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Review article

Virtual reality exergames for enhancing engagement in stroke rehabilitation: A narrative review

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A B S T R A C T

This narrative review focuses on upper-limb stroke rehabilitation and virtual reality (VR) exergaming interventions that seek to facilitate the rehabilitation process. We examine exergaming interventions from the perspective of diegesis ("narration"), an aspect often overlooked despite its significance in neuronal rehabilitation. The importance of diegesis and narrative engagement in rehabilitation exergames started becoming clear only recently, with findings in the field of neurology underscoring the impact of purpose-driven task engagement on neuroplasticity. We begin this review by examining various frameworks for stroke rehabilitation exergames and identifying the gaps in the existing literature. We continue with summarizing the literature on exergames in upper-limb stroke rehabilitation, emphasizing the contribution of diegesis on exercise motivation and engagement. Finally, we conclude this review by offering insights into the current state of research, along with future perspectives on the topic.

1. Introduction

Stroke is a neurological condition that stands as one of the foremost causes of mortality globally, and its incidence is estimated to rise steadily in the coming decades, even among individuals under the age of 55 [1,2]. Most stroke survivors suffer from severe disabilities due to the neuronal damage that it inflicts. These impairments can be motoric (e.g., poor grip strength, limited range of movements, lack of coordination, etc.) and cognitive (somatoparaphrenia, memory decline, speech difficulty, etc.), often leading to emotional struggle and other complications that further diminish quality of life [3]. However, it is feasible to achieve partial or even full recovery from stroke through rehabilitative interventions. The recovery outcomes can be maximized when the rehabilitation therapy is initiated promptly, as the early post-stroke period is characterized by an increase in neuronal reorganization referred to as brain plasticity [4]. Training therapies, encompassing a multitude of therapeutic techniques, play a pivotal role in modulating cortical plasticity [5]. The brain can generate alternative neuronal pathways to perform functions previously managed by neural pathways damaged by brain injury [5,6]. Plasticity is a multifaceted process that affects the sensorimotor system and is influenced by genetic, epi-genetic, environmental, and activity factors [7]. Among these factors, activity is the most permutable as intensive and purposeful practice with repetitive and targeted exercises of varying difficulty is essential for facilitating neuroplasticity and improving motor performance [8,9]. Therapeutic approaches for upper-limb rehabilitation include a range of methods such as occupational therapy, mirror therapy, constraint induced movement therapy, repetitive task therapy, and strength training, among others [4]. For relevant reviews see Anwer et al. [5] and Deutsch and McCoy [7]. Exergaming interventions serve as suitable examples of therapeutic techniques for upper-limb stroke rehabilitation, as they can be integrated into each of the above-mentioned therapies, while evidence shows that using digital exergames can be part of an effective rehabilitation strategy [10].

Exergames belong to a sub-category of serious games that incorporate physical activity into their gameplay mechanics [11].

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Exergame applications are accessible across various devices, including smartphones, virtual bracelets and gaming consoles, desktop computers, virtual reality (VR) headsets, and robot exoskeletons. While the majority of commercial exergames target individuals who aim to maintain or improve their physical condition, there is a specific subset of purpose-designed exergames tailored to focus on the physiological, motor, and cognitive aspects of recovery in rehabilitation [12]. Purpose-designed exergames prioritize rehabilitation-specific goals over entertaining aspects of the gaming experience (e.g., capturing the position of the player's body parts and displaying performance information regarding the motor-oriented functions of the player) [13]. Both commercial and purpose-designed exergames find applications in healthcare for patient rehabilitation, leveraging their interactive nature to transform repetitive exercise into an enjoyable activity [11,14]. Furthermore, exergames are found to stimulate the development of learning skills, such as attention, visual-motor coordination, and logical spatial reasoning and orientation, which are particularly beneficial for stroke patients undergoing therapy [4,15]. In stroke rehabilitation exergaming, purpose-designed games are found to be more effective than commercial counterparts, as they can be more easily customized according to each patient's clinical symptoms, severity of deficits, and rehabilitation goals [16–18].

The adoption of VR technology in purpose-designed exergames has emerged as a standout approach due to its demonstrated effectiveness and enhanced proprioceptive sense of movement control during upper limb rehabilitation, surpassing conventional treatment methods [10,19]. The meta-analysis conducted by Maier, Ballester, Duff et al. [20] highlights the use of immersive VR as an effective rehabilitation technology as it allows stroke survivors to engage autonomously in ecologically valid environments tailored to their abilities. Additionally, the cost-effectiveness of VR over other systems like Robot Assisted Technology (RAT) [10] enables stroke survivors to continue their rehabilitation routine after their hospital discharge, all within the familiarity and comfort of their own home, which avails the emergence of telerehabilitation as a widespread practice. Stroke telerehabilitation is considered equally effective as conventional rehabilitation [21], and it offers the benefit of minimizing the need for stroke survivors to commute to a healthcare facility, making it a convenient option for them [20].

In the following sections, this narrative review delves into a comprehensive examination of the design elements inherent to VR stroke rehabilitation exergames, drawing examples from the literature to illustrate key points. Furthermore, it discusses the transformative impact of technological advancements, which have greatly augmented the practical value of exergames in upper limb rehabilitation. The narrative review primarily focuses on the diegetic systems employed in upper-limb stroke rehabilitation exergames and their pivotal role in connecting players with the overarching objectives of enhancing post-stroke quality of life. However, before delving into a retrospective analysis of prior research, we lay the theoretical foundations by exploring the interconnected concepts of diegesis, engagement, and purposefulness, elucidating their critical significance within stroke rehabilitation exergames.

2. Theoretical perspectives on virtual reality exergames for rehabilitation

A recent significant finding in the field of rehabilitation highlights the impact of cognitive factors (attention, visuospatial skills, memory, executive function) on the recovery of motor functionality in stroke patients [12]. Supported by Mura et al.'s [22] meta-analysis, exergames have been shown to improve cognitive functioning among patients with neurological disorders, potentially impacting overall motor rehabilitation outcomes. Doumas et al. [10] in their meta-analysis on serious games and stroke rehabilitation, proposed that future research should prioritize exploring the cognitive determinants that influence the functional recovery of stroke survivors. Ning et al. [11] also argue that purpose-designed rehabilitation exergames often neglect to integrate cognitive exercise elements into serious games, despite their potential benefits. However, the lack of cognitive engagement in rehabilitation exergames can be attributed to the complex design challenge of integrating various game elements, including both motoric and cognitive tasks, into a cohesive and engaging serious game [23].

According to the framework of Maier, Ballester, and Verschure [24], the 15 principles of an effective rehabilitation program include massed practice/repetitive practice, spaced practice, dosage/duration, task-specific practice, task-oriented practice, variable practice, increasing difficulty, multisensory stimulation, rhythmic cueing, explicit feedback/knowledge of results, implicit feedback/knowledge of performance, modulate effector selection, action observation/embodied practice, mental practice, and social interaction. This framework was used in the meta-analysis conducted by Maier, Ballester, Duff et al. [20] to assess the efficacy of upper limb rehabilitation in VR. The analysis revealed that several principles including variable practice, implicit feedback, increasing difficulty, task-specific practice, and explicit feedback were implemented more frequently than others. However, while this meta-analysis approach provides useful insights into the components of most upper limb rehabilitation applications, it does not delve into the cumulative conceptual design or the cohesiveness of individual components in each system. Fereira and Menezes [4] identified seven principles for successful stroke rehabilitation exergames, emphasizing factors such as fidelity of therapeutic gestures within the virtual environment, system flexibility in accommodating the player's motor capabilities, inclusion of explicit and implicit feedback and increasing difficulty, content diversity for satisfying a wide range of personal preferences, clarity of game rules, and game rewards. This framework acknowledges the significance of player engagement through content diversity and rewards. Nevertheless, it falls short in offering solutions for maintaining continuous long-term engagement, particularly regarding content diversity and reward systems.

2.1. *The importance of task engagement*

The need for healthcare professionals to incorporate gamification into rehabilitation exercises [25] emerged primarily from patients' aversion towards the monotony typically associated with such practices. However, designing a serious game that considers stroke patients' intrinsic motivation can be a far more complex challenge compared to designing an entertainment game [26]. This complexity arises mainly because the concept of "fun" can be only contextually defined. In traditional games, fun emerges from striving towards mastery of the game challenges, driven solely for the satisfaction it brings [27]. However, in the context of purpose-designed exergames [15] for stroke rehabilitation, fun takes on a difference dimension, as patients engage in these exergames fully aware that they serve as interventions administered by therapists to address real-life problems. This inevitable awareness can easily diminish the enjoyment factor, jeopardizing the effectiveness of the intervention.

Even though the prospect of improving motor functions incentivizes patients to return to the serious game irrespective of its entertainment value [9], the risk of boredom and monotony during exercises poses a significant challenge to the quality of training and the overall rehabilitation process. Therefore, it is crucial for the exergame to employ techniques that immerse the patient into the gameplay and sustain their engagement overtime [14]. This presents yet another challenging hurdle for game designers, as they must design highly repetitive and yet inspiring exercise regimens tailored for stroke survivors, all while accounting for their disabilities, individual interests, and preferred playstyles. Bartle [25,28] organizes playstyles in four categories that summarize typical behavioral tendencies of gamers: (a) the achiever playstyle describing players who are most oriented towards game mastery, (b) the explorer playstyle mostly exhibited by curious individuals who enjoy exploring and discovering, (c) the socializer playstyle for those who enjoy interacting with other individuals during gameplay, and (d) the killer playstyle which is mostly exhibited by overly competitive individuals. However, despite its significance in gaming research, and the various gamer typologies that have been developed over the years [29], the concept of playstyles remains notably absent from literature on exergame design for stroke rehabilitation.

Furthermore, the existing scientific literature mainly focuses on the heuristic value of applications, rather than their long-term use, even though there is an apparent need for further research on player engagement. The framework proposed by Maier, Ballester, and Verschure [24] considers gameplay motivation and engagement as highly subjective aspects without offering further elaboration within its structure. Components such as structure, narrative, identity, purpose, and mechanics, as identified by McGinnis et al. [30] are often considered of secondary importance, despite their potential to significantly enhance rehabilitation practices when integrated cohesively. Mitgutsch and Alvarado [23] argue that even if an exergame adheres to all textbook principles, its success in providing an engaging experience is determined by the configuration of its various elements. As emphasized in the literature, despite engagement being a pivotal component in purpose-designed games, researchers still lack a fundamental understanding of engagement and strategies for attaining optimal levels of enduring engagement in serious games [31].

Academic discussions on player engagement often revolve around the theory of flow, according to which people are more likely to engage in an activity and maintain a state of deep concentration for longer periods when the challenges of the activity align with their skill level. Entering this state of deep concentration, known as the “flow zone”, can make even difficult tasks feel effortless, while any frustration experienced is perceived as “pleasant” [26,32]. Additionally, time may seem to flow faster than usual, and the mind becomes fully focused on the present moment while in this state. It is important to note that although the flow zone is highly associated with enjoyment and can be an indicator of having fun, it can occur irrespective of the experience of fun [27]. The theory of flow is particularly important in the context of stroke rehabilitation exergames because, considering the aforementioned characteristics of the flow zone, it can be regarded as the optimal state for eliminating boredom and maximizing therapeutic outcomes during rehabilitation training [33].

2.2. The importance of purpose-driven tasks

While there is no “magic ingredient” to ensure engagement in the context of stroke rehabilitation exergames, it is worth noting that players are more inclined to engage with a serious game for longer periods, when they perceive a sense of purpose within it [23]. Conversely, the absence of purpose (i.e., the lack of understanding regarding the reasons behind it and potential outcomes) can be demotivating [26]. In this context, “purpose” is used both as the determination of achieving game-specific goals within the game narrative (e.g., achieving high scores in the exergame), and the desire to improve the quality of life in real-life situations (e.g., being able to open a door using the door handle), which exists outside the game narrative. Hereafter, to differentiate between these two dimensions of purpose, we adopt the terms "intra-diegetic" (i.e., within the narrative of the fictional world) and "extra-diegetic" (i.e., outside the narrative of the fictional world) from the field of narratology, in which diegesis is the term used to designate the narrative’s spatiotemporal universe [34]. When considering engagement from an intra-diegetic perspective, it strongly associates with various elements of the game content, including the formation of social identity, challenges, in-game relationships, game constraints, and freedom of choice, all of which also relate to the experiential process of real-life learning [28].

Kniestedt et al. [31] propose reframing engagement in serious games by emphasizing purposefulness and clarifying what it entails. They acknowledge that attention is a limited resource and propose a model that places purposefulness at the core of engagement. As they point out, the design of commercial games tends to focus on the intra-diegetic purpose of the game, which aims to entertain the player, whereas the design of serious games focuses on the extra-diegetic purpose, where the goal is to positively impact the player’s life in a meaningful way (e.g., improving motor functionality to the extend where one can independently prepare a simple meal, improving executive functioning, etc.). However, the intra-diegetic purpose of exergames (e.g., finishing the race in first place, achieving a new high score, etc.) can also be particularly important in neural rehabilitation, as short-term, goal-oriented, and purpose-driven tasks are found to influence the mirror neuron system and neuroplasticity. Even though researchers acknowledge that a balance between intra- and extra-diegetic elements is important for successful exergame applications [35], literature on the intra-diegetic elements of rehabilitation exergames remains limited.

Kniestedt et al. [31] also acknowledge that the overlap between the intra- and extra-diegetic purposes of any game should be carefully considered, otherwise the game runs the risk of failing to achieve its primary design goal, whether it is to be an efficient rehabilitation tool or a commercial success. In the case of stroke rehabilitation, an exergame would be deemed inefficient if it does not result in improved quality of life after prolonged use, but it would also be inefficient if it fails to provide incentives for patients to effortlessly engage with and adhere to rehabilitation training from the beginning. Exergame designers intuitively attempt to achieve a synergetic overlap between diegetic systems (e.g., narrative, mechanics) and their extra-diegetic purpose, aiming to encourage patients to continue exercising while being mentally engaged with the gameplay. Design elements within these systems pertain towards macro-involvement (e.g., impressing loved ones by achieving new high scores) and micro-involvement (e.g., personal satisfaction with mechanics and storytelling) within the game [31].

With fields of psychology and neurology underscoring the impact of purpose-driven task engagement on rehabilitation, diegesis and narrative engagement in rehabilitation exergames warrant more attention. This narrative review aims to shed light on this often-overlooked aspect of purpose-designed rehabilitation exergames. After examining the significance of the theoretical concepts like engagement and purposefulness in designing exergames for stroke rehabilitation, in the next section we delve into exploring the influence of intra-diegetic narrative on these games.

3. Virtual reality exergames for stroke rehabilitation from a narrative perspective

During the early stages of utilizing VR for upper-limb rehabilitation, the significance of the intra-diegetic narrative in purpose-designed games was overlooked; however, its crucial role in enhancing the overall experience and the subsequent rehabilitation training became evident due time. A notable early example of this can be found in the intervention conducted by Broeren et al. [36], which utilized a stereoscopic display and a haptic device to simulate the experience of breaking bricks through the force of a ball. The player had to strike the ball with a haptic stylus, earning points for every broken brick [36]. The game showed promise in increasing patient engagement during rehabilitation of the affected upper limb, as evidenced by the interview with the participant in the case study. Building upon this, Broeren et al. [37] sought to examine this intervention further, focusing on motivation as a critical factor in rehabilitation. They concluded that VR capabilities, such as stimulus controllability, environmental validity and performance feedback, could enhance motivation in the context of stroke rehabilitation [37]. Subsequently, the work of Broeren et al. [38] attempted to incorporate their previous findings into a new intervention with greater program variability. While some mini-games retained the previous brick-breaking concept, the intra-diegetic system was changed to allow a more interesting and meaningful narrative resembling activities like space-tennis tournaments or archery. Reportedly, patients were initially hesitant towards playing the games, but hands-on experience stimulated their interest, leading to a desire to continue playing in the future [38]. Throughout this series of studies, the intra-diegetic narrative was gradually refined through experimentation, highlighting its importance in optimizing the effectiveness of VR-based rehabilitation interventions.

At the beginning of the previous decade, there was a noticeable increase in the adaptation of the intra-diegetic systems from mainstream games in purpose-designed exergames for upper limb rehabilitation. These exergames typically employed non-immersive VR alongside robotic exoskeletons or data gloves to facilitate the necessary movements of the affected upper limb and provide feedback. For instance, the classic *Spheroids* game was adapted into a purpose-designed exergame using a rehabilitation gaming system, which mapped the user's movements onto those of the avatar in the virtual environment [39]. This adaptation was specifically developed to allow the user to observe from a first-person perspective the upper extremities movement of the avatar during bimanual task-oriented action execution. Similar approaches were applied to adapt tabletop games, such as *Air hockey* [40,41] and *Memory cards* [42,43]. As these exergames required task-oriented actions and the observation of upper limb movements, the memory cards exergame offered additional benefits such as memory training for patients who suffer from cognitive decline following a stroke. In a relevant study, that measured motivation using the Intrinsic Motivation Inventory (IMI) [44], stroke patients who participated in a multiplayer version of the memory cards VR exergame reported significantly higher enjoyment compared to its single-player counterpart [43].

Alongside the growing trend of adapting intra-diegetic systems from mainstream games to purpose designed exergames for upper limb rehabilitation, many designers and developers embarked on exploring other innovative approaches. Lewis et al. [45] conducted a study that introduced a unique design method that involved the navigation of an object through a virtual environment. Participants could maneuver a submarine through undersea targets aiming to reach a specific destination by moving their upper extremities according to their rehabilitation regimen. The study stands out for its incorporation of participant interviews to gather their perspectives on the tested exergame, revealing an enjoyable experience overall. While some participants were drawn to the challenge and novelty of the exergame, many derived their enjoyment primarily from the exergame's extra-diegetic purpose (i.e., rehabilitation). An interesting finding from the interviews was that the unfamiliarity of the simulated ocean floor had a positive impact on participants' suspension of disbelief regarding any inaccuracies in sensorimotor contingencies during the VR experience [45]. The exploration of the virtual world as an incentive for maintaining engagement during gameplay is also evident in the *Rutgers Arm II* system's treasure hunt game [46]. Stroke patients were encouraged to discover as many hidden underground treasures as possible within a specified time period while controlling a virtual shovel using rehabilitation training movements of their affected upper limb. The authors argue that the duration of gameplay served as an indicator of successful engagement. The *RehabMaster* rehabilitation system and its exergames were designed in collaboration with therapists specializing in stroke rehabilitation, focusing on incorporating gaming principles highly relevant to therapy, such as the principle of meaningful play [47]. The included exergames (e.g., goalkeeping or bug-catching) were easy to understand and highly customizable to the specific needs and preferences of stroke patients.

3.1. The approach of mini exergame bundles

Following the approach by Broeren et al. [38], many rehabilitation exergame designers have adopted the strategy of offering a collection of mini-games within a game bundle, an approach aimed to combat boredom by introducing novelty through variety. These bundles often include activities of daily living (ADLs) as well as more sports-oriented exergames (e.g., bowling, goalkeeping, fruit picking, whack-a-mole) [48,49]. The overarching objective of these exergames is to replicate a single engaging action multiple times in order to promote neuroplasticity [50]. Additionally, many of these exergame bundles provide performance feedback and offer the flexibility to adjust difficulty levels according to the patient's needs and lifestyle, which is essential to maintain motivation [9,13,51]. Fluet et al. [51] used a method called "scaffolding", which involves offering in-game rewards such as introducing new game features and better graphics as the player's performance improves. This approach enriched the intra-diegetic narrative and provided additional motivation, successfully promoting the adherence of chronic stroke patients to rehabilitation treatment over a 12-week period [51]. Hung et al. [52], who compared the "game-bundle" exergaming approach between a group of stroke patients who were exposed to the exergames and a therapist-only control group, reported that patients' engagement level during gameplay was associated with a reduction in impairment. This study was one of the few that conducted a 3-month follow up and used a validated psychometric tool, the Pittsburgh Rehabilitation Participation Scale (PRPS), to measure engagement. Engagement was defined in terms of patient participation, effort, and motivation [53]. Although patients' engagement level was lower than expected, it was higher than that of the control group. The researchers noted "Our Kinect2Scratch games were not created by professional game-developers; therefore, the games may not contain as many ludic elements or high-quality graphics and sounds as commercial games" [52].

Similarly to the study of Fluet et al. [51], Hung et al. [52], also associated higher engagement levels with improved graphics. They also acknowledge the difference in engagement capability between commercial and purpose-designed exergames as well as the fact that the intra-diegetic dimension of rehabilitation exergames can greatly benefit from the close collaboration between healthcare professionals and game developers. Another design strategy that has shown promising results in terms of engagement and enjoyment is the incorporation of a multiplayer component in the exergaming system [54,55]. Allowing players to play cooperatively or compete against other patients or the therapist while choosing from a variety of exergames has been found to increase motivation through social interaction. Given that many stroke patients demonstrate symptoms of depression, the long-term in-game socialization aspect of multiplayer activities appears to have a positive impact on mental health [56,57]. However, it is worth noting that depression can sometimes deter patients from participating in social exergaming activities [52]. Overall, the effects of exergaming on depressive symptoms in chronic stroke patients remain inconclusive [58].

3.2. The approach of standalone exergames

There have also been numerous standalone exergames for post-stroke upper limb rehabilitation, an approach attempting to provide a more comprehensive game experience by focusing on a single intervention that incorporates various therapeutic elements crucial for upper-limb rehabilitation. However, there are certain challenges in designing standalone exergames that may affect engagement. Firstly, they lack the advantage of novelty introduced through different games within the system and secondly, the game mechanics can be too complex for some patients, potentially hindering their ability to fully participate [35]. To mitigate the risk of burn out or boredom, standalone exergames often rely on borrowing game designs that have been proven to be successful in engaging players for extended periods. While such design strategies are often found in exergame bundles as described earlier (e.g., *Flying bird*) [59], a prime example of a standalone exergame is the adaptation of the popular commercial game *Fruit ninja*. Originally popular among smartphone users in the United States in 2012 [60], the exergame adaptation requires patients to slice virtual fruits tossed midair using their affected upper limb, earning points for successfully sliced fruit within a specified timeframe. However, it is worth noting that the study using this game adaptation mostly focused on user performance rather than engagement, comparing game scores in non-immersive VR and Augmented Reality (AR). The results showed that AR scores were higher due to its ability to enhance visuomotor integration, thus providing a more intuitive experience [60], particularly relevant to the mechanics of this specific game. Other examples of intra-diegetic narratives that have demonstrated motivational qualities for patients, such as high duration of training adherence [61] and self-report motivation [59] even without constant therapist supervision, include virtual simulations of canoeing and underwater fishing, respectively [61,62].

3.3. The ADL exergame approach

While stroke rehabilitation VR exergames that simulated ADLs were documented in the literature during the first half of the previous decade [63], there was a notable increase of ADL exergame studies in the latter half. These ADL exergames consist of a range of activities (e.g., cleaning windows, pouring wine, catching butterflies, buying groceries), blurring the boundary between playing games and performing real-life tasks. The objective is to empower patients by allowing them to choose the gamified activities that resonate with their individual sense of purpose [64]. Additionally, they aim to transfer the skills acquired in controlled virtual scenarios to analogous real-life situations [65]. This direct alignment of the intra-diegetic system of ADL exergames with the overarching purpose of rehabilitation therapy is considered their primary advantage. While patients' perspectives on ADL exergames have generally been positive, there have been isolated cases where patients expressed strong disinterest [65,66]. Nonetheless, ADL exergames have been found to be more motivating than traditional rehabilitation exercises [67], although this conclusion is primarily based on studies with short intervention periods. It remains uncertain whether ADL exergames can maintain their motivational impact in the longer term. Bellomo et al. [68] studied the effects of ADL exergames on stroke patients for up to 12 weeks, however, the patients' motivation and engagement levels remain unclear. The study primarily focused on the improvement of limb functionality and the acceptability of new technologies rather than directly assessing motivation and engagement levels.

3.4. The immersive VR exergame approach

Immersive VR appeared in the rehabilitation literature more prominently at the beginning of the last decade, as head-mount displays progressively became more ergonomic and lightweight, making them suitable for stroke patients. The full-scale sensory immersion and multisensory integration facilitated by head-mount displays play a key role in capturing and maintaining the patient's attention during therapeutic exercises. Unlike non-immersive VR, fully immersive VR envelops the visual field with computer-generated images of a virtual environment, creating a more immersive experience [69,70]. Despite technical differences, the intra-diegetic characteristics of immersive versus non-immersive exergames for stroke rehabilitation share similarities. In both types of VR, stroke patients are required to simulate simple tasks that align with their rehabilitation goals. These tasks are often presented as unrelated mini-games [16,69,71] or interconnected mini-games with specific themes, such as farming [72] or rearranging a living room [73]. Overall, research on fully immersive and semi-immersive VR interventions focuses on their efficacy in stroke rehabilitation, underscoring their effectiveness and emphasizing the need for the development of applications that leverage the immersive capabilities of VR [73].

A novel use of the immersive capabilities of VR from an intra-diegetic perspective is demonstrated in the study of Elor et al. [74] The goal of *Project Butterfly* is to safeguard a virtual butterfly from natural hazards by using the controls of an HTC VIVE kit. The game allows the stroke patient to intuitively perform a wide range of upper-limb movements within a three-dimensional virtual environment, enhancing interest and challenge levels in the exergame, thus leading to higher motivation to continue playing while veiledly exercising the impaired limb. Furthermore, the theme of caring for another living being was found to further enhance motivation through storytelling [74]. The study employed physiological indicators for evaluating user experience, such as the blinking frequency to measure attention, and found increased user attention. Throughout the eight-week experimental phase, patients' motivation to achieve a new high score remained relatively high.

3.5. Exergame gameplay approaches for increased engagement and motivation

The visual aspects of exergames per se, irrespective of the level of sensory immersion, can also serve as important intra-diegetic elements within the game world, contributing to player engagement during rehabilitation. Patients have previously expressed how the beautiful visual scenery of the virtual environment greatly contributed to their ongoing engagement with the game [75]. In some cases, when patients were asked for feedback, they expressed a desire for more realistic graphics, assuming that enhanced realism can help them become more emotionally invested in the virtual world ultimately increasing their motivation to participate [33,76]. However, it is crucial to consider that beautiful scenery can be highly subjective, and for people with neurological impairments, highly detailed and photorealistic environments can overwhelm their cognitive capacity and cause discomfort [33,77]. Therefore, the customizability of the graphic elements of the exergames becomes imperative. For instance, in the study by Viglialoro et al. [78], the proposed exergame for stroke rehabilitation entails a line-tracing task on a desk pad that requires precise movements using the impaired upper-limb. The patient's score depends on the accuracy of the line-tracing. The introduced system is versatile in many aspects as it is suitable for different ages and for patients with various mobility limitations, but it also allows the therapist to configure trajectory parameters and difficulty levels, and interestingly, replace the image revealed after the line-tracing task with a new one. This element of surprise can enhance curiosity and excitement, motivating patients to complete the line-tracing task several times [78]. Furthermore, it has been hypothesized that providing on-screen visual feedback, such as for example through a virtual character (avatar) performing a similar movement, can activate mirror neurons, which has been proposed as a potential aid in stroke recovery [79]. Specifically, the virtual kinematic representation of an upper limb, when synchronized to the movement of the paretic limb can provide instant neural modulation and help with strengthening the control of the paretic limb [80,81]. These changes in structural brain plasticity caused by visuomotor integration during an exergame intervention have been demonstrated in an MRI study conducted by Keller et al. [82].

In-game achievements and rewards also constitute intra-diegetic elements that significantly impact the neurophysiology of the brain during exergame interventions. In the experimental study conducted by Widmer et al. [83], the exergame *Meteors* required participants, who were strapped with kinematic sensors on their arm, forearm, and trunk, to move their paretic limb in order to deflect incoming meteors threatening the earth. The experimental group received enhanced graphical elements, feedback regarding in-game achievements, and a monetary reward for participation in the experiment, leading to increased motor recovery and neuroplasticity compared to the control group. However, it is worth noting that the game used both in-game and real-life rewards in a single experimental condition, rendering implications that are specific to the intra-diegetic narrative of the exergame unclear. Similarly, *Project Star Catcher*, an immersive VR exergame for upper-limb rehabilitation [84], uses the reward mechanism to incentivize hemiparetic players to use their paretic limb more than the contralateral one. This is done in order to prevent "learned non-use", which refers to the maladaptive tendency of neglecting one's paretic limb and heavily relying on the contralateral one, often resulting in the permanent inactivity of the paretic limb [85]. The game mechanics of *Project Star Catcher* allowed stroke patients to use either the paretic or the contralateral arm, but they were incentivized to use their paretic arm more, as the system bestowed more scoring points when successfully using the paretic arm. While participants provided positive feedback regarding motivation to play the game, adherence to using the paretic limb significantly decreased as the game difficulty increased, highlighting the complexity of reward mechanisms in maintaining engagement during rehabilitation [84].

4. Discussion

Many research papers on VR motor rehabilitation tend to view VR exergames as inherently more engaging and interesting compared to traditional rehabilitation interventions. However, it is important to acknowledge that VR exergames can become monotonous and laborious when repetitive, leading to a decline in player motivation when the game rewards lose their appeal [4,86]. This decline is especially evident among patients who are accustomed to playing commercial entertainment games and have higher expectations regarding the overall gameplay experience. This was evident in the studies of Standen et al. [9] and Demers et al. [65] where stroke patients reported quickly losing interest in the repetitive rehabilitation exergames, justifying this statement by citing the stark contrast in entertainment quality provided by commercial computer games. While the evolution of rehabilitation apparatus offers convenience, its impact on the rehabilitation experience remains predominantly superficial. Greater attention to patient characteristics, such as age group and gaming preferences, is necessary to understand the extent of the issue related to the decline in interest among "gamer" patients in purpose-designed exergames due to mandated comparisons. Additionally, investing in intra-diegetic systems to make these exergames more attuned with entertainment games could help mitigate this problem. The appropriateness of exergames for stroke patients depends not only on the severity of their disability and their acceptance of technology but also on more intangible factors such as individual personalities and playstyles [25].

It is worth noting that many rehabilitation game designers appear to assume that stroke patients are predisposed to achieving game mastery, most probably because of the outcome-driven structure of rehabilitation programs [26]. Some of the exergames presented in this review favor explorer and socializer playstyles such as for example in the themes of underwater exploration [45], treasure hunting [46], and cooperative mini-games [55]. However, the achiever playstyle is predominant, with most exergames featuring a scoring system as their main gameplay feature. Nevertheless, this approach may not fully align with the diverse personalities and playstyles of stroke patients. Research has identified different categories of patients based on their playstyles, including those who respond well to exergame interventions, those who persistently choose games not beneficial to their condition, those who prefer traditional rehabilitation methods, and those who resist exergames due to emotional issues [33]. Indeed, some patients are devoid of any lusory (playful) attitude, while others may require a sense of autonomy that gameplay rules and pressure to win the game can disrupt. In such cases, alternative expressive activities like drawing could be employed to evoke intrinsic motivation for exercising the impaired limb [26]. However, for those who positively respond to exergames, taking into consideration their individual playstyles and personality characteristics can lay the groundwork for exergame designers to gain more insight regarding the improvement in the experience aspect of purpose-designed exergames as well as breeding new ideas. For instance, incorporating nuanced social interactions with non-playable characters and regularly introducing new locations to explore in an exergame could appease socializers and explorers, respectively.

Purpose-designed exergames for upper-limp rehabilitation aim to complement rehabilitation therapy and improve the patients' quality of life by providing exercises that align with their everyday tasks. These games simulate activities of daily living, aiming to minimize limb impairment and capitalize on patients' motivation to engage in rehabilitation. Interestingly, in the study by Seo et al. [66], it was observed that the motivation to continue playing a game and the perceived suitability of games for rehabilitation were negatively correlated. Patients tended to find sports and fictional games more motivating but less appropriate for rehabilitation, while ADL exergames were seen as more suitable for rehabilitation but less motivating. This suggests that patients may find activities of daily life too mundane and uninspiring to distract them from the arduous rehabilitation exercises. Healthcare professionals are cognizant of this challenge and often attempt to address boredom by incorporating high variability and novelty through mini-game bundles [87]. However, there is insufficient evidence to suggest that high variability can maintain engagement once the novelty factor depletes for every mini-game [20]. It appears that the primary purpose of rehabilitation alone is insufficient to maintain long-term compliance and, ultimately, meaningful engagement with the ADL exergame regimen. Moreover, as the population of casual gamers increases worldwide and the average attention span of younger generations declines [88], expecting digital natives to consistently engage in repetitive task-oriented serious games for extended periods of time while enjoying them becomes increasingly unrealistic. Simply put, relying on the novelty of mini-games to reduce boredom during rehabilitation appears effective in the short term. However, the long-term effects of exergame rehabilitation training, once the novelty wears off, remain largely unaddressed in the literature. Therefore, further research is needed to examine the relationship between the novelty factor and patients' sustained interest over weekly or monthly intervals, despite the time-consuming nature of such studies.

Furthermore, the willingness to engage in VR rehabilitation exergames is influenced by cognitive processes and affective factors. Chen et al. [89] assessed patient attitudes towards VR rehabilitation interventions and discovered that the perception of VR technology as more useful than other therapeutic tools in improving rehabilitation outcomes, along with its perceived ease of use (influenced by perceived player performance), are crucial factors in fostering prolonged engagement with the VR rehabilitation intervention. Digital natives appeared to be more despondent in improving their condition through exergames compared to older adults [89], citing reasons such as their higher entertainment expectations and the elderly's often-exaggerated perception of the therapeutic capacity attributed to the unfamiliar VR technology. Therefore, it is imperative for researchers to focus more on aspects related to the gamification of rehabilitation exercises. These aspects include the sustainability of attention, the level of enjoyment after novelty wears off, and the suitability of exergames for chronic stroke patients, considering both the pathologies and preferred (if any) playstyles of participants. This focus can provide game designers and developers with valuable insights to develop more robust rehabilitation exergaming experiences, ultimately enhancing the quality of healthcare for chronic stroke patients while encouraging them to continue exercising. For instance, these insights can elucidate the differences in motivation among stroke patients across various age groups regarding specific exergame approaches or the acceptance of complexity in both game mechanics and graphics relative to the severity of cognitive impairments.

Moreover, the presence of chronic pain in the affected limb, a common experience among stroke patients, serves as a significant demotivating factor, diverting patients' attention away from the enjoyable aspects of exergames and potentially inducing movement-related anxiety [90]. Evidence suggests that employing analgesic placebo techniques in immersive VR can result in lower pain ratings compared to physical reality. This is attributed to distractions provided within immersive virtual environments and heightened attention to bodily cues, such as those experienced during virtual embodiment. However, further research is needed to clarify whether virtual embodiment in immersive VR can effectively serve as a non-pharmacological intervention for alleviating symptoms of chronic pain [91].

Nonetheless, virtual embodiment appears to be a crucial component in immersive VR rehabilitation interventions, particularly for patients with proprioceptive sensitivity who may benefit from observing their affected limb (or a synchronous 3D representation of it) while performing exergame tasks [71]. From a neuropsychological perspective, the perceived morphology and functional integrity of the body are integral to the sense of body ownership and may contribute to metacognitive and narrative aspects of self-identity [92]. Despite the potential of using various virtual avatars with role-playing features in immersive VR to enhance the narrative quality and entertainment value of games, the comprehensive use of full-bodied VR avatars is seldom employed in stroke rehabilitation research. There is a need for more studies focusing on the psychological (e.g., sustained motivation, engagement, enjoyment) and neurological (e.g., motor functionality, proprioceptive sensitivity) implications of immersive VR embodiment in exergame interventions for rehabilitation patients. The bodily sensation in immersive VR can also be linked to kinesthetic empathy and the comprehension of emotive expressions, which can stimulate neurons associated with motor learning [93,94]. Considering that inferences of sensorimotor changes can induce brain plasticity [95], the combination of virtual embodiment in immersive VR with purposeful, goal-oriented tasks is likely to enhance rehabilitation outcomes.

In many of the papers included in this narrative review, it remained unclear whether the utilized games were purpose-designed for rehabilitation or commercially available, a common issue in the literature [73]. Furthermore, there was often insufficient emphasis or neglect in providing detailed descriptions of the game content, game mechanics, and other critical aspects of the games used as interventions. One such example is the study by Laffont et al. [96], which concluded that games were not superior to conventional rehabilitation for upper limb in sub-acute stroke. However, in hindsight, Laffont et al. [96] acknowledged that more attention should have been placed on the characteristics of the game(s) that influenced the study outcomes in order to identify areas for improvement. Indeed, it is essential to consider the specific characteristics that define the exergame experience and its overall narrative. Charles et al. [26] highlight this point by drawing a parallel between stroke rehabilitation and the classical Hero's journey, a universal storytelling structure. They portray stroke as a call to action and the patient as the hero, who is involuntarily set on an uncertain path of self-improvement. This parallel suggests that exergame narratives for stroke rehabilitation should reflect the various stages of the Hero's journey, which begin with the "call to adventure" and conclude with the "freedom to live" [97,98]. Incorporating these narrative elements is crucial for goal setting and the transformative process of re-defining one's future self.

5. Future perspectives

Moving forward, it is imperative for future studies to continue prioritizing the optimization of engagement in serious games. It is crucial to stress that applications with therapeutic objectives should not compromise these goals for entertainment purposes, nor should they prioritize fun engagement at the expense of therapy. Instead, a balanced approach that integrates both aspects should be sought. The effectiveness of such narratives in guiding patients and improving exercise quality should be evaluated. In general, establishing guidelines for rehabilitation exergame scenarios, especially for immersive VR and AR that may require different narrative approaches from previous technologies, is essential [72]. Additionally, as studies indicate that immersive VR can have a greater cognitive impact compared to previous technologies [99], further research into the field of VR neurorehabilitation is warranted to understand how it can be leveraged for more effective rehabilitation. Emerging trends in the field suggest continued exploration of the immersive capabilities of VR technology for the creation of rehabilitation exergames in the future. Emerging trends in the field suggest continued exploration of the immersive capabilities of VR technology for the creation of rehabilitation exergames in the future. Enhanced multisensory integration, virtual embodiment and social metaverse platforms can eventually contribute to a convergence between intra- and extra-diegetic purpose that serves the primary design goal of ADL exergames in a much more meaningful and entertaining way than current ADL exergames. However, the impact of VR and emerging technologies on the healthcare landscape is yet to be determined [100].

By focusing on the intra-diegetic aspects of rehabilitation exergames, discussions surrounding the secondary goals of rehabilitation, such as safety requirements and the role of the therapist beyond game assignment, are often undermined [101]. While addressing these secondary goals is expected, they primarily pertain to the extra-diegetic purposes of rehabilitation exergames, which have been extensively explored in previous research [5,11,21]. This narrative review proposes a different perspective that advocates for a shift in focus regarding rehabilitation exergames. It suggests viewing them primarily as gaming experiences designed to engage their audience, ultimately empowering them to achieve their rehabilitation goals.

6. Conclusion

Numerous exergame applications designed for upper limb stroke rehabilitation tend to prioritize the extra-diegetic aspect of these games, primarily focusing on measures of rehabilitation effectiveness. However, there is an implicit assumption that these games are inherently engaging. In order to improve and prolong the effectiveness of VR stroke rehabilitation treatments, future studies should pivot towards crafting more engaging experiences tailored specifically for stroke patients. Based on the findings of this review, the initial steps to achieve this goal involve gaining deeper insights to address current gaps in the literature. These gaps pertain to a) the overall design of the exergame experience and how it addresses challenges such as maintaining rehabilitation adherence and compliance despite adversity, and b) the interaction between the user and exergame content, considering the unique characteristics of both the individual and the gameplay. By placing greater emphasis on enhancing purpose-driven task engagement, therapists and researchers can encourage sustained participation in these treatments, ultimately leading to enhanced rehabilitation outcomes.

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Christos Hadjipanayi: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Domna Banakou:** Writing – review & editing, Supervision. **Despina Michael-Grigoriou:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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