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Beyond “just” fun: The role of exergames in advancing health promotion and disease prevention

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ABSTRACT

Applying innovations in digital health technologies, such as exergames, has been recommended by official bodies like the World Health Organization for health promotion and disease prevention across various populations and age groups. Given a key advantage of interactive and gamified digital health technologies is promoting user engagement, a substantial proportion of studies have implemented recreational exergames - games primarily designed to make specific activities more fun and entertaining. In this article, we aim to move beyond the benefits of "just" providing a more engaging environment for physical and motor-cognitive activities/exercises by shedding light on serious exergame features that enhance the ecological validity of exercises and offer unique advantages for tailoring interventions beyond conventional approaches. To this end, we review the roles and mechanisms of specific exergame features in supporting adherence to relevant behavior change, neuroscience, and exercise science principles, and integrate our findings into the ‘Beyond “Just” Fun of Exergames Framework’. This framework (i) implements a definition and classification approach to harmonize and provide more nuanced terminology for specific application scenarios of exergame technologies, and (ii) delineates best practices for the theoretically grounded selection and implementation of exergame features in health promotion and primary through tertiary disease prevention (including rehabilitation). By introducing this framework, we aim to support a paradigm shift by guiding game designers, researchers, and exercise and therapy practitioners from entertainment-centered recreational solutions towards serious exergames that are purposefully designed with adequate theoretical underpinnings, thereby unlocking the full potential of exergame-enhanced interventions for individuals and public health needs.

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1. Introduction

1.1. Background

In 2018, the World Health Organization's (WHO) Global Action Plan on Physical Activity (PA) was adopted with the target of reducing global levels of physical inactivity by 15 % by 2030 (World Health Organization, 2019). The newest estimates, however, suggest that nearly one-third of adults globally (31.3 %; 1.8 billion) were insufficiently physically active in 2022. Moreover, about half of the world's countries and two-thirds of its regions show upward trends of insufficient PA and are therefore likely to miss the 2030 PA target (Strain et al., 2024). Such high levels of physical inactivity have not only negative effects on the individual (e.g., higher risk for non-communicable disease) but also on the societal level (e.g., higher healthcare costs) (Santos et al., 2023). Thus, novel and effective approaches are urgently needed to tackle the public health issue of physical inactivity.

Innovations in digital health (e.g., electronic/mobile health applications or exergames) have been recommended as a promising and scalable solution to help counteract this trend and contribute to health system improvements (Singh et al., 2024a; Mazeas et al., 2022; World Health Organization, 2019). Utilizing such digital health technologies has been demonstrated to increase PA and reduce sedentary behavior, with effects that appear to be generalizable across diverse user populations (i.e., adolescents to older adults, healthy individuals to adults with chronic diseases) (Singh et al., 2024a; Mazeas et al., 2022). Moreover, using interactive and gamified digital health technologies to implement structured PA (i.e., physical exercise or training) is considered a more promising approach to improve cognitive and physical performance than conventional physical and/or cognitive training (Stojan and Voelcker-Rehage, 2019; Temprado, 2021; Torre and Temprado, 2022a). In fact, a recent meta-meta-analysis of 2724 randomized controlled trials with a pooled sample size of 258,279 participants observed that exergame-based training was the exercise modality that showed the greatest effects on general cognition and memory (Singh et al., 2025). Exergame-based training is therefore recommended for health promotion and disease prevention across various populations and age groups, including those at risk for or with impairments in cognitive (Manser et al., 2024) or physical (Hernandez-Martinez et al., 2024) functioning and emotional well-being (Marques et al., 2023).

The main rationale for incorporating interactive and gamified digital health technologies into healthcare (Gajardo Sánchez et al., 2023) and exercise contexts (Manser et al., 2024; Koivisto and Hamari, 2019; Matallaoui et al., 2017) has been the assumption that it provides superior enjoyment compared to conventional therapies/exercises, which promotes higher adherence and thus maximizes effectiveness (Duval et al., 2024; Tan et al., 2024; Hadjipanayi et al., 2024; Ferreira and Menezes, 2020). Indeed, the efficacy of interactive and gamified digital health technologies in promoting engagement and motivation is well-documented (Marques et al., 2023; Tan et al., 2024; Marshall and Linehan, 2021; Dubbeldam et al., 2024), which largely explains superior adherence to exergame- and other digital health technology-enhanced training compared to conventional approaches (Dubbeldam et al., 2024; Valenzuela et al., 2018; Rüth et al., 2023). Given such positive effects of interactive and gamified digital health technologies on user engagement, a substantial proportion of studies have implemented recreational exergames - games primarily designed to make specific activities more fun and entertaining (Manser et al., 2024; Torre and Temprado, 2022b). While this approach may be suitable for promoting unstructured forms of PA, the frequent use of recreational games has also been observed in exergame-based interventions classified as 'training' (Manser et al., 2024). In such purposive, planned, and structured interventions, the selection, design, and functionality of recreational exergame features may, however, be insufficiently grounded in relevant frameworks, principles, or guidelines to support the achievement of specific, measurable, and attainable health goals (Manser et al., 2024; Gajardo Sánchez et al., 2023; Matallaoui et al., 2017; Torre and Temprado, 2022b).

To enhance the credibility of research on exergames, the field is experiencing a paradigm shift, with the growing recognition of the value of systematic, iterative, and user-centered methodologies with co-design procedures. These rigorous procedures manifest in the development of (i) serious exergames (games with a purpose beyond play) (Manser et al., 2024; Huber et al., 2024a; Manser and de Bruin, 2021; Li et al., 2020) and (ii) individually tailored exergame-based training concepts that are backed up in behavior change, neuroscience, and exercise science principles (Manser et al., 2024; Marshall and Linehan, 2021; Torre and Temprado, 2022b; Perrot and Maillot, 2023; Röglin et al., 2023). To maximize their effectiveness in health promotion and disease prevention, there is also growing recognition of the importance of *"serious"* exergame features that go beyond *"just"* providing a more fun and entertaining environment (Manser et al., 2024; Marshall and Linehan, 2021; Torre and Temprado, 2022b; Perrot and Maillot, 2023; Röglin et al., 2023).

While some of these serious exergame features have previously been critically discussed with regard to addressing cognitive functioning, including immersion and variability (Perrot and Maillot, 2023), as well as to enhance neurorehabilitation (Prosperini et al., 2025), various additional features that are somewhat neglected in contemporary scientific practice might be of high relevance to promote overall health (Manser et al., 2024; Marshall and Linehan, 2021). Such additional features include but are not limited to how the game narrative is framed to ensure providing an appropriate exercise intensity (Manser et al., 2024; Huber et al., 2024a), the specificity and ecological validity of the exergame tasks (Manser et al., 2024; Torre and Temprado, 2022b), monitoring and correcting exercise fidelity (e.g., correctness and quality of movements, strategies used to maintain postural stability) (Manser et al., 2024; Torre and Temprado, 2022b), or the integration of remote social game features, such as collaborative challenges or online leaderboards with benchmarking of performance (Manser et al., 2024).

However, there is currently a lack of consensus on the selection, design, functionality, and implementation of distinct gamification features in digital health research in general (Koivisto and Hamari, 2019) and exergame features in particular. This lack of generally accepted consensus extends to the use of terminology surrounding exergame technology and its application in different contexts (e.g., PA promotion, structured motor-cognitive exercises).

1.2. Objectives

We aim to provide a guiding framework to harmonize research, development, and practice around exergames that (i) implements a definition and classification approach to provide a more nuanced terminology for context-specific applications of exergame technologies and (ii) delineates best practices for the theoretically grounded selection and implementation of exergame features in advancing health promotion and disease prevention.

To that end, we posed the following research questions:

i: How have terms related to interactive and gamified digital health technologies and their application in different contexts (e.g., PA promotion, structured motor-cognitive exercises) been used? Which ambiguities need to be resolved for clarification and harmonization of exergame-related terminology?

ii: Which features have been used in previous exergame studies, and to what extent has their application complied with relevant behavior change, neuroscience, and exercise science principles? How can implementing these features in exergame technology advance health promotion and disease prevention beyond conventional approaches to promote physical activity?

2. Methods

2.1. Overview

To develop a theoretically sound framework that is grounded on established scientific principles, we completed the following methodological steps:

First, given the heterogeneous definitions and contextualization of *"exergame"* and *"exergaming"* in the literature (Röglin et al., 2023), we first reviewed the terminology in the field (Section 4.1) and developed a novel definition and classification approach (Section 4.2) to harmonize terminology with the broader field of PA and exercise science.

Second, we critically reviewed the current state of evidence of how specific exergame features can be utilized to advance health promotion and disease prevention beyond conventional approaches, grounded in relevant behavior change, neuroscience, and exercise science principles, and focusing on serious exergame features. We structured this review by aligning our definition and classification approach with the timely organization of specific sub-steps through which exergames can support the stepwise behavior change from the implementation of initial interventions towards long-term, sustained behavior change (Section 5).

Finally, our analysis and critical reflection on the current corpus of evidence converged in the development of the 'Beyond "Just" Fun of Exergames Framework' (Section 6), that aims to facilitate the transfer of our findings to (clinical) practice and prompt further research and development.

2.2. Rationale for Narrative Review and Evidence Synthesis

We opted to perform a narrative review instead of a systematic review because of (i) the relatively broad scope of our research objectives, and (ii) the absence of a large and specific enough literature base to conduct a systematic review (e.g., on the mechanisms of specific exergame features on brain health). This decision is also grounded in the observation that the major concern of previous research in the field was to promote user engagement and enjoyment (as described in the Introduction), while neuroscience and exercise science principles have been somewhat neglected (e.g., as observed in previous systematic reviews on adherence of exergame-based training approaches to motor learning principles (Demers et al., 2021) or on principles of neurorehabilitation (Maier et al., 2019a), which is consistent with the observations in the broader field of digital health technologies (Baretta et al., 2019).

2.3. Adherence to Guidelines

This review followed recommendations and quality criteria for planning, conducting, and reporting high-quality narrative reviews (Sukhera, 2022; Baethge et al., 2019).

2.4. Literature Search

To ensure coverage of relevant literature, we drew on an established and comprehensive search strategy created during an earlier systematic review (Manser et al., 2024) that was used to update our literature search up to January 2025. The search strategy was developed in collaboration with a professional librarian around the PICOS approach (i.e., acronym for Population, Intervention, Comparison, Outcomes, and Study type). The professional librarian then translated the strategy into precise search strings for each database, including Medline, Embase, CINAHL, APA PsycINFO, Cochrane Library, Web of Science Core Collection, Scopus, and Pedro. These search strings consisted of Medical Subject Headings (MH), free text words, and Boolean operators. Examples for search terms included MH "human", NOT MH "animal", MH "exergaming", "exergames", MH "Virtual Reality+ ", MH "Augmented Reality", MH "User-Computer Interface+ ", MH "Games+ ", MH "Exercise+ ", "videogame", "train*", "game*", "gami*", "play*", "exerc*", "therap*" "treat*", "rehab*", MH "Cognition", or MH "Neuropsychological Tests+ " for a small selection. The search strings were applied without any filtering options or limits. For more details, please refer to the published search strategy and search strings for each database (Manser et al., 2024).

Since this search strategy did not exclude any specific age groups or populations and was developed focusing on sensitivity of the search, it was deemed suitable for our research objectives and was updated up to January 2025. To ensure that all relevant literature was captured, we also subscribed to PubMed alerts for all new articles published in 2024 and 2025 that included the Medical Subject Heading (MeSH) *"exergaming"* and did reference checks of previous reviews on similar topics as well as more targeted literature research for topics where insufficient literature was identified in the initial searches.

2.5. Literature Screening

For the definition and classification approach, we included papers of any type proposing definitions for exergame technology and their application scenarios. There were no specific exclusion criteria to ensure broad coverage and representativeness of the identified literature. For the review on how specific exergame features can be utilized to advance health promotion and disease prevention beyond conventional PA or rehabilitation approaches, we included articles that provided evidence on the design, application, and/or efficacy of specific exergame features to support implementation of relevant behavior change, neuroscience, and exercise science principles. There were no restrictions on the type of population or type of articles in the initial literature screening.

2.6. Evidence Synthesis

Identified and eligible literature was hierarchically reviewed and narratively synthesized based on the established levels of evidence (Burns et al., 2011), prioritizing evidence from review articles (systematic over scoping over narrative) and meta-analyses, and stepwise expanding to randomized controlled studies and lower level evidence in case the literature synthesis resulted in incomplete coverage of the defined behavior change, neuroscience, and exercise science principles. Following recommendations for the conduct of narrative reviews (Sukhera, 2022), this literature search, analysis and interpretation process was iteratively continued between April 2024 and May 2025 until a sufficient thematic analysis and interpretation, defined by consensus between the author team, was reached.

3. Harmonizing terminology around exergames

3.1. Narrative review of previous terminology

The earliest attempts to combine *"movement"* and *"gaming"* in a term date back to 1982 (Röglin et al., 2023). Since then, a variety of terms have proposed, as summarized by Röglin et al. (2023), with the most prominent term still being 'exergaming' (a portmanteau blending the words 'exercise' and 'gaming'), followed by alternatives such as 'active videogames', 'virtual reality exercise', or 'exertion games'.

The term 'exergame' was first defined in the scientific literature in 2008 as an interactive exercise videogame that combines elements of player movement, engaging recreation, immediate performance feedback, and social connectivity via competition (Smith et al., 2011). In 2010, Oh and Yang criticized that the term 'exergame' may have started to be used without consideration of the traditional definition of exercise and proposed two definitions: (i) an *"exergame"* is a videogame that promotes (either via using or requiring) players' physical movements (exertion) leading to an energy consumption higher than that of sedentary; (ii) *"exergaming"* is an experiential activity of playing exergames (Oh and Yang, 2010). These definitions, however, still did not meet all formal criteria for exercise (specific, planned, and structured forms of physical activities) (Herold et al., 2019), prompting various revised definitions in an attempt to better harmonize the terminology with exercise science criteria.

In 2013, the American College of Sports Science (ACSM) defined exergaming as technology-driven PA, such as videogame play, that requires participants to physically exercise to play the game (Witherspoon, 2013). In 2016, Pirovano et al. defined exergames as an exercise with a game built into its structure and distinguished between 'simple' and 'therapeutic' exergames (Pirovano et al., 2016). In 2022, the National Institutes of Health introduced a MeSH for 'exergaming', defined as videogaming that involves the player's whole body in physical exercises to play the videogames (National Institutes of Health, 2022). Most recently, Šlosar et al. (2022) suggested a categorization building on ACSM's definition expanding on key aspects that (i) exergames are training interventions that use digital device(s) (i.e., personal computer or virtual/augmented/mixed reality (VR/AR/XR)) with (ii) confirmed human-computer interaction and (iii) an energy expenditure exceeding 1.5 metabolic equivalents of task (Šlosar et al., 2022). Meanwhile, several systematic or scoping literature reviews have proposed specific definitions, such as exergames as a category of serious games that includes physical exercises as part of the intended gameplay (Abd-Alrazaq et al., 2022), exergaming as a form of physical exercise that is interactively combined with cognitive stimulation in a gaming environment (van Santen et al., 2018), or exercise in a virtual environment; including television, computer, smartphone, digital videogames, and other screens (Dubbeldam et al., 2024).

These definitions, while now aligning with the criteria of the term exercise, exclude the use of exergames for merely promoting physical and motor-cognitive activity. However, PA promotion may represent a critical first step in promoting behavior changes toward a more active lifestyle and thus can be considered a practically highly relevant, and often applied (Mazeas et al., 2022), use case for exergames. The growing popularity of exergaming for PA promotion in various settings has led to ambiguous use of exergame technology-related terms in contemporary scientific practice. Given that such an ambiguous terminology can be a major source of difficulty for scientific communication including the dissemination and translation of findings to real-world settings, efforts to harmonize the terminology that explicitly considers the context in which exergame technologies are applied are required.

3.2. *Definition and classification approach*

To harmonize terminology, we present a definition (Fig. 1) and classification (Tables 1 and 2) approach that offers more nuanced terminology, both in relation to exercise science and the context of specific applications of exergame technology.

This definition and classification approach clearly distinguishes between the technology component(s) (exergame hardware and software)

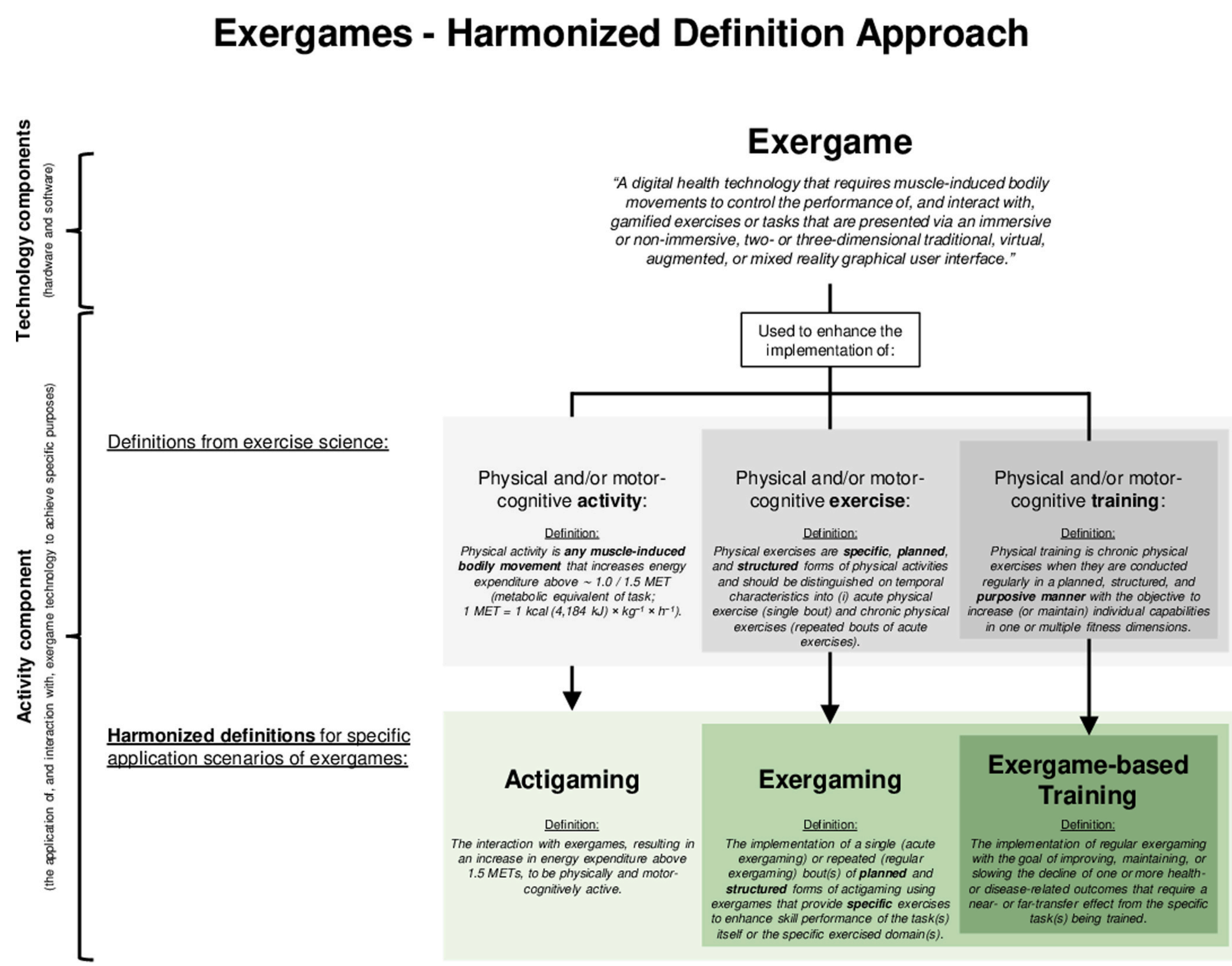

Fig. 1. Harmonized Definition Approach for Exergames that offers harmonized and more nuanced terminology, both in relation to exercise science and the context of specific applications of exergame technology.

Table 1
Classification approach of exergames (technology component; i.e., exergame hardware and software).

Classification	Classification Criteria	Examples
Recreational Exergames	Exergames that are or have been designed mainly to provide a more fun, enjoyable, and/or entertaining environment to promote physical and/or motor-cognitive activity are primarily entertainment-centered.	CycloBEAT, iWall, Pokémon GO, Ring Fit Adventure, Wii Sports, and Fit
Serious Exergames	Exergames that are or have been designed to fulfill all of the following criteria: (i) designed to address an **overarching goal(s)** that goes beyond providing a more enjoyable and/or entertaining environment to promote physical and/or motor-cognitive activity (e.g., primary to tertiary prevention, to enhance the implementation of physical and/or motor-cognitive activity/exercise) (ii) designed **purposefully**, informed by at least two out of the three sources: (1) scientific evidence, (2) scientific theory(ies), framework(s), and/or (3) co-design procedures, (iii) designed for, or suitable to be customized to, a **specific target population(s)** (iv) designed with a clear intention for a specific **context(s) of use** (e.g., primary healthcare, telemedicine, community health services, or similar environments)	Body-Brain Trainer, ddrobotec®, Dividat Senso (Flex), Exercube, ExerG, Quick Board, smart±step

and the activity component (the application of, and interaction with, exergame technology to achieve specific purposes). In this context, we argue that the definition of exergames (i.e., technology component) should not be confused with the exercise sciences' definition and interpretation of the term exercise. Instead, our harmonized definition approach considers the application purpose of exergame technologies (i.e., activity component) as a criterion for aligning our taxonomy with exercise science terminology.

3.2.1. Definition and classification of exergame technology

In light of the above considerations, we define an *"exergame"* as *"a digital health technology that requires muscle-induced bodily movements to control the performance of, and interact with, gamified exercises or tasks that are presented via an immersive or non-immersive, two- or three-dimensional traditional, virtual, augmented, or mixed reality graphical user interface."* Exergames can be classified as *"recreational exergames"* (entertainment-centered) or *"serious exergames"* (goal-directed, purposefully designed exergames). Refer to Fig. 1 (definition) and Table 1 (classification) for more details, critiera, and examples.

In this context, the terms 'exercise' or 'task' can, from the user interface perspective, also encompass purely cognitive tasks, resulting in combined physical-cognitive activity when the user interacts with the technology. Exergames can therefore be utilized to implement various forms of physical and/or motor-cognitive activities.

3.2.2. Harmonized definitions for specific application scenarios of exergames

The broadest category entails any type of physical and/or motor-cognitive activity resulting in a relevant energy expenditure increase to meet exercise science criteria for PA. This might entail the interaction with recreational dancing, skiing, boxing, or bowling exergames as an enjoyable approach to being physically and motor-cognitively active. We propose the term *"actigaming"* to distinguish this application scenario from more specific and purposeful applications referring to subconstructs of actigaming, namely acute or chronic exercise (defined as *"exergaming"*) and training (defined as *"exergame-based training")*; see Fig. 1. Since the distinction between chronic exercise and training is not as clear-cut and has been contextualized in different ways (Herold et al., 2019; Caspersen et al., 1985), we provide the following distinction:

Exergaming refers to specific, planned, and structured forms of actigaming that focus on goals directly related to the skill performance of the exercised task(s) itself (e.g., improving basketball or bowling performance) and/or the specific exercised domain(s) (e.g., increasing muscular power output in a particular movement, or enhancing performance in neurocognitive subdomains like selective attention or working memory; examples see Table 2).

Exergame-based training, as a specific subtype of chronic exergaming, requires goal setting related to broader health- or disease-related outcomes that necessitate near- or far-transfer effect from the specific task (s) being trained, supported by appropriate planning and principles to achieve these goals (examples see Table 2). These outcomes include but are not limited to general disease progression, walking ability, risk of falls, global or multi-domain-specific cognitive performance, activities of daily living (ADL), cardiorespiratory fitness, or balance.

3.2.3. Classification of specific application scenarios of exergames

Applications of exergames can be distinguished depending on the type and specificity of activity. All exergames inherently require some cognitive activity, while motor and cognitive processes are functionally related (Leisman et al., 2016). Because actigaming does not require a high specificity of stimuli, we only provide classifications for exergaming and exergame-based training. When endurance and/or muscular resistance exercise(s) are specifically targeted and the cognitive effort is unspecific (i.e., only related to interaction with the graphical exergame interface that has not been designed to target specific domain-specific higher-order cognitive functions), we refer to *"physical exergaming"* or *"physical exergame-based training"* (examples see Table 2).

When the exercises/training target domain-specific higher-order cognitive functions, we base our classification on the categorization proposed by Torre and Temprado (2022) (Torre and Temprado, 2022b). Such higher-order cognitive functions may include complex attention (e.g., processing speed, divided attention), executive functions (e.g., working memory, inhibition, cognitive flexibility), or perceptual-motor functions (e.g., visuo-constructional reasoning, perceptual-motor coordination) (Sachdev et al., 2014). Refer to Table 2 for more details and examples.

Importantly, within all the above-presented definitions and subclassifications, the physical, motor, and/or cognitive exercise demands can span a continuum from low to high levels. Therefore, the proposed terminology complies with the 'working two-dimension model' (Kao et al., 2024) that operationally defines the cognitive and motor demands involved in PA (Kao et al., 2024), or other comparable frameworks (Mavilidi et al., 2022, 2018).

4. Narrative review on how specific exergame features can support health promotion and disease prevention

PA should be integrated into the individual's daily life routines to meet the WHO's PA guidelines (or similar ones) to effectively promote overall health (Bull et al., 2020; Ina et al., 2023; Posadzki et al., 2020). However, overcoming physical inactivity and/or sedentary behavior represents a significant challenge. It has become evident that the provision of such guidelines, which often entail directives like *"engage in this level of PA"* or *"exercise more"*, is relatively ineffective for triggering

Table 2
Classification approach of specific application scenarios of exergames (i.e., activity component (the application of, and interaction with, exergame technology to achieve specific purposes)) based on the type and specificity of exercises/training.

Classification	Classification Criteria	Examples
Exergaming:		
Physical Exergaming	Acute or chronic exergaming specifically focusing on: (i) endurance and/or muscular resistance exercise(s) with the aim to improve task-specific aerobic and/or muscular performance.	Descriptive Example: Participants engage with an exergame simulating a rowing race 3 times a week for 45 min, aiming to improve rowing-specific muscular power output. The game requires participants to maintain a steady speed while adapting to changing wind conditions. It simulates high-intensity interval training with 9 blocks, each consisting of 1 min of heavy headwind and 4 min of backwind. The game is adjusted so that participants maintain 85–95 % of their maximum power output during headwind and 30–40 % during backwind. Example from the literature: Rhodes et al., (2018)
Physical-Cognitive Exergaming	Acute or chronic exergaming specifically focusing on the combination of: (i) endurance and/or muscular resistance exercise(s) AND (ii) additional (thinking while moving) or incorporated (moving while thinking) domain-specific cognitive exercise(s) with the aim to improve (the interaction of) task-specific aerobic and/or muscular performance and the specific exercised neurocognitive subdomain(s).	Descriptive Example: Participants engage with an exergame that combines cycling with memory tasks (i.e., thinking while moving) 3 times a week for 30 min, aiming to improve both aerobic capacity and recognition memory. The game simulates a cycling race and requires participants to cycle on a stationary bike. The game is adjusted so that participants maintain an exercise intensity of 50–60 % of heart rate reserve. During cycling, participants are asked to closely observe the virtual environment and press a button every time they see a specific item (e.g., a windmill, a blue bird, a river) for a second time. Correct responses are rewarded with a time bonus in the race and offering a shortcut for 10 consecutive correct responses.
Motor-Cognitive Exergaming	Acute or chronic exergaming specifically focusing on the combination of: (i) complex motor skills exercises AND (ii) additional (thinking while moving) or incorporated (moving while thinking) domain-specific cognitive exercise(s) combined with low cardio-vascular (i.e., endurance) effort with the aim to improve (the interaction of) task-specific motor skills and/or performance and the specific exercised neurocognitive subdomain(s).	Descriptive Example: Participants engage with an exergame that requires the rhythmic performance of complex stepping sequences aligned with the music beat in response to executive cognitive tasks (a sequence of arrows showing the direction and length of the required step; similar to Dance Dance Revolution) with a differential response required for differently colored arrows (moving while thinking). Participants exercise with the game for 15 min daily, aiming to improve reactive stepping accuracy and executive cognitive performance, whereas the game adjusts its difficulty continuously in response to player performance. Example from the literature: Zhang et al., (2021)
Multi-Domain Exergaming	Acute or chronic exergaming specifically focusing on the combination of: (i) complex motor skills exercises AND (ii) endurance and/or muscular resistance exercise(s) with at least moderate intensity AND (iii) additional (thinking while moving) or integrated (moving while thinking) domain-specific cognitive exercise(s) with the aim to improve (the interaction of) task-specific aerobic and/or muscular performance, task-specific motor skills and/or performance, and the specific exercised neurocognitive subdomain(s).	Descriptive Example: Participants engage with an exergame that requires complex whole-body movements with integrated strengthening exercises for the lower limbs (e.g., squats, lunges, side steps) in response to visual and auditory cues displayed in a virtual rollercoaster. The game requires a differential response to duck (i.e., squats) or swerve (i.e., lunges for red-colored items and side steps for items in remaining colors but only if combined with an auditory cue) to avoid virtual obstacles. The game is adjusted to keep participants within an exercise intensity of 70–80 % of heart rate reserve and perform 3 sets of 40 repetitions per exercise. The game is played 3 times per week, with progression in the number of sets and repetitions, aiming to improve selective attention, muscular endurance, and reactive stepping. Example from the literature: Šlosar et al., (2021)
Exergame-based Training:		
Exergame-based Physical Training	Exergame-based training specifically focusing on: (i) endurance and/or muscular resistance exercise(s) with the aim to improve, maintain, or slow the decline of one or more health- or disease-related outcomes that require a near- or far-transfer effect from the specific task(s) being trained.	Example from the literature: In elementary school children, a complex 6-month intervention consisting of exergame-based physical training games focusing on movements combining resistance and aerobic activity with the aim of improving physical fitness and body composition was conducted. The training was performed 3x/week for 45 min with the intensity of the games varying from moderate to high. The exergame tasks included, for example, river rafting where they navigate rapids by physically leaning and paddling, thereby enhancing their upper body strength. Other activities, such as space jumping and obstacle courses, require players to jump, duck, and maneuver around obstacles, which was targeted to improve cardiovascular fitness. The incorporation of these varied activities aimed to provide a comprehensive approach to physical fitness, engaging different muscle groups and promoting a holistic development of children's physical abilities. Caloric expenditure was estimated using a wearable heart rate monitor and ranged between 4 and 8 calories per minute, depending on the intensity of the game and the level of engagement (Marsigliante et al., 2024).
Exergame-based Physical-	Exergame-based training specifically focusing on the combination of:	Example from the literature: In individuals with mild-to-moderate dementia, a complex 12-week

(continued on next page)

Table 2 (*continued*)

Classification	Classification Criteria	Examples
Cognitive Training	(i) endurance and/or muscular resistance exercise(s) AND (ii) additional (thinking while moving) or incorporated (moving while thinking) domain-specific cognitive exercise(s) with the aim to improve, maintain, or slow the decline of one or more health- or disease-related outcomes that require a near- or far-transfer effect from the specific task(s) being trained.	intervention consisting of cognitive-aerobic bicycle training on a stationary bike connected to a video screen was conducted, aiming to reduce the level of frailty and improve physical performance. The aerobic training component consisted of cycling for 30–50 min per session and aimed at achieving an intensity of 65–75 % of heart rate reserve after 12 weeks of training. The cognitive training component consisted of following a route through a digital environment (often a city familiar to the participant, yielding pleasant memories) while performing cognitive tasks targeting response inhibition, task switching, and processing speed. These cognitive tasks were incorporated into the cycling routes that were shown on the video screen. There were 7 different cognitive training levels, and the difficulty of the cognitive tasks increased per training level to ensure that the training remained cognitively challenging (Karssemeijer et al., 2019).
Exergame-based Motor-Cognitive Training	Exergame-based training specifically focusing on the combination of: (i) complex motor skills exercises AND (ii) additional (thinking while moving) or incorporated (moving while thinking) domain-specific cognitive exercise(s) combined with low cardio-vascular (i.e., endurance) effort with the aim to improve, maintain, or slow the decline of one or more health- or disease-related outcomes that require a near- or far-transfer effect from the specific task(s) being trained.	Example from the literature: In addition to usual care for chronic stroke survivors, a complex 12-week intervention was performed with the aim of improving global cognitive performance, gait, and dual-task mobility in chronic stroke patients. The training follows a personalized training concept (i.e., PEMOCS) that assigns, tailors, and progresses individual motor-cognitive exergames following principles for neuroplasticity, (motor) skill learning, and training. Participants train twice a week for 12 weeks. Training sessions last between 30 (beginning) and 40 (end) minutes, progressing in duration for 2 min every second week and resulting in 840 min total training time planned. Motor and cognitive tasks of the exergame-based training are allocated to various difficulty levels along a skill-progression scheme with three dimensions. Based on the participant's subjective ratings of their perceived motor-cognitive task difficulty and their perceived performance, progression through the difficulty levels is determined individually for each participant. Therefore, the training is personalized within a standardized progression scheme. Additionally, variability rules ensure variation in training (Huber et al., 2024b).
Exergame-based Multidomain Training	Exergame-based training specifically focusing on the combination of (i) complex motor skills exercises AND (ii) endurance and/or muscular resistance exercise(s) with at least moderate intensity AND (iii) additional (thinking while moving) or integrated (moving while thinking) domain-specific cognitive exercise(s) with the aim to improve, maintain, or slow the decline of one or more health- or disease-related outcomes that require a near- or far-transfer effect from the specific task(s) being trained.	Example from the literature: In addition to usual care for the secondary prevention of mild neurocognitive disorder, a complex 12-week intervention was performed. Participants are instructed to train $\geq$ 120 min/week (distributed to $\geq$ 5x 24 min) at home and are individually supervised. The training follows a personalized and individually tailored training concept (i.e., Brain-IT) that assigns each participant with a collection of exergames targeting relevant mechanisms of action to alleviate the pathological state in mild neurocognitive disorders. The training combines physical (stepping on the sport to reach 40–60 % of heart rate reserve), motor (reactive stepping tasks and sequences), and cognitive (targeting the domain-specific cognitive performance (i.e., learning and memory, complex attention, executive function, and visuospatial skills) exercises with integrated adjunctive neuromodulatory techniques in the form of Vagus nerve stimulation (e.g., via heart rate variability guided biofeedback breathing). The volume and specificity of neurocognitive exercises are individually assigned and progressed according to a participant's disease etiology and baseline neuropsychological performance and progress during the training period, also following a structured approach to ensure variability (Manser and de Bruin, 2024).

long-term behavior changes (Rhodes et al., 2019). Illustrated by the example of obesity management, adherence to the WHO's PA guidelines (Bull et al., 2020) has only marginally increased from 9.4 % in 1997 to 15.0 % in 2018 and remains worryingly low (López-Gil et al., 2024).

According to Singh et al.'s (2024) systematic review (Singh et al., 2024b), the first stage of habit formation (i.e., deciding to take action and translating intention into behavior) in the context of health behaviors is influenced by the type of habit, with self-selected habits leading to stronger habit formation. Later stages of habit formation are mainly influenced by affective judgment (i.e., enjoyment of the behavior), creating daily routines, and the stability of the context in which the behavior is performed. Therefore, they suggested that targeting simple, repetitive, and enjoyable behaviors with clear cues and immediate rewards can build momentum for more challenging habits (Singh et al., 2024b).

Given that exergames can be designed to provide these conditions, the first step by which exergames can support health promotion is to contribute to support facilitators and overcome barriers to getting physically and motor-cognitively active, thereby initiate habit formation to adhere to WHO's PA (Bull et al., 2020), or similar guidelines.

4.1. First step: actigaming - supporting the initial behavior change

4.1.1. Identification of relevant principles, frameworks, and/or guidelines to support the initial behavior change of overcoming physical inactivity and/or sedentary behavior

Garcia et al.'s (2022) systematic review of 44 reviews identified a range of barriers and facilitators of domain-specific PA that were categorized into intrapersonal factors, social environment and interpersonal factors, built environment factors, and programmatic factors (Garcia et al., 2022). Among the key barriers to leisure-time PA were (i) a lack of time and access, (ii) negative emotions related to PA practice, and (iii) poor health. Experiencing (i) pleasure and fun with PA was among the most important facilitators for PA, along with (ii) better skills, (iii) higher motivation and goal setting, and (iv) positive beliefs about the PA consequences (Garcia et al., 2022). Therefore, the following section will review and discuss how specific exergame features can strengthen facilitators and mitigate barriers for PA, and link this process to selected behavior change frameworks.

4.1.2. Narrative review how specific exergame features can support the initial behavior change of overcoming physical inactivity and/or sedentary behavior

Hammady et al. (2022) systematically reviewed game features that have been most frequently applied in serious (exer-)games and are associated with positive effects on players' intended behavior change. They included over 200 studies and found that the top 5 most frequently implemented game features included 'rewards', 'challenges', 'points/scoring', 'feedback', and 'competition'. The top 5 most often adopted behavior change theories underlying these game feature selections were the 'Self-Determination Theory', followed by the 'Theory of Planned Behavior', 'Social Cognitive Theory', 'Motivational Theory', and 'Flow Theory'. Interestingly, these features align well with the key exergame features that contribute to providing a fun and engaging way to be physically and motor-cognitively active.

A substantial body of research has explored the capacity and mechanisms of exergame features to enhance enjoyment and engagement in actigaming. A broader consensus seems to have emerged on four core feature categories that contribute to these outcomes: (i) challenge, (ii) feedback, (iii) rewards, and (iv) immersion (Röglin et al., 2023; Lyons, 2014). Since the use of exergames to promote enjoyment is not the focus of this work, we kindly refer the reader to previous publications that have discussed these aspects in more detail, including the reviews of Lyons (2014), Röglin et al. (2023), Hadjipanayi et al. (2024), and in part also Matallaoui et al. (2017). For older adults, the ExerGameFlow model was proposed, which describes features and criteria that should be implemented in actigaming to promote enjoyment. In addition to the four core feature categories, it provides recommendations for features to support goal setting, skill development, and social interactions (Rytterström et al., 2024).

All these exergame features can effectively support the facilitators for PA by offering an enriched and enjoyable environment for physical and/or motor-cognitive activity with individualized goal setting, continuous feedback, and individually adaptive challenges that promote skill development, which facilitate positive beliefs (i.e., perceived usefulness) about actigaming. This exergame-enriched environment has consistently shown superior enjoyment compared to other PA types (Rüth et al., 2023; Lee et al., 2017), which facilitates (Valenzuela et al., 2018; Zhao et al., 2020; Mura et al., 2018) or even internalizes (Zhao et al., 2020; Manser et al., 2023) motivation for PA and/or exercise. With this, the most relevant facilitators for PA are well-supported by specific exergame features, which can promote positive behavior changes (Hammady and Arnab, 2022; Ryan and Deci, 2000) that might go beyond those achievable by conventional physical and/or motor-cognitive activity forms.

By also contributing to overcoming barriers related to accessibility and delivering cost-effective, engaging, and culturally relevant interventions, serious exergames can revolutionize physical and motor-cognitive activity promotion and rehabilitation, especially in low-to-middle-income countries (Dereje et al., 2025). Specifically, they provide novel opportunities to overcome negative emotional experiences related to physical and motor-cognitive activity in a safe and controlled environment. Indeed, actigaming generally increases positive emotional experience (including positive affect), even in clinical populations that may not be highly technologically literate (Marques et al., 2023). According to the Affective-Reflective Theory of physical inactivity and exercise (Brand and Ekkekakis, 2018), creating positive affective responses plays a fundamental role in initiating and maintaining PA behavior. In this regard, actigaming can enhance immediate affective valuation by creating an enjoyable and entertaining environment, which, in turn, might positively influence reflective evaluations and intentions to engage in PA. Such a potential dual impact on both affective and reflective processes might help counteract potential negative perceptions and resistance often associated with conventional physical and motor-cognitive activities and positively shape habit formation and -strength in the broader context of health behaviors (which included mainly PA and eating habits) (Singh et al., 2024b). Thereby, actigaming can be a powerful option to promote a more physically and motor-cognitively active lifestyle, which is consistent with predictions of the Theory of Effort Minimization in PA (Cheval and Boisgontier, 2021). Consequently, actigaming has been recommended both as a leisure activity and for health promotion (Marques et al., 2023).

In summary, while there are still vast opportunities to deepen our understanding and optimize user experience (Perez et al., 2025), exergames excel in incorporating features that enhance enjoyment (*"fun"*) and positive emotional experience in physical and motor-cognitive activity. By activating the mesolimbic dopaminergic pathways and the associated reward system of the brain as well as reinforcing self-regulation abilities, actigaming aligns well with the requirements to promote sustained PA behavior and has been highlighted as particularly promising for populations at risk for physical, motor, and cognitive decline (Gerber et al., 2025). While these benefits are undoubtedly decisive for the appeal, promise, and potential of actigaming, exergames offer numerous additional unique opportunities beyond conventional approaches (*"beyond fun"*) to promote behavior change towards sustained physical and/or motor-cognitive activity. These "serious" exergame features will, from now on, be the focus of this review.

Exergames allow for monitoring and providing individualized feedback on the time (per session) and volume (e.g., step count, volume of moderate to vigorous PA, metabolic equivalent of task minutes) of activity that can be tied to the goal of meeting PA recommendations (e.g., from the WHO (Bull et al., 2020)). This approach has the potential to encourage more regular PA, as is the case with wearable activity trackers, which are effective in increasing PA in a variety of age groups and clinical and non-clinical populations, with clinically important benefits being sustained over time (Ferguson et al., 2022).

Moreover, exergames allow for flexible integration of hybrid or home-based actigaming in a well-controlled environment, combining the strengths of center-based (e.g., one-on-one supervision and social interaction) and home-based approaches (e.g., a remotely supervised on-demand activity that can be flexibly integrated into daily life routines and reduces barriers to PA) (Herold et al., 2024). The systematic review of Rüth et al. (2023) provides evidence that, even in unsupervised actigaming with commercially available systems for rehabilitation in the general adult population, high (> 70 % of the intended goal) attendance adherence rates were observed in 53 % of reviewed studies, with only one study observing a low (< 30 %) attendance adherence (Rüth et al., 2023). Dubbeldam et al. (2024) confirmed these findings in the broader context of home-based technology-enhanced PA. In their scoping review, they observed statistically significantly higher adherence in interventions that were tailored (83 ± 15 %) versus those that were not (75 ± 21 %) (Dubbeldam et al., 2024), further strengthening the fields' efforts to go the extra mile through user-centered co-design to improve tailoring of PA concepts and technologies.

Finally, exergames usually offer algorithms that either allow for individually adjusting and progressing the training demands in the game controls or achieve such a tailoring in real-time according to game performance metrics (i.e., closed-loop in-game performance progression) (Demers et al., 2021; Maier et al., 2019a). This enables even individuals with poor health to participate in actigaming by ensuring they are appropriately physically and motor-cognitively challenged. This assumption is supported by Dubbeldam et al.'s (2024) scoping review, in which the authors conclude that there are no compelling reasons to exclude specific older populations from home-based, technology-enhanced PA interventions, as factors such as age, health status, and residency did not negatively impact dropout rates, adherence, or result in intervention-related adverse events (Dubbeldam et al., 2024). As an example, in the systematic reviews from Rüth et al. (2023) and Swinnen et al. (2022), high attendance adherence rates (mean = 84.4 % (Swinnen et al., 2022), majority of studies > 70 % of adherence (Rüth et al., 2023) were reported, even though they focused on older adults with clinical disorders (e.g., stroke, heart failure, lower limb amputation, multiple sclerosis, or cancer), or institutionalized individuals with major neurocognitive disorders (NCD), respectively.

In summary, exergames provide a variety of technical features that effectively support facilitators while lowering specific barriers for physical and motor-cognitive activity. With these advantages, actigaming is well-situated to address the initial step for health promotion, even for individuals with poor health status. However, to also effectively contribute to disease prevention and management, the design and application of exergames need to be tailored to a specific goal and characteristics of the target population(s) (Manser et al., 2024; Manser and de Bruin, 2021). This could be achieved by step-by-step advancing towards more specific (Section 4.2) and purpose-driven (Section 4.3) interventions.

4.2. s Step: exergaming - progressing to specific, planned, and structured activity

4.2.1. Identification of relevant principles, frameworks, and/or guidelines to support progressing to specific, planned, and structured physical and/or motor-cognitive activity

Given that exercise is a subset of (physical) activity (Herold et al., 2019), the behavior change step from actigaming to exergaming mainly relates to (i) providing a more *planned* and *structured* approach with (ii) a higher level of *specificity* to improve skill performance of the task(s) itself or the specific fitness domain(s). Consequently, the general exercise variables, including (i) exercise intensity, (ii) exercise duration, and (iii) type of exercise need to be considered (Herold et al., 2019). Additionally, basic principles of experience-dependent neural plasticity should be taken into account to promote skill (re-)learning (Huber et al., 2024a; Kleim Jeffrey and Jones Theresa, 2008). Therefore, we ground our review on these variables and principles.

4.2.2. Narrative review: how specific exergame features can support progressing to specific, planned, and structured physical and/or motor-cognitive activity

4.2.2.1. General exercise variables. Planning and structuring of specific interventions is within the responsibility of the end-user and/or their exercise instructor(s). However, various exergame features can enhance the users' adherence to general exercise variables.

Most importantly, exergames are versatile tools that allow for the implementation of different *exercise types* with the same equipment (see classification approach; Section 4.2). According to recommendations (Manser et al., 2024; Torre and Temprado, 2022b; Manser and de Bruin, 2021; Herold et al., 2018), a highly effective and ecologically valid exercise type to improve both physical and cognitive performance are simultaneous-incorporated motor-cognitive exercises performed in a standing position focusing on stepping or whole-body movements. Alternative forms to implement this exercise type may be dance-based exercises, which are safe and effective in enhancing physical and/or cognitive fitness (Clifford et al., 2023). However, adopting exergames provides unique advantages to control, monitor, and individually tailor these exercises to the individual needs and goals of the end user (as detailed in previous sections). Concerning the control of *exercise intensity*, the use of exergames has three main advantages, which we will describe below in more detail:

First, Davis et al. (2021) and Marshall and Linehan (2021) observed in their systematic reviews that exergaming in *enriched virtual environments* can lead to lower levels of perceived exertion compared to conventional exercises when both are conducted at a comparable exercise intensity (i.e., objectified by physiological markers). This effect may be potentiated by cooperative, competitive (virtual computer or human opponent), or multiplayer modes (Marshall and Linehan, 2021). As a result, the users might be pushed to overcome the human tendency of effort minimization (Cheval and Boisgontier, 2021) and exercise at a higher physiologically measured exercise intensity. Findings of numerous systematic reviews suggest that such higher exercise intensities might provide a stronger physiological stimulus to trigger the release of neurotrophic factors (e.g., brain-derived neurotrophic factor) that can promote synaptogenesis, neurogenesis, and angiogenesis (Rotondo et al., 2023; Jemni et al., 2023; da Cunha et al., 2023; García-Hermoso et al., 2023; Sivaramakrishnan and Subramanian, 2023; Ashcroft et al., 2022; Wang et al., 2022), which, in turn, may ultimately converge in more pronounced distal changes such as neuroplastic (e.g., structural brain changes) and cognitive performance changes. This assumption is supported by a moderator meta-analysis for exergame-based training concerning improvements in executive functioning (Manser et al., 2024). However, Marshal and Linehan (2021) argued that people typically have some level of control over their engagement with the game systems in real-world settings, so exertion may vary strongly based on the specific difficulty level, skill, or other factors (Marshall and Linehan, 2021). To overcome this limitation, additional exergame features might be needed to ensure fidelity to the target intensity.

Second, there is evidence that exergames including *biofeedback* about the exercise intensity (e.g., via tracking and displaying heart rate (reserve) in real-time) may encourage players to exercise at higher intensities (Marshall and Linehan, 2021). However, this feature is also applicable to conventional exercises. The *"real"* advantage of employing exergames appears to be the opportunity for implementing a *biocybernetic adaptation loop* (Manser and de Bruin, 2021). A biocybernetic adaptation loop is a modulation technique using closed-loop control to detect deviations from an optimal state of real-time body signals of internal training load (such as heart rate variability, or electroencephalography data), and changes the human-computer interface (game) to 'pull' the psychological state of the user in a desired direction (e.g., moderate exercise intensity) (Manser and de Bruin, 2021; Ewing et al., 2016; Muñoz et al., 2018a). In other words, adapting the external load (i.e., work that an individual performs regardless of internal characteristics in a specific environment) to achieve a specific internal load (i.e., individual and acute psychophysiological response) (Herold et al., 2019; Impellizzeri et al., 2019). This approach allows to adapt of the game scenarios (i.e., game speed or complexity; factors of external load) in real-time to keep the internal training load in a defined range, instead of requiring the player to actively adapt their behavior to reach a certain target internal load, potentially making it more user friendly and increasing the ease of use in ensuring exercise fidelity (e.g., to a specific exercise intensity). This assumption is supported by the findings of Muñoz et al. (2018b) who observed in an experimental study that this approach increased the time spent in the recommended heart rate levels by 40 % compared to conventional exercise. However, more research in this area is required, especially concerning identifying physiological markers that provide a valid, reliable, and responsive proxy measure of internal training load, with a specific focus on disentangling the contributions of physical, motor, and cognitive exercise demands (Manser et al., 2024; Kao et al., 2024; Herold et al., 2020).

Third, exergames can be programmed for *monitoring* exercise duration *adherence*, training *fidelity* (e.g., exercise intensity, quality of movements) (Manser et al., 2024), *and game performance* (e.g., a proxy for motor-cognitive performance to adjust game complexity; refer to Loh et al.'s book for details on methodologies (Loh et al., 2015a) as well as a theoretical framework (Loh et al., 2015b) for serious games analytics). Providing individualized feedback on these exergaming variables could extend to feedback on the time and volume of the activity (as discussed in Section 4.1), or motion quality, potentially further promoting regular participation. However, there is currently a lack of motion quality assessments in exergaming studies, which Dill et al. (2024) highlighted as a critical issue, necessitating further research (Manser et al., 2024).

These three key advantages position exergames at the forefront for advancing effective exercise approaches, as Netz (2019) proposed that (adherence to) optimal exercise intensity and motor-cognitive task complexity are driving mechanisms for global and task-specific neuroplasticity, respectively (Netz, 2019). The majority of studies on exergame-based training (Manser et al., 2024) and technology-supported PA interventions in general (Dubbeldam et al., 2024) seem to have recognized the importance of appropriately controlling exercise intensity and individually tailored and/or progressed exercises. However, recent reviews observed that only 42 % (Manser et al., 2024) or 14 % (Dubbeldam et al., 2024) of studies reported and/or provided sufficient details on exercise intensity, whereas details on cognitive demands were neither assessed nor reported in any of the analyzed studies (Manser et al., 2024). This highlights the importance of focusing future research on evaluating the role of specific exergame features to deliver an optimal training load (Manser et al., 2024; Kao et al., 2024; Herold et al., 2020), and buttress the need to transparently report on exercise variables following established recommendations (Manser et al., 2024) when aiming to utilize such data to improve the effectiveness of exergame-based interventions.

4.2.2.2. Principles of experience-dependent neural plasticity. The principles of experience-dependent neural plasticity highlight the importance of structured, repetitive, and meaningful exercises to promote the brain's ability to reorganize and adapt, thereby enhancing recovery and functional outcomes (Kleim Jeffrey and Jones Theresa, 2008). In Supplementary Table 1, we provide a thorough review with examples of how distinct exergame features can support the implementation of each of these principles. While all principles can be supported by specific exergame features, we provide a summary of our most important findings in the following.

Adherence to the principles of *"use it and improve it"*, *"specificity"*, and *"salience matters"* can be supported by offering (i) a library of (co-designed) mini-games (Hadjipanayi et al., 2024; Demers et al., 2021; Maier et al., 2019a) coupled with the concept of MYCHOICE (Manser and de Bruin, 2021, 2024), containing (ii) serious games (Kleim Jeffrey and Jones Theresa, 2008) that entail (iii) functionally relevant tasks (Demers et al., 2021; Maier et al., 2019a) with (iv) high ecological validity (Demers et al., 2021; Maier et al., 2019a). MYCHOICE aims to promote intrinsic motivation via autonomy by offering players to select their preferred games from a game library that offers different games for each skill/function category to be trained before the start of an exercise session (Manser and de Bruin, 2021, 2024; Wulf and Lewthwaite, 2016; Lemos et al., 2017). Implementing such exergame features can support and maximize skill (re-)learning by using functionally relevant tasks to target specific neural pathways, and match with evidence-based recommendations (Stojan and Voelcker-Rehage, 2019; Temprado, 2021; Manser et al., 2024; Torre and Temprado, 2022b; Manser and de Bruin, 2021; Wuest et al., 2014).

To support adherence to these principles, there are initial conceptual frameworks available to target specific brain functions in chronic stroke patients (Huber et al., 2024a) and individuals with mild NCD (Manser and de Bruin, 2021, 2024) by selecting, categorizing, and implementing existing or newly developed exergames into the neurocognitive (sub) domain(s) and/or motor skill categories to be trained. Complementing this approach by implementing logbooks that send out (i) context-aware exercise reminders and provide (ii) positive reinforcement for maintaining a streak, along with (iii) providing mini-challenges, seems a reasonable supportive measure to *"use it to improve it"*. These findings have, however, been derived from findings of the broader field of PA promotion (Smith et al., 2020), physical therapy (Jangi et al., 2018) or exercise (Ibeneme et al., 2021) or related fields including broader gamification applications (such as education/learning, crowdsourcing, social behavior, but also including health/exercise) (Koivisto and Hamari, 2019). The lack of studies investigating the (in)effectiveness of these features in the context of exergames highlights opportunities for future development, research, and practice in this field of research.

To promote adherence to the principles of *"repetition matters"* and *"intensity matters"*, a range of exergame features are available. Integrating a biocybernetic adaptation loop (as discussed in the section *"General exercise variables"*) combined with cooperative and/or competitive player modes (Marshall and Linehan, 2021) seems to be the most promising avenue for future research aiming to elucidate and provide an optimal training load to trigger specific adaptations relevant to overall health. The unique opportunity for users/patients to repetitively exercise in a controlled and enriched environment (Aminov et al., 2018) has also been argued to increase the likelihood that users perform a higher number of repetitions compared to conventional therapy interventions (Huber et al., 2024a). Increasing the exercise frequency and number of repetitions could be further promoted by the emerging trend of telehealth platforms to deliver hybrid exergame-based exercise or training with remote supervision. This approach has recently been recommended (Manser et al., 2024) because it promotes the intervention effectiveness and may contribute to optimizing the utilization of (healthcare) resources (Herold et al., 2024; Stanmore et al., 2019; Chen et al., 2023; Prosperini et al., 2021).

To promote *"transference"*, creating ecologically valid tasks seems of the highest importance (Kleim Jeffrey and Jones Theresa, 2008), which is empirically supported for exergame-based training aiming at cognitive performance improvements (Manser et al., 2024). To monitor skill performance progression, most exergames provide in-session metrics (e.g., game performance metrics). However, these in-session metrics may reflect, to a certain degree, learning and/or habituation effects instead of *"pure"* performance enhancements (Kaiser et al., 2024). To verify whether the exercise/training stimulus is sufficient to induce intended skill-related improvements (in the context of exergaming) or near- and far-transfer effects (in the context of exergame-based training), a parallel evaluation module should be integrated, which would allow the regular evaluation of the (lack of) transfer effects. This approach can provide valuable information to inform decision-making on the individual tailoring of the exercise regime, accounting for the level of the end users' progress (Kaiser et al., 2024; Seinsche et al., 2022).

Finally, the principles of experience-dependent neural plasticity postulate that combining exercises with peripheral or central stimulation might be required to drive *"transference"* effects in a functionally beneficial direction (Kleim Jeffrey and Jones Theresa, 2008). In this regard, a novel and promising area of research relates to integrating adjunctive neuromodulatory techniques into the exergaming narrative to amplify the neuroplastic effects induced by physical and/or motor-cognitive exercises. Such techniques could include non-invasive brain stimulation techniques (e.g., transcranial magnetic or direct current stimulation) or Vagus nerve stimulation (e.g., via heart rate variability guided biofeedback breathing) (Davidson et al., 2024; Lehrer and Gevirtz, 2014). While there is a strong rationale (Mantovani et al., 2024; Teo et al., 2016; Evancho et al., 2023) and initial findings are promising (Manser and de Bruin, 2024; Mantovani et al., 2024; Teo et al., 2016; Moret et al., 2021), more systematic and rigorous investigations are required to strengthen this recommendation by providing additional confirmatory empirical evidence. Specifically, (i) the hypothesis that the addition of such adjunctive neuromodulatory techniques to exergaming induces positive synergistic effects (Manser and de Bruin, 2024) and (ii) how this approach can be optimally integrated into the exergaming narrative need to be tested.

In this regard, a more specific focus on transference can be considered the next relevant behavior change step. This involves progressing to a subconstruct of chronic exergaming that defines the transference of the trained tasks to the improvement, maintenance, or slowing of the decline of health- or disease-related outcomes as a primary goal (i.e., exergame-based training).

4.3. Third step: exergame-based training - targeting health- or disease-related outcomes

4.3.1. Identification of relevant principles, frameworks, and/or guidelines to support progressing to physical and/or motor-cognitive training

According to recent evidence-based recommendations, exergames and exergame-based training concepts should be purpose-developed (Manser et al., 2024) and adhere to general training principles (Herold et al., 2019). For neurorehabilitation purposes, the training should also adhere to the principles for neurorehabilitation (i.e., that integrate motor learning and brain plasticity mechanisms) (Maier et al., 2019b) to promote transference from the task being trained to the targeted health- or disease-related outcomes. We argue that these principles should also be applied to prevent neurodegenerative or neurological disorders, or if the aim is generally to improve and/or maintain brain health. Therefore, we base our review on these key principles.

4.3.2. Narrative review how specific exergame features can support progressing to physical and/or motor-cognitive training

We provide a meticulous evidence synthesis, including examples, of which and how specific serious exergame features can be implemented to better adhere to these 6 General Training Principles and 15 Principles of Neurorehabilitation (i.e., that integrate motor learning and brain plasticity mechanisms) in Supplementary File 2. Given the large amount of evidence, we provide a brief narrative synthesis of these findings in the following section, and kindly refer the readers to Supplementary File 2 for a more detailed presentation of the findings concerning each of the 6 General Training Principles and 15 Principles of Neurorehabilitation.

We identified a range of exergame features that can support adherence to *"general training principles"* that were already recognized as relevant for the general exercise variables and principles of experience-dependent neural plasticity. These include the creation of serious games (Kleim Jeffrey and Jones Theresa, 2008) with ecologically valid tasks (Temprado, 2021; Hadjipanayi et al., 2024; Demers et al., 2021; Maier et al., 2019a) that are varied and progressed with the help of user and/or game levels (Demers et al., 2021; Maier et al., 2019a), closed-loop adaptivity (Ferreira and Menezes, 2020; Demers et al., 2021; Maier et al., 2019a), intensity biofeedback (Marshall and Linehan, 2021), and/or biocybernetic adaptation (Manser and de Bruin, 2021; Muñoz et al., 2018b). For the temporal organization and systematic manipulation of training variables, providing a separate instructor module provides a means to support the exercise instructor(s) (or the primary end-user in case of self-regulated training) in creating exercise/training plans, and thus to organize training periodization and programming (Seinsche et al., 2022).

We identified two systematic reviews that analyzed adherence of exergame-based training concepts to the *"principles of neuro-rehabilitation"* (Maier et al., 2019b) or its subconstructs. Demers et al. (2021) focused on integrating motor learning principles for upper limb rehabilitation in individuals with cerebral palsy. Maier et al. (2019) examined adherence to the principles of neurorehabilitation in upper limb stroke rehabilitation. Both reviews identified a large range of exergame features suitable for implementing these principles. However, adherence to these principles varied strongly depending on the specific principle and was consistently higher in serious exergames compared to "off-the-shelf" recreational exergames (see Supplementary Table 2).

Specifically, more than 50 % of serious exergames provided features to account for the principles of *'variable practice'*, *'increasing difficulty'*, *'explicit feedback/knowledge of results'*, *'implicit feedback/knowledge of performance'* in both reviews, with conflicting results for the principles *'task-specific practice'* and *'multisensory stimulation'*. While we identified suitable exergame features to better adhere to the remaining neuro-rehabilitation principles, there is still vast room for improvement in implementing these features. In the following, we discuss which, according to our findings, are the most promising exergame features in this regard.

While the principle of *'variable practice'* has been well adhered to, this was mainly based on offering a collection of mini-games within a game bundle (i.e., a group of games available to train task-specific skills and/or performance) to introduce novelty through variety (Hadjipanayi et al., 2024; Maier et al., 2019a). To further improve training stimuli, Huber et al. (2024a) proposed that variable practice should also be controlled by providing algorithms to systematically manipulate the task sequence predictability and the variability distribution of the interstimulus interval.

For the principle of *'rhythmic cueing'*, integrating music or rhythmic auditory stimulation bears great potential to enhance the effectiveness of exergame-based training (Braun Janzen et al., 2022). Bégel et al. (2017) recommended that developers should pay particular attention to providing sufficient temporal precision in data acquisition and stimulus presentation by following available guidelines for devising such serious music games targeting the integration of rhythmic auditory cueing (Bégel et al., 2017). To implement the principle of *'multisensory stimulation'* in exergames, rhythmic auditory cues could be combined with visual and tactile cues. Exemplarily, AR-based cueing has been recognized as a promising tool in Parkinson's disease (PD) rehabilitation to treat freezing of gait, and the possibilities and efficiency of implementing such cues will continue to increase with the evolving capabilities of AR hardware (Baugher et al., 2023). Recent findings suggest that individuals with PD can modify their gait to AR cues from state-of-the-art headsets as effectively as to real-world cues (Hoogendoorn et al., 2024). The integration of this strategy into exergame-based training is, however, yet to be explored. A pioneering study implementing AR-based cueing to assist exercise execution in individuals with PD who have more severe gait limitations is currently ongoing (Geerse et al., 2024).

'Motor imagery' has mainly been used as a stand-alone intervention, precluding its integration and optimization by specific exergame features. Eaves et al. (2016) and Almufareh et al. (2023), however, suggested in their narrative reviews that when combined with action observation, motor imagery could be integrated using VR/AR applications. This highlights opportunities for better integrating this important principle of neurorehabilitation. Al-Qaysi et al. (2021) and Almufareh et al. (2023) further proposed that the augmenting effects of VR/AR-based motor imagery coupled with action observation could be further potentiated by integrating neuromodulatory approaches, such as biofeedback and neurofeedback, into smart brain-computer interfaces. However, more research is needed to individually tailor these interventions and elucidate their mechanisms of action (Almufareh et al., 2023; Al-Qaysi et al., 2021; Stefano Filho et al., 2024), for which Al-Qaysi et al. (2021) provided specific recommendations.

Finally, *'social interaction'* has been identified as an important moderator for the effectiveness of exergame-based (Manser et al., 2024) and conventional training (Rieker et al., 2022). So far, social interaction has mainly been implemented by exercising in groups. To allow individuals with limited mobility or who live too far away to regularly attend center-based group sessions to benefit from higher levels of social participation, recommendations for alternative technical features to incorporate social elements into the home-based exergame-based training have been proposed (Manser et al., 2024). These recommendations included collaborative challenges or online leaderboards with benchmarking of the gaming performance (Manser et al., 2024). Ideally, a stepwise approach from supervised training to independent hybrid or home-based training with exergame features for ongoing social connectedness may be implemented to promote continued adherence to exergame-based training. However, only a fraction of exergame-based training has been conducted individually at the participants' homes (Manser et al., 2024). Thus, future efforts in the field of exergame-based training are necessary, while the current practice should draw on the findings of the broader field of serious games. In this regard, the 20 features categorized in six game mechanic typologies identified by Wang et al.'s systematic review (2021) (Wang and Huang, 2021) can be used to inform the design and integration of exergame features to address the principle of ‘social interaction’.

In summary, various exergame features, such as serious game designs, algorithms to manipulate task sequence predictability and variability, AR-based cueing and motor imagery, collaborative challenges, or online leaderboards can enhance adherence to general training and neurorehabilitation principles. Consistent implementation of these features potentially increases the effectiveness of exergame-based training to improve specific health- or disease-related outcomes. To date, however, research on exergame-based training has been conducted with relatively limited observation periods, so that little is known about the adherence to and (retention of) effects of long-term (> 12 months) training (Ismail et al., 2022).

To the best of our knowledge, only one published study investigated such long-term effects of exergame-based training. Sturnieks et al. (2024) observed in their randomized controlled trial that exergame-based training resulted in a significantly lower proportion of people who reported one or more falls during the 12-month follow-up period (36.0 % for the exergame versus 48.2 % for the control group). However, only 20.6 % of participants reached the training goal of 120 min per week, averaged across the 12-month intervention period (Sturnieks et al., 2024). In contrast, Mazeas et al.’s (2022) systematic review of the broader field of technology-enhanced PA promotion suggested that the positive effect on PA behavior can persist over extended follow-up periods, and may therefore not merely be driven by the novelty effect caused by the playful nature of gamification (Mazeas et al., 2022). The effects were, however, relatively modest, and diminished over time, so further research is necessary to substantiate (or refute) these findings (Mazeas et al., 2022).

In light of this current state of evidence, there appears vast room for improvement in the design of the training concepts and/or the selection and implementation of specific exergame features to support long-term adherence and promote the ultimate goal of consolidating the behavior change with the sustained integration of physical and/or motor-cognitive training as part of daily life. To capture this step and prompt future research in this context, we extend our definition and classification approach by the term *“exergame-enriched lifestyle”*, referring to the *“the continuous (i.e., (a series of) macro cycle(s) of ≥ 12 months) integration of exergame-based training as part of everyday life”*. In the following section, we will discuss how specific exergame features can support this last step.

4.4. Fourth step: exergame-enriched lifestyle - consolidate the behavior change

According to Hadjipanayi et al. (2024), an important determinant for sustained engagement is the narrative purpose of exergames. This purpose can be built both in the *"intra-diegetic"* (i.e., within the narrative of the fictional world) and *"extra-diegetic"* (i.e., outside the narrative of the fictional world) dimension. The design of commercial games has primarily focused on the intra-diegetic purpose of the game (e.g., finishing the race in the first place, achieving a new high score), which aims to entertain the player(s). In contrast, the design of serious games has focused on the extra-diegetic purpose with the goal to positively impact the player’s life in a meaningful way (e.g., improve motor function to the point where one can independently prepare a simple meal, improve memory to the point where one can independently shop for groceries). The latter contextualizes the desired performance improvement within real-world capabilities, thereby adhering to the experience-dependent neuroplasticity principle of salience and promoting the transference of trained skills to real-world scenarios (Hadjipanayi et al., 2024).

Hadjipanayi et al. (2024) argued that a balanced approach that integrates both intra-diegetic and extra-diegetic narratives should be sought when designing exergames to provide a sense of purpose that is both engaging within the game and meaningful in real life. By finding the appropriate balance, exergames can potentially provide a means for sustained adherence to physical and/or motor cognitive training. We kindly refer the reader to the narrative review of Hadjipanayi et al. (2024), which provides an in-depth analysis and discussion of how such a balance can be achieved in the context of stroke rehabilitation, discussing strategies like mini exergame bundles (i.e., offering a collection of mini-games within a game bundle to balance between ADL-oriented exergames and sports-oriented exergames and to introduce novelty through variation) or scaffolding (i.e., offering in-game rewards such as introducing new game features and better graphics as the player’s performance improves).

5. Integrating these findings: the ‘beyond “just” fun of exergames framework’

In this section, we present the ‘Beyond *“Just”* Fun of Exergames Framework’ (Fig. 2) along with best practice recommendations for the implementation of this framework (Table 3). This framework integrates (i) the extended definition and classification approach, and (ii) the findings from our review on the roles and potential mechanisms of specific exergame features to support adherence to relevant behavior change, neuroscience, and exercise science principles.

Importantly, while the stepwise approach outlined in the framework may be most beneficial for promoting sustained behavior change, the *framework can be applied with different entry points* (e.g., direct implementation of exergame-based training), as the upward steps address subconstructs of physical and/or motor-cognitive activity. Note that in such cases, all lower-level recommendations in the framework apply (e.g., in the example of exergame-based training, the recommendations for actigaming and exergaming apply)

6. Implications

The ‘Beyond *“Just”* Fun of Exergames Framework’ provides recommendations concerning best practices for a theoretically grounded selection and implementation of specific exergame features to advance health promotion and disease prevention. Current evidence suggests that exergame-enhanced interventions that are purposefully designed with adequate theoretical underpinnings and/or better adherence to relevant behavior change, neuroscience, and exercise science principles are more effective in improving cognitive (Manser et al., 2024) and physical (Maier et al., 2019a) endpoints, however, these principles are often insufficiently followed (Manser et al., 2024; Demers et al., 2021; Maier et al., 2019a). Consequently, applying this framework for the theoretically grounded selection and implementation of exergame features will help overcome the currently present limitations by guiding game designers, researchers, and exercise and therapy practitioners in the design and application of serious exergames. Therefore, applying this framework has the potential to unlock the full potential of exergame-enhanced interventions for more effectively addressing individual and public health needs. This is particularly relevant for designing, developing, and implementing exergame-enhanced interventions to improve healthcare for vulnerable populations with diseases or disorders for whom PA or training is recommended as a potential disease-modifying intervention. Such vulnerable cohorts encompass but are not limited to individuals with cardiovascular diseases (Tian and Meng, 2019; Izquierdo et al., 2025), cancer (Izquierdo et al., 2025), frailty (Izquierdo et al., 2025), mental health disorders (including depression, anxiety and psychological distress) (Izquierdo et al., 2025; Singh et al., 2023), metabolic disorders (including obesity and diabetes) (Izquierdo et al., 2025; Colberg et al., 2016; Kanaley et al., 2022), neurodegenerative and neurological disorders (Izquierdo et al., 2025; Kantawala et al., 2023; Veronese et al., 2023; Chen et al., 2021; Langeskov-Christensen et al., 2024; Kleindorfer et al., 2021; Ambrosetti et al., 2020; Geidl et al., 2018; Quinn et al., 2020; Dalgas et al., 2019; Xiang et al., 2022) (including NCDs (Izquierdo et al., 2025; Veronese et al., 2023; Chen et al., 2021), PD (Langeskov-Christensen et al., 2024),

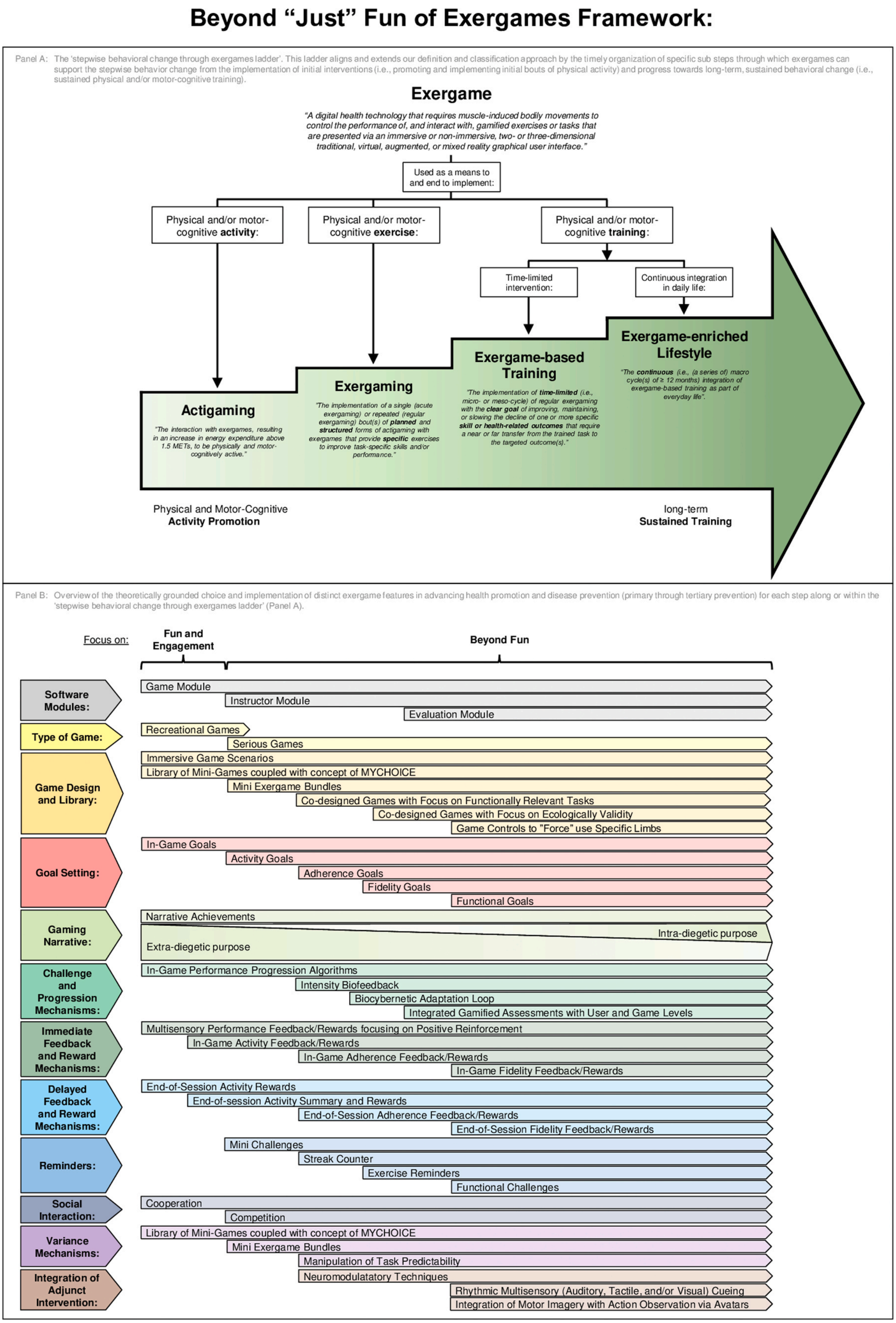

Fig. 2. Beyond "Just" Fun of Exergames Framework.

Table 3
Best practice recommendations for the implementation of the 'Beyond *"Just"* Fun of Exergames Framework' for the theoretically grounded selection and implementation of distinct exergame features in advancing health promotion and disease prevention (primary through tertiary prevention; including rehabilitation). The specific levels described in the best practice recommendations relate to the stepwise integration of specific exergame features within the respective category, as illustrated in Fig. 2.

Category	Best Practice Recommendations
Software Modules	Exergames typically consist of hardware and software. The software visible to the end-users can typically be divided into different modules, each providing specific exergame features relevant to different aspects of a structured intervention and the contexts of specific applications of exergames along a stepwise behavior change. Therefore, these software modules form the backbone of every exergame. In the following, we provide an overview of which modules are relevant to implementing which exergame features, which will be addressed in the following sections in more detail: Level 1: Overcoming initial behavior change with the help of exergames is initially all about the gamified experience of being physically and motor-cognitively active. This activity is conducted in the **game module,** which is designed to be visible to primary end-users. The game module should include, in addition to the actual games to be played, goal setting, a library of mini-games coupled with the concept of MYCHOICE, game instructions, monitoring of game performance, feedback and rewards mechanisms, and/or reminders. Level 2: When moving towards more structured interventions, an **instructor module** is required to support the exercise instructor(s) (i.e., secondary end-users, such as therapists, behavior change coaches, medical doctors, researchers, or the primary end-users in case of self-regulated training). Such an instructor module should provide options for creating and/or managing exercise/training plans, training periodization and programming, mini exergame bundles, goal setting and monitoring of adherence and fidelity to the exercise/training plan, (remote) supervision, and/or sending out reminders. Level 3: Finally, an **evaluation module** should be offered to allow the integration of gamified assessments to regularly verify whether the exercise/training stimulus is sufficient to induce the desired skill-related changes (in the context of exergaming) or near- and far-transfer effects (in the context of exergame-based training and an exergame-enriched lifestyle). The data should inform decision-making on individually tailoring, adjusting, and progressing the exercises in the instructor module.
Type of Game AND Game Design and Library	Level 1: To support initial behavior change in the context of actigaming, priority should be given to promoting intrinsic motivation via autonomy support by providing a library of **immersive recreational mini-games** coupled with the **concept of MYCHOICE**. This means the players can choose whichever game(s) they like most to be physically and motor-cognitively active, depending on their individual preferences. The aim of this phase is solely to provide an enjoyable experience in being physically and motor-cognitively active. Level 2: To promote progression to specific, planned, and structured activity (i.e., exergaming), recreational games should be replaced by **serious games** that are (or have been) designed to exercise task-specific skills and/or performance. Instead of providing the entire library of games to select from, create **mini exergame bundles** that group all available games within a specific category of task-specific skills and/or performance. Continue with the concept of MYCHOICE to allow players to select their preferred games to exercise a specific skill or function. Level 3: Once progressing to exergaming, one should ensure to use **co-designed serious games** that are (or have been) collaboratively designed and developed with a user-centered focus to match the specific target population's preferences and needs while taking into consideration their individual playstyles (e.g., achiever, explorer, or socializer) and personality characteristics (e.g., introverted to extroverted, conscientious, need for autonomy, emotional resilience, openness to experience, motivation type, risk-taking, social interaction preference). These games should focus on providing **functionally relevant tasks** to align the selection of available games with the requirements defined in the exercise prescription. Continue with the concept of MYCHOICE to allow players to select their preferred games from the available games for each skill or function that, according to the overarching training concept, should be conducted in a specific training session. Level 4: To facilitate transference from the trained task to one or more specific skills or health-related outcomes, provide **co-designed serious games** focusing on the **ecological validity** of the game tasks and environment. Continue with the concept of MYCHOICE to allow players to select their preferred games from the available games for each skill or function that, according to a training concept, is to be trained in a specific session. Level 5: Ensure that the player's use different limbs or muscles during practice to promote a more flexible and robust motor learning or, in the case of hemi-paretic impairments, ensure that the player focuses on the use of the impaired limb, in order to complement the previous levels with **game controls to *"force"*** the **use** of **specific limbs.** In particular, the game tasks should be designed to ensure and/or reward balanced use of all limbs according to an overarching training concept. As an example, bonus points could be rewarded for the balanced (50−50) use of the left and right limb in healthy individuals, or adherence to the goal of performing 75 % of movements with the paretic limb and 25 % with the healthy limb in hemi-paretic stroke rehabilitation (i.e., based on principles of the constraint-induced movement therapy).
Game Narrative	Since completing this behavior change step to integrate an exergame-enriched lifestyle cannot be planned but is rather expected to happen as a stepwise transition over time, it is reasonable to favor the early integration of a balanced approach of intra- and extra-diegetic game narratives to support habit formation of using exergames. Specifically: Level 1: Focus on providing a narrative with a clear **intra-diegetic purpose** in the early stages of an intervention that focuses on the activity and progresses to focus on performance (i.e., actigaming, exergaming) and provide **narrative achievements** aligned with this focus. Level 2 + : Extend the game narrative continuously with extra-diegetic purposes to (i) promote the transference of trained skills to health- or skill-related outcomes aligned with clear goal(s) of the exergame-based training; and (ii) provide a **balanced environment** to simultaneously promote the experience of pleasure and fun (i.e., by the extra-diegetic purpose) and positive beliefs about the benefits of the activity (intra-diegetic purpose). This approach is most likely to facilitate the transition to an exergame-enriched lifestyle.
Goal Setting	To support the stepwise behavior change process, goal setting should be individualized and aligned with the game narrative as well as with the immediate and delayed feedback and reward, and its underlying mechanisms of action. Level 1: To support initial behavior change in the context of actigaming, goal setting should first focus on overcoming the barriers and supporting the facilitators for physical and motor-cognitive activity. Therefore, goal setting should be linked to the intra-diegetic purpose of the game and the positive reinforcement mechanisms to promote intrinsic motivation. To achieve this, challenging but achievable **in-game goals** embedded in the game narrative should be integrated to support an external and game-directed focus. For example, players could be tasked with collecting special items scattered throughout the game world by performing physical activities to advance the storyline. The goal might be to collect several items to unlock clues and solve a mystery integrated into the game narrative. Level 2: Once the player has overcome the initial barriers for physical and/or motor-cognitive activity and starts forming a habit, the goals should be expanded to providing **activity goals** for a given session, such as a target volume of physical and motor-cognitive activities completed. This could include measures such as the total number of steps taken during actigaming, the number of calories burned, or the total time a player has been active. Level 3: When progressing to exergaming, goal setting should be expanded to defining specific **adherence goals** linked to planned exercise variables (i.e., exercise frequency, intensity, and duration).

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Table 3 (*continued*)

Category	Best Practice Recommendations
	Level 4: As a next step, goal setting should be extended to exercise fidelity. These **fidelity goals** should define goals related to adherence to specific exercise variables, correctness and quality of movements, and/or strategies used to maintain postural stability, which could be linked the game metrics such as task completion accuracy or trajectory error. **Level 5:** Finally, when progressing to exergame-based training, the goal setting should additionally be directed towards specific **functional goals.** Ideally, these goals are linked to outcomes obtained in the exergame evaluation module or with standardized assessments and could be defined to improve by a specific percentage in a specific functional outcome over a pre-defined period.
Challenge and Progression Mechanisms:	**Level 1:** To support initial behavior change in the context of actigaming, focus on the use of **in-game performance progression algorithms** to provide an individually adaptive challenge by matching the game task requirements to the user's skill level in real-time. Focus on providing an optimal challenge-skill balance to induce, in the optimal case, a flow state. **Level 2:** In a second step, provide **intensity biofeedback** (i.e., biofeedback about the exercise intensity (e.g., via tracking and displaying heart rate reserve in real-time)) and encourage players to exercise at a predefined exercise intensity (e.g., moderate exercise intensity, defined as 40–60 % of heart rate reserve) to progress to a structured approach to provide the planned exercise intensity in the context of exergaming. **Level 3:** In a third step, complement the in-game performance progression algorithms with real-time adaptation of task demands via a **biocybernetic adaptation loop** to ensure training fidelity to the targeted exercise intensity in the context of exergaming and optionally continue to provide biofeedback and/or neurofeedback about the internal training load. This approach has the same goals as intensity biofeedback. However, instead of requiring the player to actively adapt their behavior to reach a certain target, the game scenarios (i.e., external load) are adapted in real-time to keep the internal training load within a defined range, potentially making it more user-friendly and increasing the ease of use in ensuring exercise fidelity (e.g., to a specific exercise intensity). **Level 4:** Finally, complement the measures of levels 1–3 within the game module by adding an evaluation module with **gamified assessments** to regularly verify whether the exercise/training stimulus is sufficient to induce the targeted skill-related improvements (in the context of exergaming) or near- and far-transfer effects (in the context of exergame-based training and an exergame-enriched lifestyle). Use the outcomes obtained within the evaluation module to inform decision-making on individually tailoring the training by accounting for the level of training progress within the game module. More specifically, use predetermined **game levels** to set the initial task requirements according to the **user level,** which is defined based on the outcomes obtained in the evaluation module and reflects the participant's capabilities (i.e., according to physical, motor, cognitive, or motor-cognitive performance assessments). Then, progress the external load/ task demands (i.e., by adapting the game level or progressing to more complex games) by following decision trees with predetermined rules for which elements of and how the external training load is adapted. These decision trees should be linked to the outcome in the evaluation module as well as in-game performance progression and may be fine-tuned by the feedback of the primary (i.e., trainee) and secondary end-users (training instructor). Importantly, before implementing an evaluation module, its assessments should be scientifically validated to ensure that they measure the intended construct(s), have good inter-rater and test-retest reliability, and are responsive to changes over time with no ceiling or bottom effects. Ideally, reference or normal values for specific target populations should be provided to allow comparisons with a reference population. In addition, the assessment module should be kept strictly separate from the game module, as these two modules have different objectives (exercising/training versus assessment). Finally, in studies that implement an evaluation module within an exergame-based training concept, the results derived from the evaluation module may only be used to assess intervention-related effects if the control intervention(s) have similar interaction times with the exergame device to ensure that measured changes are related to functional changes and not just habituation or learning effects due to repeated use of the exergames.
Immediate Feedback and Reward Mechanisms:	**Level 1:** To support initial behavior change in the context of actigaming, providing appropriate feedback and rewards plays a key role. To support one of the most important facilitators of physical activity (i.e., experiencing pleasure and enjoyment in physical activity) and to reduce one of the most important barriers to physical activity participation (i.e., negative affective or emotional experiences associated with physical activity), real-time feedback should focus on providing **multisensory in-game performance feedback/rewards focusing on positive reinforcement** in the context of actigaming. At this stage, feedback and rewards should be focused on the activity at hand to provide an external and game-directed focus that is not yet linked to goals related to the behavior change to ensure it reinforces competence and thus contributes to an internalization of motivation. Such feedback can be contextualized by providing multi-sensory feedback immediately after correctly completed tasks. We recommend that corrective feedback should be very subtle and provided only to the extent necessary to ensure task comprehension and thereby competence, while external rewards should only be provided to support the players' autonomy because they might otherwise decrease intrinsic motivation. **Level 2:** In a second step, priority should be given to **in-game activity feedback/rewards** by providing real-time information about the volume of physical and motor-cognitive activities completed, such as the number of steps taken, the number of calories burned, or the total time spent (physically and/or motor-cognitively) active. This real-time feedback could also be complemented by special rewards like bonus points, power ups, or scaffolding (e.g., introducing new game features and/or better graphics as a reward for the completed activities) and serves as a first step to link the feedback mechanisms to a participant consciously values goals (e.g., increasing physical activity behavior) to promote identified regulation. **Level 3:** When progressing to exergaming, the adherence to the planned exercise variable (i.e., exercise intensity and duration) should be rewarded with **in-game adherence feedback/rewards** by providing real-time feedback and rewards. Adherence feedback and rewards should focus on promoting the players to adhere to the defined exercise characteristics (e.g., intensity and duration) and to the planned exercise regime. **Level 4:** During exergame-based training, adherence to the training plan, which should be based on relevant underlying neuroscientific principles, should be rewarded by providing **in-game fidelity feedback/rewards** via both explicit and implicit feedback. Explicit feedback refers to knowledge of results and may include feedback on average completion time, task completion accuracy, or trajectory error. Implicit feedback refers to knowledge of performance and encompass, among other metrics, real-time visualization of arm/hand movement and other kinematic properties (speed, rotations, synergies compensations) to reduce the sensorimotor prediction error and promote learning that can be virtually (e.g., visually increase on the screen) or acoustically (e.g., audio indications of speed of movement, joint angles) enhanced.
Delayed Feedback and Reward Mechanisms:	**Level 1:** To complement immediate feedback and reward mechanisms, when starting a behavior change journey, the delayed feedback should first focus on providing **end-of-session activity rewards** as positive reinforcement for attending an actigaming session, ignoring the type, volume, or quality of the activity. Such feedback could, for example, be implemented by providing badges for each completed actigaming session to reinforce repeated actigaming behavior. **Level 2:** In the second step, priority should be given to **end-of-session activity summary and rewards** by providing information about the completed volume of physical and motor-cognitive activities. This action may include measures such as the total number of steps taken during actigaming, the number of calories burned, or the total time the primary end-user has been active and can be complemented by special rewards like badges, trophies, or scaffolding (e.g., introducing new game features and/or better graphics as a reward for the completed activities). This type of feedback is a first step to link the feedback mechanisms to the participant's consciously valued goals (e.g., increase physical activity behavior) to promote identified regulation.

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Table 3 (*continued*)

Category	Best Practice Recommendations
	Level 3: When progressing to exergaming, **end-of-session adherence feedback/rewards** on the adherence to planned exercise variable (i.e., exercise intensity and duration) should be provided. Such feedback could include, but is not limited to, the percentage of exercise time spent within the targeted exercise intensity or the percentage of planned exercise duration completed. **Level 4:** During exergame-based training, compliance with the training plan, as well as relevant underlying neuroscientific principles, should be rewarded by providing **end-of-session fidelity feedback/rewards**. This should include both explicit and implicit feedback. Explicit feedback refers to knowledge of results and may include feedback on average completion time, task completion accuracy, or trajectory error. Implicit feedback refers to knowledge of performance and could entail real-time visualization of arm/hand movement and other kinematic properties (speed, rotations, synergies compensations) to reduce the sensorimotor prediction error and promote learning that can be virtually (e.g., visually increase on the screen) or acoustically (e.g., audio indications of the speed of movement, joint angles) enhanced.
Reminders	**Level 1:** To align reminders with goal setting, we propose that **mini-challenges** should be implemented once goal setting has progressed to level 2. Invitations for mini-challenges could, for example, be sent out once or twice a week to remind players and contribute to promoting a habit of regular actigaming. Ideally, these mini challenges should be directly linked to the specific goals that may include a certain number of steps taken during actigaming, the number of calories burned, or the total time the primary end-user has been active, and could be framed by the number of games or game tasks completed in a session. **Level 2:** Once a specific frequency for the use of exergames is defined (level 3 of goal setting), a **streak counter** should be implemented to create psychological drive and behavioral momentum to maintain a streak. The streak counter should be linked to the adherence goals and track the number of consecutive days/weeks the player adhered to the planned exercise variables (i.e., exercise frequency, intensity, and duration). **Level 3:** As a next step, integrating exercise logbooks into the exergame system that sends context-aware **exercise reminders** to adhere to the exercise plan is recommended, especially when adherence stagnates or declines, or where the potential for breaking streaks is imminent. **Level 4:** Finally, once functional training goals are defined, mini-challenges could be extended to **functional challenges** by inviting the primary end-user to take part in a functional test in the evaluation module aligned with the defined training goals.
Social Interaction	**Level 1: Cooperation** can effectively promote enjoyment and thus intrinsic motivation via relatedness, which, in turn, can support the initial behavior change in the context of actigaming. Depending on the primary end-user's preferences and needs, cooperation can be promoted by either using group training with cooperative game elements, or by integrating cooperative game elements into the game narrative to allow the player to cooperate remotely within the game scenarios. Such cooperative game elements include but are not limited to virtual group sessions or multiplayer modes with collaborative challenges, scheduled online tournaments, tradeable resources, information division, community forums with chatting/calling features, group briefings, group scores, or joint rewards and victories. **Level 2:** We recommend that the game narrative should only be extended by the dimension of **competition** when corrective feedback and external rewards (see above) are provided once the player has overcome the initial barriers for physical and/or motor-cognitive activity and starts to build a certain routine. Depending on the primary end-user's preferences and needs, competitive elements can be implemented using, among other approaches, group training with competitive game elements, or adaptations of the game narrative to allow the player to compete remotely within the game scenarios. Concrete examples of competitive game elements are online leaderboards with benchmarking of performance or scheduled (online) tournaments.
Variance Mechanisms	**Level 1:** In the context of actigaming, priority should be given to providing a library of **immersive recreational mini-games** coupled with the **concept of MYCHOICE** allows players to select game(s) they like most to be physically and motor-cognitively active. **Level 2:** When progressing to specific, planned, and structured activity (i.e., exergaming), it is recommended to provide **mini exergame bundles** that group all available games within a specific category of task-specific skills and/or performance and regularly introduce novelty through variety by either allocating new games to the training plan or, ideally, continuing with the concept of MYCHOICE to allow players to select their preferred games to exercise a specific skill or function. **Level 3:** To optimally support motor(-cognitive) learning in the context of structured exercise or training, variation should be extended to the option of purposefully **manipulating the task predictability**. More specifically, algorithms to systematically manipulate the task sequence predictability [e.g., from simple 4-stage sequences of required responses (e.g., left, left, forward, right) that are repeated (fully predictable) to random (completely unpredictable) sequences of required responses] or the variability distribution of the interstimulus interval (e.g., from zero variation to some large Gaussian variation around that interstimulus interval) should be used.
Integration of adjunct interventions	**Level 1:** Integrate adjunctive **neuromodulatory techniques** into the exergaming narrative to amplify the neuroplastic effects induced by physical or motor-cognitive exercises. More specifically, exercises could be augmented by peripheral or central stimulation techniques to support experience-dependent neural plasticity and promote transference effects. Such techniques could involve non-invasive brain stimulation techniques (e.g., transcranial magnetic or direct current stimulation) or Vagus nerve stimulation (e.g., via heart rate variability guided biofeedback breathing). **Level 2:** Integrate **rhythmic auditory** cues (e.g., via rhythmic auditory stimulation or music) combined with **tactile and/or visual** (may be in augmented or virtual reality) cues to modify gait and/or motor performance during exergame-based training and/or to assist the exercise execution of individuals with more severe physical limitations (e.g., of postural control or gait). **Level 3:** Integrate **motor imagery combined with action observation** using virtual or augmented reality applications with **avatars** to promote motor performance improvements and learning.

stroke (Kleindorfer et al., 2021; Ambrosetti et al., 2020), motoric cognitive risk syndrome (Xiang et al., 2022), and multiple sclerosis (Geidl et al., 2018; Dalgas et al., 2019), osteoporosis (Izquierdo et al., 2025), or sarcopenia (Izquierdo et al., 2025).

While this framework provides relevant guidance to game designers, researchers, and exercise and therapy practitioners, it is important to note that it does not eliminate the need for a multidisciplinary exergame design team. In contrary, we intentionally make no recommendations regarding the specific design of the discussed exergame features because the design should be tailored to the specific needs of the primary end-users, following user-centered co-design and development procedures. In this respect, the Medical Research Council's (MRC) guidelines for the development and evaluation of complex interventions (Skivington et al., 2021), the Generative Co-Design Framework for Healthcare Innovation (Bird et al., 2021), or the Multidisciplinary Iterative Design of Exergames (MIDE) - Framework (Li et al., 2020) and its refined methodology from the 'Brain-IT' project (Manser and de Bruin, 2021) can provide guidance on how to structure such a developmental process, which can be further refined by aspects to inform the design of new digital health technologies from the NASSS (nonadoption, abandonment, scale-up, spread, and sustainability) framework (Greenhalgh et al., 2017) and the PRACTical planning for Implementation and Scale-up (PRACTIS) - Guide (Koorts et al., 2018). It is therefore recommended to combine the 'Beyond "Just" Fun of Exergames – Framework' with such rigorous user-centered and iterative co-design procedures to maximize the impact of research on exergames and exergame-enhanced interventions.

Furthermore, as highlighted in Section 4.4, there is room for improvement in the design and long-term evaluation of serious exergames and exergame-based training concepts to consolidate a behavior change – for which we introduce the term *"exergame-enriched lifestyle"* – as well as the implementation of serious exergames into health and welfare services. Specifically, most intervention studies in sports and exercise medicine, physical therapy, or related fields are terminated at the efficacy trial stage due to the lack of context-specific dissemination and implementation strategies to drive the sustainable translation of evidence-based interventions in real-world settings (Oluwatoyosi et al., 2020), which also applies to research on exergames. Given that this framework integrates recommendations to support long-term adherence and behavior change consolidation, it should be used as a starting point to design and evaluate serious exergames and exergame-based training concepts specifically focusing on consolidating a behavior change and integration in health and welfare services – thereby contributing to address the lingering evidence-to-practice gaps (Oluwatoyosi et al., 2020).

7. Outlook

In prompting further research directions, we propose that priority should be given to further refine and consolidate the 'Beyond *"Just"* Fun of Exergames Framework' by addressing the following key aspects:

First, while the proposed exergame features (i) align with relevant behavior change, neuroscience, and exercise science principles, and (ii) many of these features have already been implemented in exergame research, we acknowledge and advocate for further empirical testing of the effects and mechanisms of action for the discussed (and additional, future) exergame features concerning their isolated and synergistic effectiveness to influence on specific outcome(s). Based on such to-be-expected and newly emerging scientific evidence, the proposed framework should be continuously updated.

Second, we acknowledge that the principles guiding our work were chosen because they are generalizable to exergame research with regard to our definition and classification approach. For specific (clinical) populations, there are more specific principles available (e.g., Izquierdo et al., 2025; Veronese et al., 2023; Fairag et al., 2024) that can complement the recommendations provided in this article to refine the theoretically grounded selection and implementation of distinctive exergame features in these specific contexts.

Third, we did not address AR and/or VR as stand-alone exergame features because we focused our review on the selection, design, and functionality of exergame features (i.e., software) rather than the hardware used to deliver these features. However, previous reviews identified several features of fully immersive VR that can support skill learning, including but not limited to multisensory interactivity with haptic feedback in a high-fidelity VR with three-dimensional representations and the presence of avatars (Tusher et al., 2024). Moreover, fully immersive VR or AR have a fundamental advantage in delivering ecologically valid game scenarios via recreating a certain level of naturalistic sensory-motor interaction between the user and graphical user interface (Tieri et al., 2018), whereas specially designed and customized VR interventions were more effective in neurorehabilitation compared to the use of commercially available VR systems (Voinescu et al., 2021). Given that we analyzed and discussed immersion as a key exergame feature with a substantial overlap with the remaining features identified and discussed in this article, our assumption that priority should be given to the selection, design, and functionality of exergame features (i.e., software) rather than the hardware used to deliver these features is supported. Nonetheless, the narrative review by Schaumburg et al. (2025) provides design recommendations for developing VR-based applications that are both effective and accessible by older adults, which can be used in conjunction with the recommendations provided here as well as co-design and development procedures.

Finally, rapid technological developments will lead to novel opportunities to improve applications of exergames in the future. For example, first research groups have started to use multimodal data combined with machine learning and other statistical techniques to classify affective or emotional responses to the exergames and to individually adapt the game content to optimize user engagement in real-time (Izountar et al., 2022; Shamim Hossain et al., 2018). Integrating these features into biocybernetic adaptation loops may be a promising approach to advance the end user's experience by using information about the user's different psychophysiological states and responses to the interaction with exergames. The better utilization of such information can guide the individualization of the type and delivery of feedback and/or graphical game content to promote training fidelity and prevent end-user frustration (e.g., due to overload). Similarly, artificial intelligence, machine learning, and other statistical techniques could be used to analyze large datasets on user performance based on exergame metrics (e.g., using the data generated both in the *"game"* and *"evaluation"* modules) and derive recommendations to individually tailor and progress exercises or training programs.

8. Conclusion

This article is the first to provide a comprehensive overview of specific exergame features that go beyond the benefit of *"just"* providing a fun and engaging environment for physical or motor-cognitive activity/exercises. Based on the findings from our narrative review, we developed the 'Beyond *"Just"* Fun of Exergames Framework' that sets a theoretically grounded and evidence-based guide for best practices in the context-dependent selection and implementation of specific exergame features. By introducing this framework, we aim to support a paradigm shift from entertainment-centered recreational solutions towards serious exergames that are purposefully designed with adequate theoretical underpinnings. Thus, our proposed framework is especially relevant for stakeholders such as game designers, researchers, and exercise and therapy practitioners, and will improve the design and development of exergames and exergame-enhanced interventions, which, in turn, are likely to unlock the full potential of exergames as a powerful tool to promote overall health, healthy aging, and disease management.

We recommend prioritizing the implementation of this framework to inform the design and development of exergames and exergame-enhanced interventions in future development, research, and practice. Additionally, we advocate for empirical validation and continuous refinement of the framework based on newly emerging scientific evidence. These efforts will support the ongoing process of maximizing the effectiveness of exergame-enhanced interventions and contribute to the broader goal of improving health promotion and disease prevention (primary through tertiary prevention) by applying innovative digital health technologies.

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Author Contributions

The review article was conceptualized by Patrick Manser, with guidance from Fabian Herold. Patrick Manser was responsible for the literature research, data collection process, data synthesis, and writing the manuscript. Eling D. de Bruin, Jean-Jacques Temprado, Louis Bherer, and Fabian Herold contributed to the refinement of the definition and classification approach and the framework, as well as to revisions of the manuscript. All authors reviewed and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The authors have nothing to declare.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neubiorev.2025.106260.

Data availability

All data analyzed in this study is included in the article and supplementary files. Further inquiries can be directed to the corresponding author.

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