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Review Article

Design Recommendations for User-Centered Games for Multiple Sclerosis Balance Rehabilitation: An Evidence Review

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ABSTRACT

Introduction: In recent years, exergames have emerged as a potential rehabilitation tool to address balance dysfunction in patients with multiple sclerosis (PwMS). Although preliminary findings have held promises, their overall effectiveness remains inconclusive, primarily because they rely on commercial games. This issue underscores the critical need for user-centered games tailored to patients' specific needs. Despite this necessity, the existing literature lacks established frameworks to develop such games, highlighting a gap. Therefore, the objective of this research was to propose the first evidence-based framework to create user-centered games for balance rehabilitation in PwMS.

Materials and Methods: A two-step method was used to achieve this objective. The first step involved examining commercial games used in clinical studies, identifying their mechanics and limitations. The second step involved reviewing the literature to identify relevant findings that could help the development of user-centered games.

Results: A set of targeted recommendations was proposed, emphasizing the need to develop adaptable games with focused therapeutic designs and to address the distinct balance impairments observed in PwMS effectively. A game prototype was also presented to illustrate the practical applications of these recommendations.

Conclusion: This research establishes the first structured framework to design user-centered exergames for balance rehabilitation in PwMS. In addition to its theoretical insights, this framework provides actionable guidelines for developing clinically effective exergames that align with patient impairments and therapeutic needs. Ultimately, this work will contribute to improved therapeutic outcomes, enhanced patient care, and advancements in both rehabilitation and game design fields.

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Introduction

Exergames are digital games that require body movements for interaction and gameplay [1, 2]. In recent years, they have emerged as innovative therapeutic tools that offer a training approach that is adherent, engaging, motivating, and effective [3].

Their interactive nature makes them more enjoyable than traditional exercises in clinical settings [4, 5]. Consequently, there has been increasing interest in utilizing them as potential interventions for balance dysfunction in patients with multiple sclerosis (PwMS).

This interest has led to numerous studies investigating the efficacy of exergames for the treatment of balance dysfunction in PwMS. Although preliminary findings have shown promise, evidence supporting their effectiveness remains inconclusive. This variability in results is largely attributable to several methodological limitations, particularly the utilization of "off-the-shelf" commercial games [6, 7]. These games are primarily designed for entertainment and are widely available in stores [8]. Before adopting them for rehabilitation, they were originally intended for healthy individuals, without considering the specific needs of disabled patients [8–10]. Typically, they feature high-intensity training demands [9], lack therapeutic designs, and rely on preset programs [6, 11] that restrict training specifications [3]. Consequently, implementing such software, which demands high motor and cognitive skills, can impede patient progress by generating irregular movement patterns and other unfavorable outcomes [12]. This gap underscores the critical need for user-centered games tailored to patients' unique abilities, thereby enhancing rehabilitation outcomes [6, 11, 12].

However, despite this need, designing these games presents methodological challenges, particularly the lack of guidelines for their design and development. Although researchers such as Robert et al. Wiemeyer et al. Caruso et al. and Paraskevopoulos et al. have proposed recommendations for the development of serious games for patients with Alzheimer disease, persons with disabilities, autistic people [13-15], and Parkinson disease patients [16], no similar recommendations have yet been established for games aimed at balance rehabilitation in PwMS. To the best of our knowledge, based on a comprehensive literature search, the current body of literature lacks such a framework, highlighting a gap in the existing knowledge.

Therefore, the objective of this research is to establish a framework that guides the development of user-centered games for balance rehabilitation in PwMS. Conceptually, the need for such a framework is grounded in three key factors. First, PwMS exhibit distinct balance challenges compared to other neurological disorders, such as Parkinson disease [17], underscoring the need for frameworks specifically tailored to their unique needs. Second, PwMS experience multifaceted balance impairments that affect static [18–22], reactive [23, 24], and anticipatory [25, 26] balance systems, indicating the need for diverse rehabilitation techniques to address these specific impairments. Third, balance is a specific motor skill rather than a general one, and interventions effective at addressing particular impairments may not lead to generalized improvements across other impairments. This condition highlights the need for targeted interventions to optimize the treatment efficacy [27]. Collectively, these factors demonstrate the need for a structured framework to assure the functionality, tempo, and optimal design of games intended for balance rehabilitation in PwMS, and to effectively address the multifaceted nature of balance impairments in this population. By proposing such a framework, the present research is the first to address this gap in the literature, which is critical for enhancing the usability and therapeutic effectiveness of such games, thereby facilitating their effective implementation in clinical practice [28, 29].

To ensure the successful development of the framework, an interdisciplinary research team comprising physiotherapists, biomedical engineers, and game designers was formed. This collaborative approach aims to establish a framework for developing games that are not only engaging but also aligned with therapeutic goals and evidence-based practices. Ultimately, this can contribute to improved therapeutic outcomes, enhanced patient care, and advancements in both rehabilitation and game design fields.

Materials and Methods

Identifying existing guidelines for the design of balance rehabilitation games for PwMS

A comprehensive literature search was conducted across PubMed, ScienceDirect, and Google Scholar to identify guidelines for developing user-centered games for balance rehabilitation in PwMS.

A set of key terms and their synonyms was used to identify relevant studies aligned with this aim. The primary search terms included "patients with multiple sclerosis," " recommendations," "balance," and "games."

The final search string was structured as follows: ("Patients with multiple sclerosis" OR "PwMS" OR "multiple sclerosis patients") AND ("recommendations" OR "guidelines" OR "framework") AND ("balance" OR "balance rehabilitation") AND ("games" OR "game design" OR "user-centered games" OR "personalized games" OR "serious games").

The search results revealed a notable absence of formalized guidelines for developing balance rehabilitation games for PwMS, thereby highlighting a gap in the existing literature.

Methods used for the framework development

To address the gap mentioned above and establish a framework for the design of user-centered games for balance rehabilitation for PwMS, a two-step methodology was employed. The first step involved an in-depth analysis of commercial games currently used for balance rehabilitation in PwMS, identifying their underlying mechanics and limitations. The second step involved reviewing the literature to identify relevant recommendations for developing such games. Both steps were adapted from the approach used by Caruso et al. [15], who proposed a set of targeted recommendations to inform the development of immersive virtual reality games for patients with autism. Unlike other frameworks that rely mainly on literature searches, Caruso et al.'s framework combines a literature review with the practical examination of existing games, providing a comprehensive foundation for structuring game design recommendations [15].

To further strengthen the framework's rigor, an interdisciplinary research team comprising physiotherapists, biomedical engineers, and game designers was formed. Both physiotherapists and biomedical engineers were responsible for identifying and analyzing clinical studies on the impact of exergames on balance dysfunction in PwMS. Specifically, their roles included extracting key findings, identifying clinical needs, and outlining the commercial games used in these studies. Afterward, these games were evaluated to determine their mechanics and limitations through a combination of literature review, video demonstrations, and collaborative discussions with game designers. Based on the overall findings, physiotherapists proposed corresponding intervention strategies, which were subsequently assessed by both game designers and biomedical engineers for feasibility in real-world applications.

In general, meetings were scheduled periodically to discuss progress, align perspectives, and coordinate tasks among team members. Feasibility was assessed in each round through a role-based delegation, with each team member leading evaluations within their respective areas of expertise. While no formal disagreements arose during meetings, challenges primarily stemmed from differences in terminology across disciplines. For instance, during discussions, physiotherapists had to clarify clinically relevant concepts (e.g. optic flow) for non-clinical team members, which were addressed through video demonstrations. Similarly, game designers explained technical terms (e.g. third-person runner games) to ensure understanding among all members.

Through this collaborative approach, the aim was to integrate clinical, technical, and design perspectives, ultimately contributing to a structured framework that supports the development of games that are both engaging and aligned with therapeutic goals and evidence-based practice.

Examination of currently used commercial games

In this step, a comprehensive literature search was conducted across various databases, including PubMed, ScienceDirect, and Google Scholar, using a set of key terms and their related synonyms.

The primary search terms included "patients with multiple sclerosis," "exergames," and "balance rehabilitation." The final search string was structured as follows: ("patients with multiple sclerosis" OR "PwMS" OR "multiple sclerosis patients") AND ("exergames" OR "exergame" OR "video games" OR "exercise-based games" OR "interactive games" OR "virtual reality games" OR "Nintendo games" OR "Nintendo game" OR "Wii Fit games" OR "game-based rehabilitation" OR "serious games" OR "kinect-based system" OR "kinect-based games") AND ("balance rehabilitation" OR "balance training" OR "balance").

To ensure methodological rigor, only full-text articles published in English in peer-reviewed journals and conference proceedings up to 2024 were included. Gray literature, such as reports, posters, theses and dissertations, and letters to the editor, was excluded. Furthermore, only studies that used the term "virtual reality games" interchangeably with "exergames" were included. However, studies focusing on immersive virtual reality technology were excluded to eliminate the influence of the specific technology on outcomes and to ensure a consistent focus on the game design itself.

Consequently, 24 clinical trials were identified through the search process. Of these, 18 met the inclusion criteria, and the remaining 6 were excluded. These 6 studies included one thesis, one letter to the editor, one abstract with no full text, and three studies that utilized fully immersive virtual reality technology.

Among the included studies, 14 used commercially available games or software [30–43], 3 used user-centered games [44–46], and 1 used commercial games with personalized elements for individualized treatment plans for each patient [47].

The commercial games acknowledged in these studies included Heading (soccer), Ski Slalom, Table Tilt, Tight Rope, Reflex Ridge, Space Pop, Just Dance, Zazen, Penguin Slide, Balance Bubble, Perfect 10, Tightrope Tension, Snowboard Slalom, Skateboard Arena, Table Tilt+, Balance Bubble+, Ski Jump, Kinect Sports®, Joy Ride®, Adventures®, Tennis, Table Tennis, Boxing, Archery, Sword Fight, Penguin Picnic, Light Race, Stack 'em Up, 20000 Leaks, and Tilt City. The majority of these games require body shifting for gameplay and interaction, whereas only a few involve stepping movements. These games were systematically analyzed to identify their limitations, and the findings are presented in the results section.

Reviewing the literature for relevant recommendations

This step involved a comprehensive literature review to identify 3 categories of critical information essential to establishing a robust framework. The first category involved reviewing studies on the impact of exergames on balance dysfunction in PwMS to identify clinical needs and develop potential recommendations to inform the effective development of such games. The second category involved extending this analysis to similar studies involving other populations, such as older adults, to identify additional insights that could enhance the design of balance rehabilitation games. The third category involved reviewing the literature to identify guidelines that inform the development of serious games for patients with disabilities, ensuring inclusion of all necessary criteria for serious games for health. By following these steps, the objective was to establish a comprehensive, well-rounded framework that incorporates the information needed to design effective games for balance rehabilitation in PwMS (Table 1).

Table 1 presents the studies we used to inform our recommendations. It includes the author's name and publication date, the targeted population, the number and gender of participants, the intended objectives, the proposed recommendations, and intervention groups identified in these studies.

Results

Findings from previous studies suggest that rehabilitation-oriented games should be adaptable and easily implemented in rehabilitation settings. Adaptability should encompass both hardware and gameplay elements, thereby enhancing accessibility and functionality in these environments [14].

Furthermore, these studies emphasize the importance of developing games with focused therapeutic designs to ensure alignment with the intended rehabilitation goals. Ideally, this condition can be achieved through an interdisciplinary approach that combines expertise from various fields with patient insights. Such an approach facilitates a comprehensive understanding of the physiological, social, psychological, and therapeutic needs of the target population and desired rehabilitation outcomes. Ultimately, by gaining a deeper understanding of patients' abilities and impairments, the development of user-centered games with focused therapeutic designs has become feasible [14, 45, 48] exergaming.

Conceptual framework for the study's objectives

Based on the suggestions above, establishing a framework tailored to this study's objectives requires integrating relevant information on the study population (PwMS) and the intended rehabilitation goal (exergames for balance rehabilitation). This information includes 1) limitations associated with the implementation of commercial games in clinical settings, 2) mechanisms underlying balance dysfunction in PwMS, 3) balance impairments observed in PwMS, and 4) the fundamentals of training. By synthesizing insights from these areas, we propose a set of evidence-based recommendations for developing games to support balance rehabilitation in PwMS. These recommendations encompass considerations for optimal game design, appropriate gameplay pacing, and strategies for effectively integrating various game parameters to maximize therapeutic efficacy.

Table 1. Summary of the retrieved recommendations from the literature

Author (y)	Targeted Population	Participants (No. and Gender)	Intended Objectives	Proposed Recommendation	Intervention Group
Wiemeyer et al. (2015) [14]	Persons with disability	NA, expert consensus article	General recommendations	Training intensity must be adaptable to the patients' needs and abilities. Game technology must be easily implemented and adaptable to the patients' needs and abilities. Designing rehabilitation games requires interdisciplinary expertise and consideration of patient and caregiver preferences.	NA
Calafiore et al. (2021) [7]	PwMS	NA, systematic review	Balance	Training should be within the patient's flowzone.	NA
Anders et al. (2020) [1]	Elderly	Total =15 Females=7 Males =8	Balance	Training should be within the patient's flowzone. Designing purposeful games requires interdisciplinary expertise. Developing dynamically adjustable games facilitates user-centered training. Different game designs and mechanics have varying effects on the same training goals. High-speed games aligned with patient abilities may enhance rapid responses to perturbations. Games requiring obstacle avoidance (dual-task) can increase cognitive load.	Single-group design; each player played eight 2-minute exergame trials across 4 conditions: 2 speed settings, with or without additional obstacles
Schättin et al. (2021) [45]	PwMS	This article encompasses two studies: Study 1; Total=16 Female=10 Male=6 Study 2; Total=25 Female= 15 Male= 10	Balance	Effective games must take patients' abilities and limitations into account.	Study 1 is a single-group feasibility study; Study 2 is a single-group design in which players initially tested 3 exergame concepts and then selected which to continue based on their preferences.
Manser et al. (2023) [48]	Elderly with mild neurocognitive disorders	Qualitative study involving 10 experts (8 females and 2 males) and 8 older adults (3 females and 5 males).	Investigate patient preferences to design games for older adults with neurocognitive disorders.	Integrating the patient's perspective is essential in game design and development. Designing games requires understanding the usage context, users' needs, proposing tailored solutions, and evaluating the design's effectiveness.	NA
Wiskerke et al. (2022) [63]	Persons with neurological disorders	Thirty stroke patients (8 females and 22 males), in addition to 51 PwMS (38 females and 13 males)	Rank virtual reality balance games by difficulty and relate them to the abilities of patients with neurological disorders.	Parameters such as play speed and extent of body leaning promote challenging training in balance rehabilitation games.	In a single-group design, participants were required to play 6 of 9 available games per session.

Author (y)	Targeted Population	Participants (No. and Gender)	Intended Objectives	Proposed Recommendation	Intervention Group
Willaert et al. (2020) [64]	Healthy older adults	Total=16 Females=9 Males=7	Evaluates whether novel exergames better enhance weight shifting and produce higher levels of muscle activity than commercial games.	Shifting body weights to the limits of stability (LOS) creates challenging balance training.	In a single group, each participant played 6 different games, with 3 trials per game.
Gouglidis et al. (2011) [60]	Older women	A total of 63 women	To explore the influence of visually-guided weight shifting training on the LOS.	Weight shifting training increases the LOS.	Three groups participated: the first performed anteroposterior weight shifting, the second performed mediolateral weight shifting, and the third served as a control with no intervention.

NA: Not applicable.

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Limitations associated with the implementation of commercial games in clinical settings

Several limitations are associated with the use of commercial games for balance rehabilitation in PwMS [6]. These limitations primarily arise from their non-therapeutic designs, which are often characterized by high-intensity training levels and preset programs. In clinical settings, the use of software that provides intense training can lead to unfavorable outcomes. These could be characterized by the elicitation of compensatory movement strategies that deviate from targeted therapeutic movement patterns as patients attempt to achieve the game objectives. In addition, the exacerbation of symptoms in patients with sensory processing impairments due to exposure to intense visual or auditory feedback designed primarily for engagement rather than rehabilitation [12]. Consequently, such adverse outcomes underscore the need to develop games that operate within the "flow-zone" of players—a state in which players are neither bored nor excessively challenged—to facilitate effective, engaging, and motivating training [1, 7]. Ideally, this state can be achieved by developing games that either incorporate machine learning algorithms to automatically adjust gameplay based on real-time performance metrics or provide clinicians with a controlled settings module that enables manual customization of the gameplay experience in response to patient performance.

An example of such a game prototype incorporating a game-setting module is shown in Figure 1. Our research team developed this prototype to address these limitations. It allows adjustment of several in-game parameters, thereby offering a personalized training approach [1, 14, 45] that is precise, specific, and progressive [1], and aligned with the principles of training [45, 49, 50] and balance rehabilitation concepts [51].

These parameters include

1) experiment time in minutes denotes the total game time, including both active gameplay and rest time. 2) repetition of instruction, which denotes the total number of directional leans required by the player. 3) resting seconds of the experiment, which denotes the total period during which the player is inactive during the game. 4) instruction until the rest period, which denotes the frequency of instructions provided before the rest period. 5) time to react to collectables denotes the time allowed for a player to respond to a stimulus. 6) optic flow speed is a parameter that controls the initiation of movement in the game's visual environment.

By calibrating these parameters to align with each patient's personalized capacity, the game automatically determines additional gameplay elements using mathematical algorithms implemented during the programming phase. These elements include:

1) game time which refers to the duration of active gameplay, excluding rest periods. 2) the total number of instructions that the player must respond to throughout the game. 3) the time interval between the appearance of each collectible (time between collectibles). 4) the frequency of rest periods during the game (number of rest groups). 5) duration of each rest period (rest time between groups) [27].

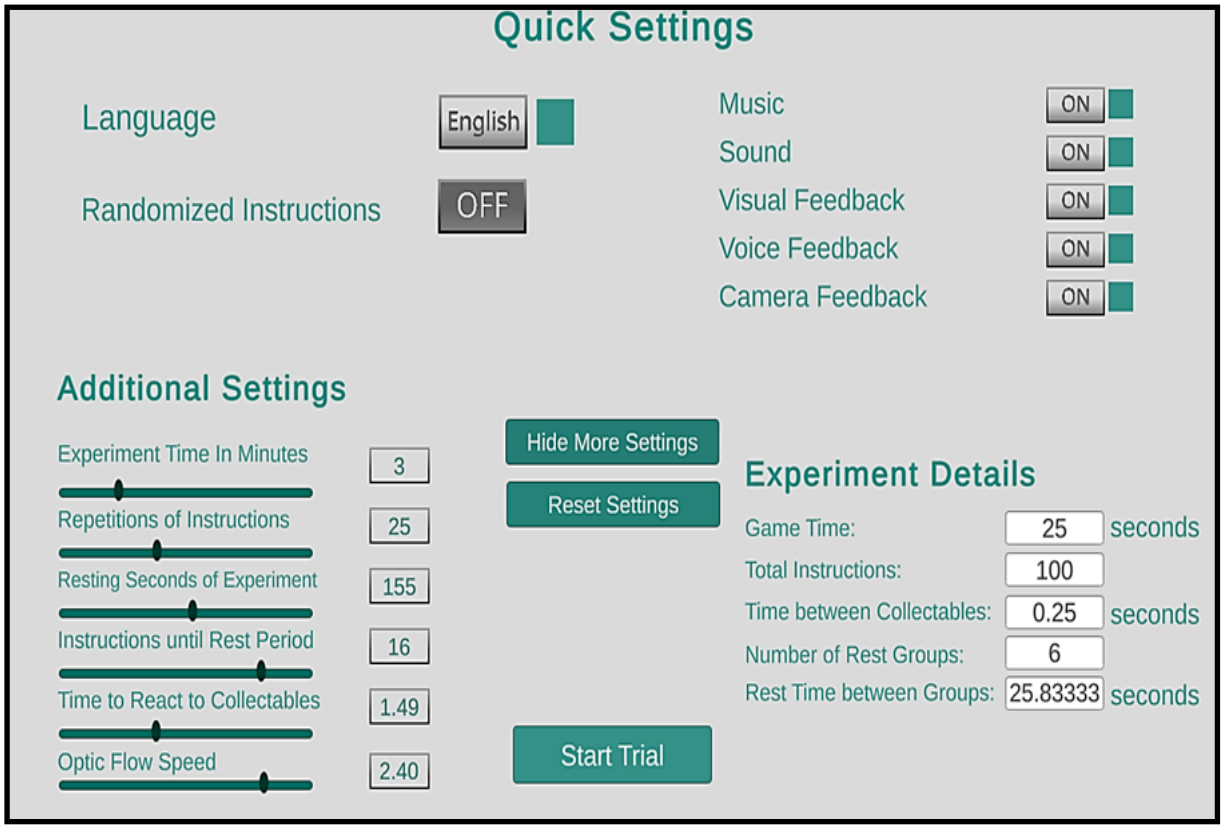

Figure 1. Illustrating a game setting module

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Note: It enables the dynamic adjustment of gameplay elements, thereby facilitating an individualized, precise, specific, and progressive training approach. This module was custom-designed for balance rehabilitation in PwMS.

The ultimate objective of implementing such an adjustable prototype is to introduce a personalized, specific, and adaptive training approach that enhances therapeutic outcomes.

Optimal game design for balance rehabilitative game for PwMS

Designing effective games for balance rehabilitation requires the precise identification of specific balance impairments to be addressed. This identification is important because different game designs and mechanics can vary significantly in their effectiveness in achieving the same therapeutic goals. For instance, high-speed exergames tailored to players' capacity elicit faster stepping responses and increased cadence, which are beneficial for improving rapid motor responses to balance perturbations. In contrast, dual-task games tend to increase cognitive load and may be more effective at targeting the cognitive aspects of balance control [1]. These results highlight the importance of selecting targeted games to address specific balance impairments and optimize the therapeutic outcomes.

For PwMS, a diverse array of game designs and mechanics is required to effectively address the multifaceted impairments affecting static [18–22], reactive [23, 24], and anticipatory [25, 26] balance systems. These impairments include delayed responses to both predictable and unpredictable displacements, diminished movement toward the LOS [25, 52–55], and impairments in sensory integration and reweighting, which are closely associated with balance dysfunction in PwMS [56–59].

To effectively address these impairments, high-speed games tailored to individual capacities can help improve responses to perturbations [1]. Games that challenge users to lean toward their LOS through weight-shifting exercises [60] are necessary to promote movement toward these limits. Games that facilitate sensory integration training, such as the approach proposed by Ibrahim et al. [27], may help address this impairment. Task-oriented games that target functional activities, such as stepping and sit-to-stand transitions, are crucial for improving stability related to specific motor skills [61, 62].

Strategies for optimizing balance rehabilitation games

Previous research has highlighted the need to precisely calibrate specific game parameters, such as the extent of body leaning required for game interaction [63, 64] and the game's speed [63], to significantly enhance the effectiveness of balance training and optimize therapeutic outcomes.

Extent of body leaning

Traditionally, many games used in clinical settings for balance rehabilitation require patients to shift their bodies in different directions to control an onscreen avatar and interact with the game. However, these games often cannot challenge the extent of the body's lean toward the LOS. Movement toward these limits is critical for activities, such as reaching and bending [65], as well as mobility [66]. As such, impairments in this capacity can lead to instability during activities of daily living [25].

To address this problem effectively, it is essential to challenge the extent to which the body leans toward the LOS [64]. Ideally, this objective can be achieved by developing games with adaptable panels, as illustrated in Figure 2. Our research team developed the panel shown in this figure and complements that shown in Figure 1. It incorporates three parameters to determine the minimum lean angle required for a patient to interact with the game. These parameters include "min lean angle left and right," which specifies the minimum degree of body lean required in both the left and right directions to interact with the game. The "min lean angle backward," which identifies the minimum degree of body leaning required in the backward direction, and the "min lean angle forward," which identifies the minimum degree of body leaning needed for the forward direction. By implementing this systematic approach, the aim was to promote body movement toward the LOS to enhance training outcomes.

Speed of the game

In addition to the extent of body leaning, the game speed is another critical aspect that requires careful consideration to optimize the efficacy of balance training [63]. The rationale for this necessity stems from previous research indicating that engaging in high-speed games that align with patients' capacities can enhance training effectiveness by reducing the reaction time required to respond to stimuli. Consequently, this improvement enables patients to respond more rapidly to perturbations, ultimately preventing falls [1, 67].

To adjust the game speed during training, several parameters, such as "repetition of instruction" and "time to react to collectables," can be integrated into the games (Figure 1). These parameters enable adjusting game speed by either increasing the number of stimuli presented to the player during the match or decreasing the time allowed for the player to respond to a stimulus. However, it remains unclear which approach is the most effective for balance training. Further research is required to determine the optimal strategy.

Pace of the games

For PwMS, balance rehabilitation games should be designed with a slower tempo than those currently used in clinical settings. This requirement is based on findings from previous research indicating that PwMS exhibit delayed reaction times compared to their healthy counterparts when performing tasks that involve body lean or when responding to both expected and unexpected perturbations [23, 25, 52, 53, 55, 66]. Designing such games with these considerations ensures not only a safe training approach but also alignment with the specific neurological and physiological needs of this population. Consequently, rehabilitation programs can be more effective in improving balance and reducing the risk of falls.

Discussion

The objective of this interdisciplinary research was to propose a framework that guides the development of user-centered games for balance rehabilitation in PwMS. This objective was achieved by synthesizing relevant recommendations from the broader literature and by identifying the mechanics and limitations of the commercial games currently used in practice. Building on the results obtained, this study proposed a set of targeted recommendations (Table 2) to guide the development of such games.

Importantly, the recommendations underscore the need to develop adjustable games rather than relying on preset designs to support a personalized, precise, specific, and progressive training approach. These recommendations, in turn, ensure that the game remains appropriately challenging for each patient and keeps them within their "flowzone." As a result, such adaptable games may improve long-term adherence to rehabilitation programs, enhance therapeutic effectiveness, and increase the usability and functionality of the games [1].

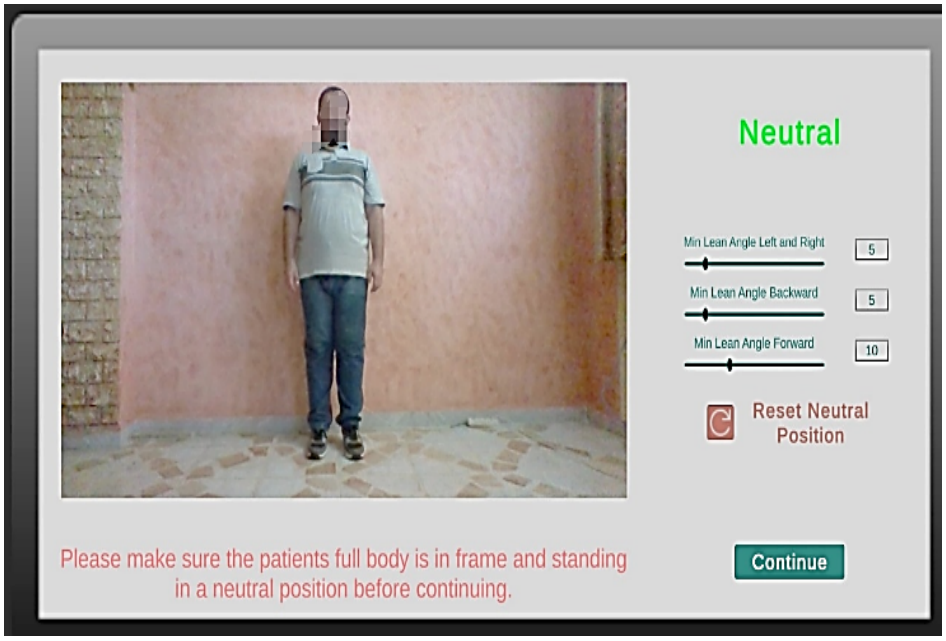

Figure 2. Illustrating a game setting module

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Note: It enables the identification of the minimal degree of body leaning required for game interaction, thereby promoting leaning toward the LOS.

Besides, the proposed recommendations highlight the significance of developing games with diverse designs and mechanics to address the multifaceted impairments affecting static, reactive, and anticipatory balance systems in PwMS. For instance, to enhance postural responses to perturbations, it is recommended to implement high-speed games that align with the patients' capabilities. To improve movement toward LOS, games that challenge the extent of body leaning toward these limits are necessary. Games that facilitate sensory integration training are recommended to address impairments in sensory integration and the reweighting process.

By implementing these targeted recommendations, we hypothesize that games can become more effective by providing individualized and specific solutions to the various impairments observed in PwMS.

Practical application

Here, it becomes important to highlight the practical feasibility of implementing the proposed recommendations, particularly those incorporated into the prototype developed by the research team. The prototype was developed in Unity, and body movement detection was implemented using the "ThreeDPoseUnityBarracuda" plugin, available on the Unity developer community. Therefore, creating a similar system should be relatively cost-effective.

In addition to development feasibility, such prototypes can be readily implemented in clinical settings. Our prototype is compatible with Windows computers and was tested on both an HP victus 15-FB2063DX laptop and a Lenovo laptop with an Intel Core i3 processor. While the game ran smoothly and without noticeable lag on the HP Victus, significant performance limitations were observed on the Lenovo device. However, the game is expected to run effectively on systems equipped with at least 8 GB of RAM, a solid-state drive (SSD), and an Intel Core i5 or preferably i7 processor, though further testing is needed to confirm this.

Preliminary, unpublished data from our team indicate that the prototype is suitable for use by individuals with disabilities up to level 6 on the expanded disability status scale, specifically for patients who experience walking difficulties and use a cane for ambulation but can stand unaided.

As such, in addition to the theoretical insights provided by the framework, its practical application and implementation appear feasible. Therefore, we recommend that future research focus on developing more user-centered games for balance rehabilitation in PwMS, as commercial games remain the predominant option in clinical practice. Indeed, aside from our game prototype, 3 additional user-centered games have been developed for PwMS [45, 46, 68]. While these prototypes were designed to provide adaptable training, each was created

Table 2. Summary of the key recommendations for the design of balance rehabilitation games for PwMS

Rehabilitation Goals	Corresponding Recommendation	Game Mechanics Examples
Games should be specifically designed to target particular impairments.	A systematic and comprehensive assessment of balance control domains should be conducted to identify impairments and select targeted interventions.	NA
Games should be designed with adaptable features.	Adaptability can be achieved either by incorporating machine learning algorithms that modify gameplay based on patient performance or by integrating a controlled settings module that enables clinicians to adjust gameplay mechanics, such as game speed and the number of stimuli, based on the patient's performance.	NA
Enhancing reduced capacities to reach the LOS.	Games should be designed to promote body leaning by incorporating weight-shifting exercises that encourage controlled movement toward the LOS.	Games should incorporate tasks that require players to lean their bodies toward a specific point to score or catch an object. If the required degree of leaning is not achieved, the players fail to score.
Enhance responses to perturbations.	High-speed games tailored to each patient's capacity are required.	Games should incorporate tasks that challenge patients' response capabilities, such as avoiding an oncoming ball. These tasks should be presented at high speeds, aligned with each patient's individualized capacity.
Addressing impairments in sensory integration and the reweighting process.	Implement games that involve sensory integration training.	Games should be designed to facilitate sensory integration training by incorporating features that target different sensory conditions, such as eyes-open, eyes-closed, and reduced visual reliance. In the eyes-open condition, patients can respond to visual stimuli. In the eyes-closed condition, patients are required to respond to auditory cues while keeping their eyes closed. To reduce visual reliance, auditory stimuli can be presented while patients are exposed to visual environments that include optic flow illusions.
Address the cognitive aspect of the postural control system.	Implement games that involve dual-task activities.	Games should be designed to require patients to focus on multiple tasks simultaneously, thereby creating a dual-task condition. In addition to physical exercise, such games should incorporate additional motor or cognitive challenges, such as avoiding obstacles, matching objects, catching, responding to objects with specific characteristics among distractors, or executing different motor responses depending on stimulus type.
Task-specific training	Beyond the above recommendations, games should be specifically designed to target functional tasks, such as stepping, sit-to-stand, or others, as balance is a task-specific motor skill that requires targeted interventions to address particular impairments effectively.	NA

LOS: Limits of stability.

with different training objectives, making direct comparisons among them challenging. Thus, more game designs targeting both similar and other objectives are needed to identify optimal training protocols within and across objectives. This information will help determine the most effective training protocols.

Conclusion

This research provides actionable guidelines for developing user-centered games for balance rehabilitation in PwMS. It underscores the need to create dynamic, adjustable games that operate at a slower tempo than the commercial games typically used in clinical settings. It also emphasizes the importance of incorporating diverse game designs and mechanics to address the multifaceted balance impairments observed in PwMS effectively. By proposing such targeted interventions, this research has the potential to improve patient care, enhance therapeutic outcomes, and influence the development of future rehabilitation games. As the first study to establish a structured framework for the design of user-centered exergames, this research represents a significant step forward in both the rehabilitation and game design fields. Beyond PwMS, the framework may be relevant to other populations, such as older adults, offering valuable insights for designing exergames tailored to their needs.

Study limitations

This research proposes a theoretical framework based on a synthesis of existing literature on game-based balance rehabilitation for PwMS, with extensions to related populations such as older adults. These conceptual analyses were subsequently adapted to address the specific rehabilitation needs of PwMS. Consequently, a key limitation of this approach is the absence of real-world implementation to support the proposed recommendations. Therefore, future empirical studies are necessary to validate and, if needed, refine the framework. Such research will be critical for identifying effective therapeutic designs and protocols tailored to this population's unique needs.

Future work

Future work will focus on validating the prototype developed in the present study. During the development phase, preliminary validation was conducted with both healthy individuals and PwMS to assess the system's basic functionality. While the initial results indicated that the game operated as intended, no structured clinical trial was conducted. Therefore, subsequent research will involve a structured clinical trial to evaluate the efficacy of the prototype and compare its outcomes with those of existing commercial games.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Conceptualization, data collection, data analysis, and writing: Hiyam Ibrahim, Emmanuel Guardiola, and Ahmad Diab; Supervision, review, and editing: Emmanuel Guardiola and Ahmad Diab.

Conflict of interest

The authors declared no conflict of interest.

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