. Game Design

Previous literature pointed out several guidelines for designing for older adults [66–68]. Gamification strategies, within game mechanics and dynamics, had been implemented and experienced, in more serious contexts, as a means to enhance enjoyment and motivation towards the tasks [69]. Moreover, gamification techniques applied to elderly care have proven benefits, also challenges, for these group [43]. Our previous experience in designing exergames for older persons [45,70], have witnessed the impact of certain gamification techniques on older persons performance reflected in a positive engagement, despite some initial issues related to a first usage. VITAAL exergame makes use of several game design elements, namely feedback, progression, time constraints and scores—considered particularly relevant for older persons' perceived performance while holding a training session [43].

Game design, gamification strategies, and user experience were developed by a UX/UI designer with experience in designing exergames for older adults, considering feedback from clinicians—physiotherapists—movement scientists and game designers.

3.3.1. User Interface

VITAAL exergame user interface is based on grounded requirements for usability regarding older persons' experience with technological systems. The interface is designed to be displayed on a PC or TV monitor, placed at a suitable distance to ensure sufficient free space for the players' body movements, without compromising the proper visualization, and understanding, of what is being displayed. Realistic and unambiguous graphics should be considered for this purpose.

The user interface sought aimed to provide: (i) a good shape-understanding within a simple and unambiguous visual representation, e.g., characters' frontal view representation to be more easily recognized, contrasting colors, and proper dimensions, (ii) a clear distinction of actionable elements by its shape, color, size, and interactive state behavior, and (iii) auditory feedback to reinforce in-game actions and events.

3.3.2. Interaction

VITAAL exergame user interaction relies on specific movements, previously aligned with the training requirements that act as commands to play the game, i.e., multidirectional steps, to provide forward, backward, right, and left commands, and elevation of the heels (adapted from the calf rises from the Otago Exercise Program [71]) to pause the game and access the Options menu. The detection of these movements was performed using the data collected from inertial sensors placed on the feet, as described in [72]. Alternatively, people with severe physical limitations may use a computer keyboard as a game controller, which in this case may limit the interventions to the cognitive training component. Older adults may also play with the support of a walker, a cane, or alike.

To learn and experience the movements effectively, in a fun and contextualized setting, the design team proposed: (i) an in-game tutorial (as recommended by [45]) for the player to try the stepping, to learn how to open the Options menu and to be introduced to the progress bar, and (ii) a main character, named Vita (Figure 3) that represents the player within its position and action in-game. Vita floats from one place to another (instead of walking, to discourage players from moving in physical space), it gives feedback on the performance through its bold and animated expressions, while evoking an empathic and joyful atmosphere free of prejudice and discriminatory stereotypes.

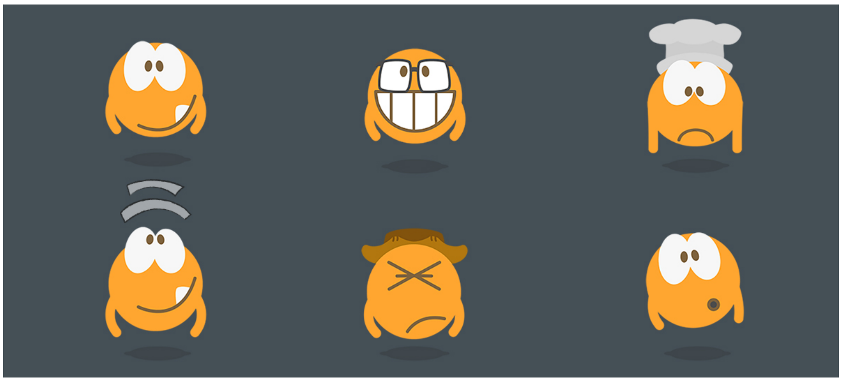

Figure 3. The main character, Vita.

3.3.3. Game Experience

VITAAL exergame experience (shown in Figure 4) is quite dependent on the training requirements, via specified body movements and cognitive exercises. In this regard the design team sought to keep the player motivated and engaged by balancing challenge and fun as follows: (i) distributing types and number of exercises by several minigames with different scenes and goals to promote variety and avoid monotony, (ii) adapting the difficulty level of each game according to the individual in-game progression to prevent frustration and foster learnability, and (iii) providing one single instruction and focus at a time to avoid an overwhelming experience. Through game mechanics progression and different difficult levels, we sought to answer to different user profiles.

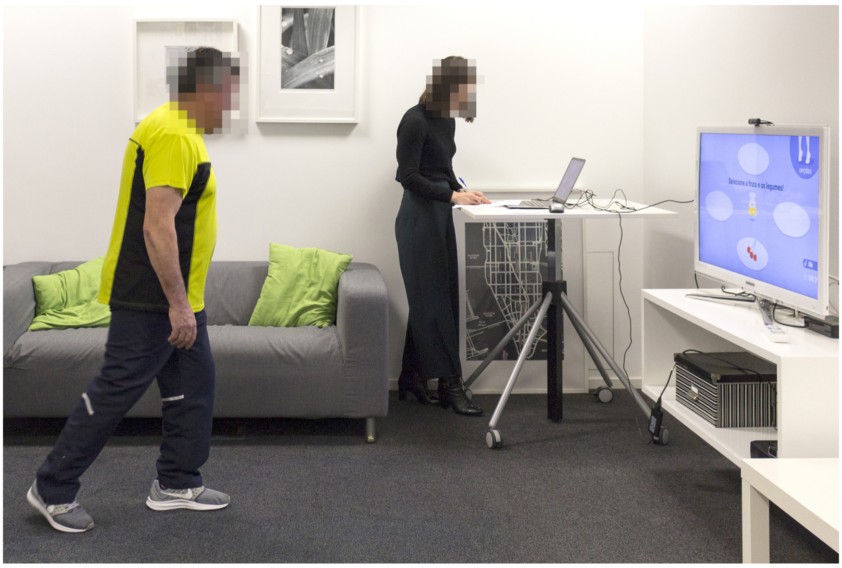

Figure 4. VITAAL exergame gameplay: interacting with the exergame by performing multidirectional steps.

3.4. Minigames

Six of the ten minigames developed for VITAAL are shown in Figure 5. Game designers, a UX/UI designer, clinicians and movement scientists were involved in the definition of the tasks and the specific objectives of each minigame. Additionally, the team relied on the feedback and developments performed under the scope of a previous project, Active@Home, which already included cognitive games based on multidirectional steps, and strength training based on Tai Chi-inspired exercises [45,49]. These games served as a basis for the development of minigames in VITAAL.

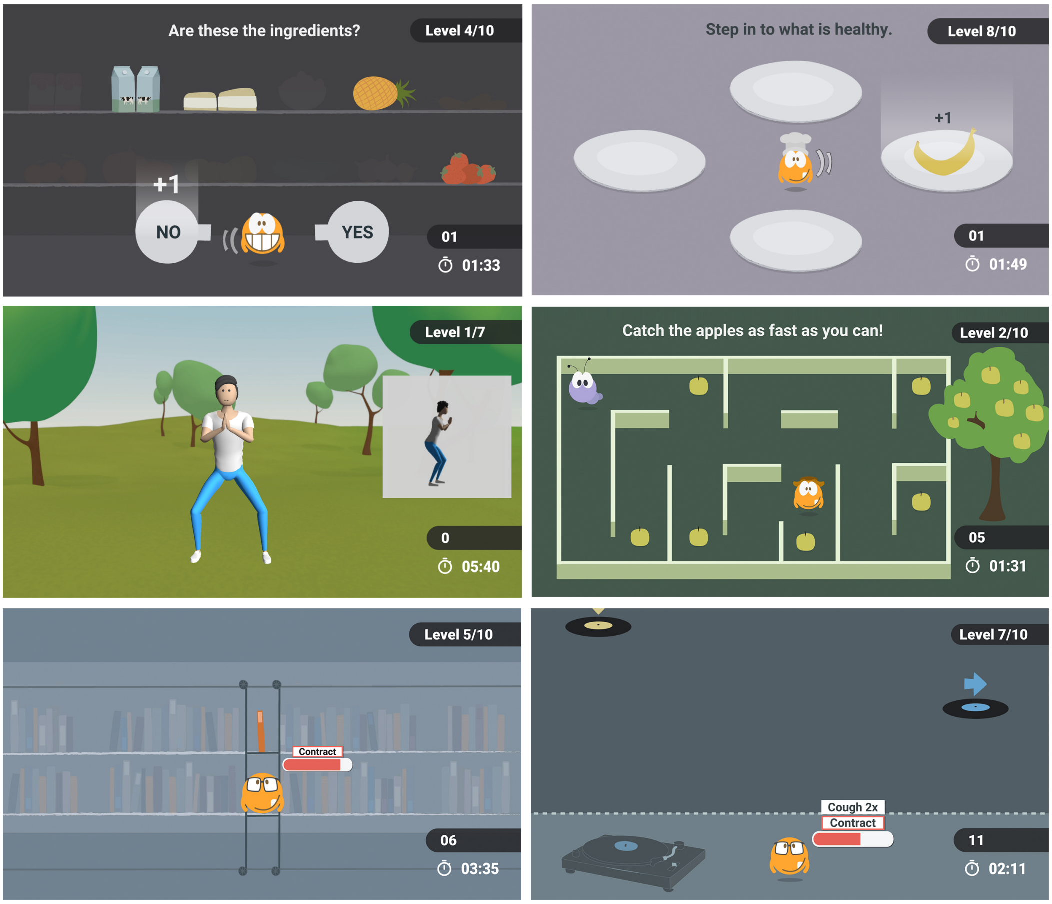

Figure 5. Six of the ten minigames. From left to right, top to bottom: Shopping list, Healthy food, Wide squats, Labyrinth, Falling books, and Music (the last two with the additional stimuli for pelvic floor muscle training in isolation or in coordination with a cough).

The tasks within minigames were defined according to the training components they represent: (i) *Cognitive training* focuses on cognitively challenging tasks that prompt the player to use multidirectional steps to provide 2- or 4-fold decisions; for instance, in the *Shopping list* minigame (Figure 5) users have a limited time to memorize a list of products and then confirm whether the products on the shelf correspond to those previously visualized or not; the *Healthy food* minigame (also shown in Figure 5) is an example of inhibition control that requires the patient to select healthy food as fast as possible, avoiding the selection of unhealthy food; (ii) *Strength training* tasks require the players to follow the movements of a virtual instructor who performs Tai Chi-inspired exercises based on narrow and wide squats; for better guidance, a frontal and lateral view of the avatar movement is provided (Figure 5); (iii) *Balance training* focuses mostly on steps that need to be performed to control Vita's movement towards an appropriate direction; for example, in the *Labyrinth* minigame (shown in Figure 5) users must avoid the worm and catch the maximum number of apples as fast as possible; (iv) *Pelvic floor muscle training* also focuses on quick and precise steps, where an additional stimulus to voluntarily contract the pelvic floor muscle (in isolation or in coordination with a cough) is included; these stimuli appear while playing the minigames *Falling books* and *Music*, as an additional task (Figure 5); when pelvic floor muscle training is not prescribed, these minigames will only target the balance training component.

A full description of all minigames developed for VITAAL is provided in Table 2.

Table 2. Minigames for motor-cognitive and pelvic floor muscle training.

Minigame	**Training Component(s)**	**Description**
Shopping list	Cognitive training (short-term memory)	Users have a limited time to memorize a list of products and then confirm whether the products on the shelf correspond to those previously visualized or not.
Shopping	Cognitive training (flexibility, divided attention)	In this game, the player needs to select whether two presented objects match in shape or in color. The correct answer evaluates the trueness or falseness of a sentence referring to the objects.
Healthy food	Cognitive training (inhibition)	The player must select healthy food as fast as possible, avoiding the selection of unhealthy food.
Pizza	Cognitive training (flexibility, selective attention)	The player must select the pizza slice that is pointing in the wrong direction while suppressing the impulse to select the most common direction.
Wide squats	Strength training	The player should follow the movements of a virtual instructor who performs Tai Chi-inspired exercises based on wide squats.
Narrow squats	Strength training	The player should follow the movements of a virtual instructor who performs Tai Chi-inspired exercises based on narrow squats.
Labyrinth	Balance training	The player must guide Vita inside the labyrinth to avoid the worm and catch the maximum number of apples as fast as possible.
Mommy chicken	Balance training	The player should catch as many eggs as possible, stealing them from the respective nests. Caution is required to avoid being caught by the chickens.
Falling books	Pelvic floor muscle training and/or balance training	The player should catch the maximum number of books, preventing them from falling off the bookshelves.
Music	Pelvic floor muscle training and/or balance training	In this game, the player must collect as many records as possible to score points. Special records will score additional points and switch to a different music style.

3.5. Evaluation and Automatic Progression Adaptation

Minigame scores reflect the performance of the player on a specific task, for instance, based on the number of right answers and average reaction time, the number of elements picked or, if applicable, the number of pelvic floor muscle contractions correctly performed.

The performance of strength training-related tasks is not evaluated within VITAAL, being maximum score achieved upon completion of the task. The team considered that by mirroring the movements of the avatar, older adults would challenge and strengthen their muscles—even without an objective evaluation and feedback for movement correctness. Reducing system complexity (using only two inertial sensors that evaluate the movements of the feet) was preferred over the use of additional sensors for full-body movement evaluation.

The exergame employs automatic progression adaptation that manipulates task difficulty and load. Each minigame includes a set of difficulty levels (a set of predefined game parameters that affect the difficulty of the game) and criteria (a set of predefined rules that describe when the player level should maintain, increase, or decrease). Difficulty levels were defined by game designers, with the support from clinicians and movement scientists, to ensure their adequacy concerning different training needs and end-user characteristics. Strength training exercises were arranged in a progressive order of difficulty, as defined by clinicians and movement scientists. The continuous adaptation of difficulty levels would ensure a progressively increasing training load and optimal challenge to prevent under- and overload [49].

The progression to the next (or previous) difficulty level is based on the scores achieved in previous training sessions. By default, all players start at the minimum difficulty level. If the last score of a task is excellent (above 90%), the difficulty level will automatically increase for the next play; otherwise, the average score of the last three plays—performed in the same level of difficulty—is used; the average score will decide whether the difficulty level should decrease (score below 50%), maintain (score between 50% and 75%), or increase (score above 75%). This set of rules apply to all tasks, except strength training-related tasks, where the fixed criteria of completing the task at least 5 times is enough to progress to the next level.

3.6. Implementation

The exergame was developed using the Unity Engine and compiled as a web-based tool to be readily accessible in any system without installation. Bluetooth® Low Energy-enabled inertial sensors—small size, portable, placed on the shoes, equipped with an accelerometer and a gyroscope—were used to monitor player movements (as described in [72]). Women with geriatric urinary incontinence may also use a vaginal dynamometer (tampon inserted into the vagina) [73] to monitor the pelvic floor muscle activation and strength while playing games for the treatment of urinary incontinence. Connection with Bluetooth devices was performed via browser using the Web Bluetooth API [74].

The VITAAL exergame was integrated with a backend (database) in connection with a clinician portal built on the Dividat Manager [75]. Among other functionalities, the backend allows recording session data, e.g., scores achieved, or training times. The clinician portal provides the clinician the ability to specify training times for a specific patient as well as perform and record standardized assessments, allowing further progress tracking and refinement of training plans [75]. Minigame parameters—e.g., scores, reaction time, difficulty level, time played—are displayed on the clinician portal through a set of graphs and tables that allow the clinician to follow the evolution of the parameters over time. System architecture is shown in Figure 6.

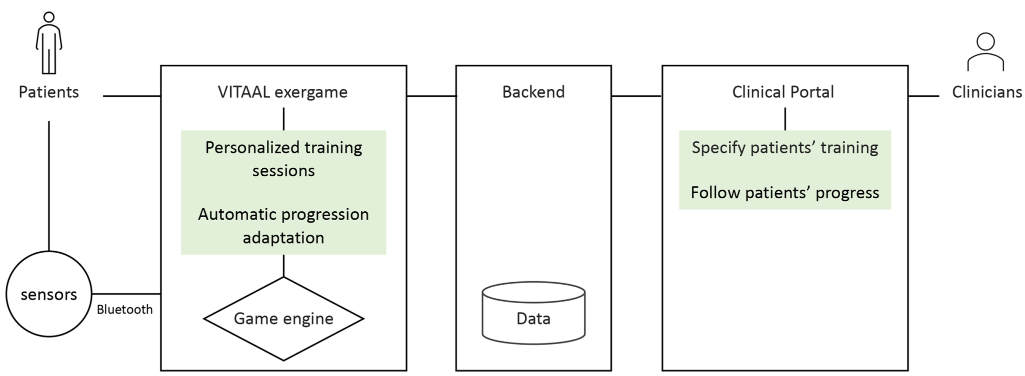

Figure 6. System architecture.

The system architecture was proposed to support exergame use by autonomously living older adults at their homes. Through the clinician portal, the clinician can remotely follow their patients' progress, as well as specify and refine training plans according to their individual progress. To play at home, patients need a laptop or PC, internet connection, and a set of sensors. Their data are recorded and stored on the backend, so that their progress can be followed over time. Alternatively, older adults (e.g., older adults living in residential care facilities) may play the exergame in a rehabilitation setting or long-term care facility, under the guidance of the clinician—as an alternative to conventional training. Under this scenario, the same equipment—laptop or PC and the set of sensors—can be shared, provided that each patient will use their credentials to sign into the game.

4. Results and Discussion

Studies recommend a multicomponent and personalized training approach for older adults with mobility limitations, cognitive impairment, and urinary incontinence [4,9,23,76]. Although exergames contribute to increased training motivation and can be used as an alternative to conventional training, current exergames fail to incorporate interventions for all required training components in one single session. To address this gap in the literature, we developed the VITAAL exergame, a personalized multicomponent approach for the geriatric rehabilitation of older adults with mobility limitations, cognitive impairment, and/or urinary incontinence.

Training requirements were evidence-based and adapted by the research team so that the training needs of the person should be optimally addressed and framed within the context of the exergame. The game design process sought to combine an effective intervention—within the specified clinical guidance—with concepts of gaming and enjoyment. The iterative design process, involving a multidisciplinary team, was crucial for the proper integration of all requirements and perspectives.

We developed an exergame solution comprising interventions for strength, balance, cognition, and pelvic floor muscle training. The clinician could specify the training times of each component, such that the intervention could adapt to the individual training needs of the patient. A set of progress bars provided information on training completion, guiding the player through the themes and ensuring the fulfilment of training needs as defined by the therapist. Other existing solutions relied on the player to control training times, assuming compliance with verbal or written instructions given by the therapist [48–50]. Our solution could manage training times automatically based on training requirements (obtained from the clinician portal) and player training times.

Ideal game experience and intervention requirements had to be balanced with the technical constraints on a take-home solution. For instance, the interaction—defined based on the movements that would suit an effective intervention—constrained the game narrative and user interface, as commands were limited to the four directions (plus the additional movement—calf rises—to access game menus). Moreover, driven by the requirement of providing an effective clinical intervention with a sustained and rich user experience, we avoided a game design based on linked stories and favored an implementation with unlimited replay value. On one side, we dropped all potential advantages of having linked stories—concerning engagement, motivation, etc. [77]; on the other side, we created a self-sustained concept: if it is sufficiently engaging and motivating, there is potential for continued play [78]. To improve game experience and user motivation, we have incorporated other gamification construction elements, such as feedback, progression, time constraints, and score [43]. According to [69], it is important to ensure an adequate level of gamification, as excessive elements may distract users from the main purpose of the activities. By design, the exergame allows the seamless integration of new contents, possibly contributing to sustain players engagement in the long-term [78], or even adapt the exergame to other disabilities.

Many exergame solutions use floor plates to support player interaction with respect to their movements [40]; others use handheld devices—e.g., the Wii Remote—that work as remote controls to interact with the game interface [40]. To evaluate full-body movements, Kinect is usually the preferred choice [31,44,47], although accuracy drops when more complex movements are executed [52]. In a previous work, four inertial sensors were used to track upper and lower limb movements, which added some complexity regarding interaction and system setup [45]. Yet, inertial sensors were considered a viable approach to monitor movements in the context of exergaming [45,79]. In this work we opted for using only two inertial sensors—placed on the feet—to simplify setup and reduce costs. However, complete movements (e.g., the strength training-related tasks) could not be evaluated. Reducing system complexity was preferred over the use of additional sensors for full-body movement evaluation. The use of the vaginal dynamometer was optional for women with urinary incontinence wanting to confirm pelvic floor muscle contraction.

We opted for a web implementation of the exergame to ensure cross-platform compatibility and easy access without installation. The complexity of the graphical game contents was adapted to meet the continuously increasing, but relatively limited performance of web browsers. Bluetooth-enabled devices could connect via web, allowing data processing in real time and interaction (and feedback) without any noticeable delay.

The VITAAL exergame was designed for use at clinics or at home—after an introductory session, the technical solution should promote independent use, with or without the support of a (remote) caregiver. Training at home is currently considered an alternative and/or complement to the training at clinics, allowing better access to services (e.g., in the context of a pandemic), promoting the continuity of treatments, and overcoming barriers related to the lack of resources at clinics [80]. The exergame operated in connection with a clinician portal that, besides allowing training specification, enabled the remote supervision of the training by the clinician. According to [81], exergames that fit older adults' characteristics and needs can be used to counteract the consequences of confinement and hospitalization, such as increased vulnerability, decreased functional capacity, and dependency. VITAAL may also find application in these contexts.

Lessons Learned

This study proved to be possible to incorporate multiple training components, specifically, balance, strength, cognition and pelvic floor muscle training, in a single exergame solution, relying on an interaction with multidirectional steps and inertial sensors placed on the feet. Although being simple, the interaction constrained game narrative and the evaluation of full-body movements. As a web-based solution, the exergame allowed cross-platform compatibility, and could communicate with Bluetooth devices without any noticeable delay. A vaginal dynamometer could be integrated to provide feedback to older women wanting to confirm pelvic floor muscle contractions. The connection with a clinician portal allows clinicians to remotely follow patient training at home, as well as prescribe and change interventions. These functionalities may support better access to services, e.g., in the context of a pandemic. The game mechanics allows adaptation to different training requirements, and ensures automatic control of training times as prescribed by the therapist. The game design and mechanics can be adapted to additional interventions.

5. Conclusions

Exergames are a promising approach to counteract age-related impairments such as mobility limitations, cognitive impairment, and urinary incontinence. To optimally address these conditions, exergames should include interventions for strength, balance, cognition and pelvic floor muscle training, in one single session. To address this requirement, we developed the VITAAL exergame, a solution for the geriatric rehabilitation of mobility limitations, cognitive impairment, and urinary incontinence. The solution incorporates a game mechanics that ensures the fulfilment of training needs as specified by the therapist. By personalizing the training times of each component, and adjusting its load, individual training needs should be optimally addressed. The exergame is cross-platform compatible, includes automatic progression adaptation, and novel means of interaction with wearable sensors.

Future work should assess interaction, usability and game experience of the newly developed exergame. These aspects shall be assessed with prospective users in a future study, ensuring the continuity of the iterative design process. The feasibility of the intervention shall be explored in a subsequent study.

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References

1. Morley, J.E. The New Geriatric Giants. *Clin. Geriatr. Med.* **2017**, *33*, xi–xii. [CrossRef]
2. Rubenstein, L.Z. Falls in older people: Epidemiology, risk factors and strategies for prevention. *Age Ageing* **2006**, *35* (Suppl 2), ii37–ii41. [CrossRef]
3. Yu, W.C.; Chou, M.Y.; Peng, L.N.; Lin, Y.T.; Liang, C.K.; Chen, L.K. Synergistic effects of cognitive impairment on physical disability in all-cause mortality among men aged 80 years and over: Results from longitudinal older veterans study. *PLoS ONE* **2017**, *12*, e0181741. [CrossRef] [PubMed]
4. Li, H.; Chen, K.; Hsu, H. Modelling factors of urinary incontinence in institutional older adults with dementia. *J. Clin. Nurs.* **2019**, *28*, 4504–4512. [CrossRef]
5. Grande, G.; Triolo, F.; Nuara, A.; Welmer, A.K.; Fratiglioni, L.; Vetrano, D.L. Measuring gait speed to better identify prodromal dementia. *Exp. Gerontol.* **2019**, *124*, 110625. [CrossRef] [PubMed]
6. Kim, K.J.; Shin, J.; Choi, J.; Park, J.M.; Park, H.K.; Lee, J.; Han, S.H. Association of Geriatric Syndromes with Urinary Incontinence according to Sex and Urinary-Incontinence–Related Quality of Life in Older Inpatients: A Cross-Sectional Study of an Acute Care Hospital. *Korean J. Fam. Med.* **2019**, *40*, 235–240. [CrossRef]
7. Le Berre, M.; Morin, M.; Corriveau, H.; Hamel, M.; Nadeau, S.; Filiatrault, J.; Dumoulin, C. Characteristics of Lower Limb Muscle Strength, Balance, Mobility, and Function in Older Women with Urge and Mixed Urinary Incontinence: An Observational Pilot Study. *Physiother. Can.* **2019**, *71*, 250–260. [CrossRef]
8. Wagg, A.; Lee, R. Urinary Incontinence in People Living with Cognitive Impairment. *Curr. Geriatr. Rep.* **2021**, 1–8 [CrossRef]
9. Sadjapong, U.; Yodkeeree, S.; Sungkarat, S.; Siviroj, P. Multicomponent Exercise Program Reduces Frailty and Inflammatory Biomarkers and Improves Physical Performance in Community-Dwelling Older Adults: A Randomized Controlled Trial. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3760. [CrossRef]
10. Kim, H.; Suzuki, T.; Yoshida, Y.; Yoshida, H. Effectiveness of multidimensional exercises for the treatment of stress urinary incontinence in elderly community-dwelling Japanese women: A randomized, controlled, crossover trial. *J. Am. Geriatr. Soc.* **2007**, *55*, 1932–1939. [CrossRef]
11. Park, H.; Kim, K.J.; Komatsu, T.; Park, S.K.; Mutoh, Y. Effect of combined exercise training on bone, body balance, and gait ability: A randomized controlled study in community-dwelling elderly women. *J. Bone Miner. Metab.* **2008**, *26*, 254–259. [CrossRef] [PubMed]
12. Baker, M.K.; Atlantis, E.; Fiatarone Singh, M.A. Multi-modal exercise programs for older adults. *Age Ageing* **2007**, *36*, 375–381. [CrossRef] [PubMed]
13. Wang, R.Y.; Wang, Y.L.; Cheng, F.Y.; Chao, Y.H.; Chen, C.L.; Yang, Y.R. Effects of a multicomponent exercise on dual-task performance and executive function among older adults. *Int. J. Gerontol.* **2018**, *12*, 133–138. [CrossRef]
14. Song, D.; Yu, D.S.; Li, P.W.; Lei, Y. The effectiveness of physical exercise on cognitive and psychological outcomes in individuals with mild cognitive impairment: A systematic review and meta-analysis. *Int. J. Nurs. Stud.* **2018**, *79*, 155–164. [CrossRef]
15. Sáez de Asteasu, M.L.; Martínez-Velilla, N.; Zambom-Ferraresi, F.; Casas-Herrero, A.; Izquierdo, M. Role of physical exercise on cognitive function in healthy older adults: A systematic review of randomized clinical trials. *Ageing Res. Rev.* **2017**, *37*, 117–134. [CrossRef]

16. Penedo, F.J.; Dahn, J.R. Exercise and well-being: A review of mental and physical health benefits associated with physical activity. *Curr. Opin. Psychiatry* **2005**, *18*, 189–193. [CrossRef]
17. Matsuda, P.N.; Shumway-Cook, A.; Ciol, M.A. The effects of a home-based exercise program on physical function in frail older adults. *J. Geriatr. Phys. Ther.* **2010**, *33*, 78–84.
18. Law, L.L.F.; Barnett, F.; Yau, M.K.; Gray, M.A. Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: A systematic review. *Ageing Res. Rev.* **2014**, *15*, 61–75. [CrossRef] [PubMed]
19. Fritz, N.E.; Cheek, F.M.; Nichols-Larsen, D.S. Motor-Cognitive Dual-Task Training in Persons With Neurologic Disorders: A Systematic Review. *J. Neurol. Phys. Ther. JNPT* **2015**, *39*, 142–153. [CrossRef]
20. Ogawa, E.F.; You, T.; Leveille, S.G. Potential Benefits of Exergaming for Cognition and Dual-Task Function in Older Adults: A Systematic Review. *J. Aging Phys. Act.* **2016**, *24*, 332–336. [CrossRef]
21. Amjad, I.; Toor, H.; Niazi, I.K.; Pervaiz, S.; Jochumsen, M.; Shafique, M.; Haavik, H.; Ahmed, T. Xbox 360 Kinect Cognitive Games Improve Slowness, Complexity of EEG, and Cognitive Functions in Subjects with Mild Cognitive Impairment: A Randomized Control Trial. *Games Health J.* **2019**, *8*, 144–152. [CrossRef]
22. Bettez, M.; Tu, L.M.; Carlson, K.; Corcos, J.; Gajewski, J.; Jolivet, M.; Bailly, G. 2012 update: Guidelines for adult urinary incontinence collaborative consensus document for the canadian urological association. *Can. Urol. Assoc. J.* **2012**, *6*, 354–363. [CrossRef]
23. Dumoulin, C.; Cacciari, L.P.; Hay-Smith, E.J.C. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women. *Cochrane Database Syst. Rev.* **2018**, *10*, CD005654. [CrossRef]
24. World Health Organization. *WHO Guidelines on Physical Activity and Sedentary Behaviour*; Guideline; World Health Organization: Geneva, Switzerland, 2020; ISBN 9789240015128.
25. Valenzuela, T.; Okubo, Y.; Woodbury, A.; Lord, S.R.; Delbaere, K. Adherence to Technology-Based Exercise Programs in Older Adults: A Systematic Review. *J. Geriatr. Phys. Ther.* **2018**, *41*, 49–61. [CrossRef]
26. Meekes, W.; Stanmore, E.K. Motivational Determinants of Exergame Participation for Older People in Assisted Living Facilities: Mixed-Methods Study. *J. Med. Internet Res.* **2017**, *19*. [CrossRef]
27. Stanmore, E.; Stubbs, B.; Vancampfort, D.; de Bruin, E.D.; Firth, J. The effect of active video games on cognitive functioning in clinical and non-clinical populations: A meta-analysis of randomized controlled trials. *Neurosci. Biobehav. Rev.* **2017**, *78*, 34–43. [CrossRef]
28. Gerling, K.; Mandryk, R. Custom-designed motion-based games for older adults: A review of literature in human-computer interaction. *Gerontechnology* **2014**, *12*, 68–80. [CrossRef]
29. Silva, L.M.d.; Flôres, F.S.; Matheus, S.C. Can exergames be used as an alternative to conventional exercises? *Motriz Rev. Educ. FíSica* **2021**, *27*, e1021020197. [CrossRef]
30. Piech, J.; Czernicki, K. Virtual Reality Rehabilitation and Exergames—Physical and Psychological Impact on Fall Prevention among the Elderly—A Literature Review. *Appl. Sci.* **2021**, *11*, 4098. [CrossRef]
31. Liao, Y.Y.; Chen, I.H.; Lin, Y.J.; Chen, Y.; Hsu, W.C. Effects of Virtual Reality-Based Physical and Cognitive Training on Executive Function and Dual-Task Gait Performance in Older Adults With Mild Cognitive Impairment: A Randomized Control Trial. *Front. Aging Neurosci.* **2019**, *11*, 162. [CrossRef]
32. Zhao, Y.; Feng, H.; Wu, X.; Du, Y.; Yang, X.; Hu, M.; Ning, H.; Liao, L.; Chen, H.; Zhao, Y. Effectiveness of Exergaming in Improving Cognitive and Physical Function in People With Mild Cognitive Impairment or Dementia: Systematic Review. *JMIR Serious Games* **2020**, *8*, e16841. [CrossRef]
33. Soares, V.N.; Yoshida, H.M.; Magna, T.S.; Sampaio, R.A.C.; Fernandes, P.T. Comparison of exergames versus conventional exercises on the cognitive skills of older adults: A systematic review with meta-analysis. *Arch. Gerontol. Geriatr.* **2021**, *97*, 104485. [CrossRef] [PubMed]
34. Alhagbani, A.; Williams, A. Home-Based Exergames for Older Adults Balance and Falls Risk: A Systematic Review. *Phys. Occup. Ther. Geriatr.* **2021**, 1–17. [CrossRef]
35. Pacheco, T.B.F.; de Medeiros, C.S.P.; de Oliveira, V.H.B.; Vieira, E.R.; de Cavalcanti, F.A.C. Effectiveness of exergames for improving mobility and balance in older adults: A systematic review and meta-analysis. *Syst. Rev.* **2020**, *9*, 163. [CrossRef]
36. Viana, R.B.; Oliveira, V.N.; Dankel, S.J.; Loenneke, J.P.; Abe, T.; Silva, W.F.; Morais, N.S.; Vancini, R.L.; Andrade, M.S.; Lira, C.A.B. The effects of exergames on muscle strength: A systematic review and meta-analysis. *Scand. J. Med. Sci. Sport.* **2021**, *31*, 1592–1611. [CrossRef] [PubMed]
37. Botelho, S.; Martinho, N.M.; Silva, V.R.; Marques, J.; Carvalho, L.C.; Riccetto, C. Virtual reality: A proposal for pelvic floor muscle training. *Int. Urogynecol. J.* **2015**, *26*, 1709–1712. [CrossRef] [PubMed]
38. Kappen, D.L.; Mirza-Babaei, P.; Nacke, L.E. Older Adults' Physical Activity and Exergames: A Systematic Review. *Int. J. Hum. Comput. Interact.* **2019**, *35*, 140–167. [CrossRef]
39. Choi, S.D.; Guo, L.; Kang, D.; Xiong, S. Exergame technology and interactive interventions for elderly fall prevention: A systematic literature review. *Appl. Ergon.* **2017**, *65*, 570–581. [CrossRef] [PubMed]
40. Skjæret, N.; Nawaz, A.; Morat, T.; Schoene, D.; Helbostad, J.L.; Vereijken, B. Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy. *Int. J. Med. Inform.* **2016**, *85*, 1–16. [CrossRef]
41. Gerling, K.; Schild, J.; Masuch, M. Exergaming for Elderly: Analyzing Player Experience and Performance. In Proceedings of the Mensch & Computer 2011, Oldenbourg Verlag, Chemnitz, Germany, 11–14 September 2011; pp. 401–411 [CrossRef]

42. Bleakley, C.M.; Charles, D.; Porter-Armstrong, A.; McNeill, M.D.J.; McDonough, S.M.; McCormack, B. Gaming for health: a systematic review of the physical and cognitive effects of interactive computer games in older adults. *J. Appl. Gerontol. Off. J. South. Gerontol. Soc.* **2015**, *34*, NP166–NP189. [CrossRef]
43. Martinho, D.; Carneiro, J.; Corchado, J.M.; Marreiros, G. A systematic review of gamification techniques applied to elderly care. *Artif. Intell. Rev.* **2020**, *53*, 4863–4901. [CrossRef]
44. Chen, M.; Tang, Q.; Xu, S.; Leng, P.; Pan, Z. Design and Evaluation of an Augmented Reality-Based Exergame System to Reduce Fall Risk in the Elderly. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7208. [CrossRef] [PubMed]
45. Guimarães, V.; Pereira, A.; Oliveira, E.; Carvalho, A.; Peixoto, R. Design and evaluation of an exergame for motor-cognitive training and fall prevention in older adults. In Proceedings of the 4th EAI International Conference on Smart Objects and Technologies for Social Good—Goodtechs'18, Bologna, Italy, 28–30 November 2018; ACM Press: Bologna, Italy, 2018; pp. 202–207 [CrossRef]
46. Marston, H.R.; Woodbury, A.; Gschwind, Y.J.; Kroll, M.; Fink, D.; Eichberg, S.; Kreiner, K.; Ejupi, A.; Annegarn, J.; de Rosario, H.; et al. The design of a purpose-built exergame for fall prediction and prevention for older people. *Eur. Rev. Aging Phys. Act.* **2015**, *12*, 13. [CrossRef]
47. Zhang, H.; Shen, Z.; Liu, S.; Yuan, D.; Miao, C. Ping Pong: An Exergame for Cognitive Inhibition Training. *Int. J. Hum. Comput. Interact.* **2021**, *37*, 1104–1115. [CrossRef]
48. Fraser, S.A.; Elliott, V.; de Bruin, E.D.; Bherer, L.; Dumoulin, C. The Effects of Combining Videogame Dancing and Pelvic Floor Training to Improve Dual-Task Gait and Cognition in Women with Mixed-Urinary Incontinence. *Games Health J.* **2014**, *3*, 172–178. [CrossRef] [PubMed]
49. Adcock, M.; Fankhauser, M.; Post, J.; Lutz, K.; Zizlsperger, L.; Luft, A.R.; Guimarães, V.; Schättin, A.; de Bruin, E.D. Effects of an In-home Multicomponent Exergame Training on Physical Functions, Cognition, and Brain Volume of Older Adults: A Randomized Controlled Trial. *Front. Med.* **2020**, *6*, 321. [CrossRef]
50. Gschwind, Y.J.; Eichberg, S.; Ejupi, A.; de Rosario, H.; Kroll, M.; Marston, H.R.; Drobics, M.; Annegarn, J.; Wieching, R.; Lord, S.R.; et al. ICT-based system to predict and prevent falls (iStoppFalls): Results from an international multicenter randomized controlled trial. *Eur. Rev. Aging Phys. Act.* **2015**, *12*, 10. [CrossRef]
51. VITAAL. VITAAL Website. Available online: https://vitaal.fit/ (accessed on 10 May 2021).
52. Ryselis, K.; Petkus, T.; Blažauskas, T.; Maskeliūnas, R.; Damaševičius, R. Multiple Kinect based system to monitor and analyze key performance indicators of physical training. *Hum. Centric Comput. Inf. Sci.* **2020**, *10*, 51. [CrossRef]
53. Elliott, V.; de Bruin, E.D.; Dumoulin, C. Virtual reality rehabilitation as a treatment approach for older women with mixed urinary incontinence: A feasibility study: Virtual Reality to Treat Mixed Urinary Incontinence. *Neurourol. Urodyn.* **2015**, *34*, 236–243. [CrossRef]
54. Seifert, A.; Schlomann, A. The Use of Virtual and Augmented Reality by Older Adults: Potentials and Challenges. *Front. Virtual Real.* **2021**, *2*, 639718. [CrossRef]
55. Herold, F.; Hamacher, D.; Schega, L.; Müller, N.G. Thinking While Moving or Moving While Thinking—Concepts of Motor-Cognitive Training for Cognitive Performance Enhancement. *Front. Aging Neurosci.* **2018**, *10*, 228. [CrossRef]
56. Okubo, Y.; Schoene, D.; Lord, S.R. Step training improves reaction time, gait and balance and reduces falls in older people: A systematic review and meta-analysis. *Br. J. Sport. Med.* **2017**, *51*, 586–593. [CrossRef]
57. Giannouli, E.; Morat, T.; Zijlstra, W. A Novel Square-Stepping Exercise Program for Older Adults (StepIt): Rationale and Implications for Falls Prevention. *Front. Med.* **2019**, *6*, 318. [CrossRef]
58. Buskard, A.N.L.; Jacobs, K.A.; Eltoukhy, M.M.; Strand, K.L.; Villanueva, L.; Desai, P.P.; Signorile, J.F. Optimal Approach to Load Progressions during Strength Training in Older Adults. *Med. Sci. Sport. Exerc.* **2019**, *51*, 2224–2233. [CrossRef]
59. de Bruin, E.D.; Schmidt, A. Walking behaviour of healthy elderly: Attention should be paid. *Behav. Brain Funct. BBF* **2010**, *6*, 59. [CrossRef] [PubMed]
60. Dumoulin, C.; Glazener, C.; Jenkinson, D. Determining the optimal pelvic floor muscle training regimen for women with stress urinary incontinence. *Neurourol. Urodyn.* **2011**, *30*, 746–753. [CrossRef]
61. Schoene, D.; Valenzuela, T.; Lord, S.R.; de Bruin, E.D. The effect of interactive cognitive-motor training in reducing fall risk in older people: A systematic review. *BMC Geriatr.* **2014**, *14*, 107. [CrossRef]
62. Segev-Jacubovski, O.; Herman, T.; Yogev-Seligmann, G.; Mirelman, A.; Giladi, N.; Hausdorff, J.M. The interplay between gait, falls and cognition: Can cognitive therapy reduce fall risk? *Expert Rev. Neurother.* **2011**, *11*, 1057–1075. [CrossRef]
63. Bamidis, P.D.; Vivas, A.B.; Styliadis, C.; Frantzidis, C.; Klados, M.; Schlee, W.; Siountas, A.; Papageorgiou, S.G. A review of physical and cognitive interventions in aging. *Neurosci. Biobehav. Rev.* **2014**, *44*, 206–220. [CrossRef]
64. Healy, A.F.; Kole, J.A.; Bourne, L.E. Training principles to advance expertise. *Front. Psychol.* **2014**, *5*, 131. [CrossRef]
65. Dormans, J. Engineering Emergence: Applied Theory for Game Design. Ph.D. Thesis, University of Amsterdam, Amsterdam, The Netherlands, 2012.
66. Weisman, S. Computer games for the frail elderly. *Gerontologist* **1983**, *23*, 361–363. [CrossRef]
67. Flores, E.; Tobon, G.; Cavallaro, E.; Cavallaro, F.I.; Perry, J.C.; Keller, T. Improving patient motivation in game development for motor deficit rehabilitation. In Proceedings of the 2008 International Conference in Advances on Computer Entertainment Technology—ACE'08, Yokohama, Japan, 3–5 December 2008; ACM Press: Yokohama, Japan, 2008; p. 381. [CrossRef]

68. Marston, H.R. Design Recommendations for Digital Game Design within an Ageing Society. *Educ. Gerontol.* **2013**, *39*, 103–118. [CrossRef]
69. Thiebes, S.; Lins, S.; Basten, D. Gamifying Information Systems—A synthesis of Gamification mechanics and Dynamics. In Proceedings of the ECIS 2014 Proceedings—22nd European Conference on Information Systems, Tel Aviv, Israel, 9–11 June 2014.
70. Silva, J.; Oliveira, E.; Moreira, D.; Nunes, F.; Caic, M.; Madureira, J.; Pereira, E. Design and Evaluation of a Fall Prevention Multiplayer Game for Senior Care Centres. In *Entertainment Computing—ICEC 2018*; Clua, E., Roque, L., Lugmayr, A., Tuomi, P., Eds.; Lecture Notes in Computer Science; Springer International Publishing: Cham, Switzerland, 2018; Volume 11112, pp. 103–114. [CrossRef]
71. Robertson, M.C.; Campbell, A.J. *Otago Exercise Programme to Prevent Falls in Older Adults*; ACC Thinksafe: Wellington, New Zealand, 2003.
72. Guimarães, V.; Sousa, I.; Correia, M.V. Detection and classification of multidirectional steps for motor-cognitive training in older adults using shoe-mounted inertial sensors. In Proceedings of the 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Berlin, Germany, 23–27 July 2019; pp. 6926–6929. ISSN 1558-4615. [CrossRef]
73. El-Sayegh, B.; Dumoulin, C.; Ali, M.; Assaf, H.; Sawan, M. A Dynamometer-based Wireless Pelvic Floor Muscle Force Monitoring. In Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Montreal, QC, Canada, 20–24 July 2020; Volume 2020, pp. 6127–6130. [CrossRef]
74. Web Bluetooth Community Group. Web Bluetooth API. Available online: https://webbluetoothcg.github.io/web-bluetooth/ (accessed on 10 May 2021).
75. Dividat AG. Dividat Senso. Available online: https://dividat.com/en/senso (accessed on 10 May 2021).
76. Jachan, D.E.; Müller-Werdan, U.; Lahmann, N.A. Impaired Mobility and Urinary Incontinence in Nursing Home Residents: A Multicenter Study. *J. Wound, Ostomy Cont. Nurs.* **2019**, *46*, 524–529. [CrossRef] [PubMed]
77. Carvalho, R.N.S.d.; Ishitani, L. Motivational Factors for Mobile Serious Games for Elderly Users. In Proceedings of the SBGames 2012, Brasilia, Brasil, 2–4 November 2012.
78. Zhao, Z.; Arya, A.; Whitehead, A.; Chan, G.; Etemad, S.A. Keeping Users Engaged through Feature Updates: A Long-Term Study of Using Wearable-Based Exergames. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, Denver Colorado USA, 6–11 May 2017; ACM: Denver, CO, USA, 2017; pp. 1053–1064. [CrossRef]
79. Adcock, M.; Sonder, F.; Schättin, A.; Gennaro, F.; de Bruin, E.D. A usability study of a multicomponent video game-based training for older adults. *Eur. Rev. Aging Phys. Act.* **2020**, *17*, 3. [CrossRef] [PubMed]
80. Hayes, D. Telerehabilitation for Older Adults. *Top. Geriatr. Rehabil.* **2020**, *36*, 205–211. [CrossRef]
81. Corregidor-Sánchez, A.I.; Polonio-López, B.; Martin-Conty, J.L.; Rodríguez-Hernández, M.; Mordillo-Mateos, L.; Schez-Sobrino, S.; Criado-Álvarez, J.J. Exergames to Prevent the Secondary Functional Deterioration of Older Adults during Hospitalization and Isolation Periods during the COVID-19 Pandemic. *Sustainability* **2021**, *13*, 7932. [CrossRef]