# The TERSICORE project: A Virtual Rehabilitation Protocol Based on Creative and Social Games in the Metaverse


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## Abstract

A growing body of evidence suggests that VR (Virtual Reality) tasks—particularly those involving artistic expression within social contexts—can significantly enhance rehabilitative outcomes. However, these approaches remain largely underexplored within the field of virtual cognitive rehabilitation. The TERSICORE project introduces an innovative protocol for virtual cognitive rehabilitation that leverages creative and socially interactive games within both immersive and non-immersive metaverse environments. It is structured around four exergames, each developed to address the rehabilitation needs of specific cognitive domains: learning and memory, perceptual motor function executive function, complex attention, and language. A fifth separate environment, a realistic virtual village scenario, is employed as a dynamic assessment tool for pre- and post-intervention evaluation, capturing ecological indicators of cognitive and functional performance. All the exergames include a range of VR tasks: solving logic-based challenges within an escape-room setting, stimulating long-term memories by using reminiscence strategies, enhancing language abilities through semantic feature pathways while participating in collaborative art gallery set up; and restoring color to well-known artworks in a cooperative context. Moreover, such tasks are specifically designed to support multi-user rehabilitation sessions, transitioning from conventional one-on-one therapeutic approaches to a collaborative, group-based model involving both patients and clinicians. These



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virtual environments are accessible through VR (Virtual Reality) headsets - i.e., immersive modality - or tablet devices – i.e., non-immersive one, enabling their use in both clinical and home-based settings. To conclude, TERSICORE represents a flexible, scalable model for virtual rehabilitation. By integrating multi-user engagement and creative experiences, the protocol aims to enhance patient motivation, increase adherence to rehabilitation programs, ultimately improving clinical outcomes.

## CCS Concepts

• **Human-centered computing** → Interaction design; Interaction design process and methods; User centered design; Interaction design; Interaction design process and methods; Participatory design; • **Social and professional topics** → User characteristics; • **Hardware** → Emerging technologies; Emerging interfaces.

## Keywords

Virtual Reality, Rehabilitation, Art, Creativity, Game, Metaverse, Sociality

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## 1 INTRODUCTION

Cognitive rehabilitation aims at restoring or compensating for deficits in complex attention, learning and memory, executive functioning, perceptual-motor function, language, and social cognition resulting from neurological injury or disease [1]. Traditional interventions predominantly adopt a dyadic therapist-patient model, wherein structured tasks are delivered in repetitive, one-on-one sessions (i.e., paper-and-pencil exercises targeting specific cognitive domains, computerized training programs that adapt difficulty based on performance, flashcard drills for memory enhancement, supervised practice of daily activities in clinical settings, and therapist-guided visualization techniques). While this approach has demonstrated efficacy, it is frequently constrained by limitations in ecological validity [2, 3] patient engagement [4] and scalability [5]. Moreover, the absence of socially embedded contexts in conventional cognitive training can reduce generalization of acquired skills to real-world settings, which are inherently interactive [6].

In recent years, digital health technologies have introduced novel paradigms for neurorehabilitation. Among these, immersive and semi-immersive virtual environments have shown promise in enhancing patient motivation and cognitive engagement by simulating complex and ecologically relevant scenarios [7, 8]. Furthermore, socially interactive digital environments—i.e., the Metaverse—offer the potential to integrate therapeutic content with interpersonal communication, joint action, and affective co-regulation, factors recognized for their role in supporting neural recovery and adaptive functioning [9, 10].

Within this evolving technological framework, the TERSICORE project introduces a novel protocol for cognitive rehabilitation that systematically integrates creative tasks, social interaction, and immersive digital media. Rather than treating cognitive domains in isolation, TERSICORE situates rehabilitation within collaborative, functional-oriented tasks that are expected to be both emotionally salient and cognitively demanding. The protocol operationalizes contemporary principles of experience-dependent plasticity by embedding structured cognitive demands into aesthetic, narrative-driven tasks designed to promote sustained engagement, interpersonal connection, and therapeutic adherence.

The present paper outlines the conceptual framework, description of the exergames, and technological implementation of the TERSICORE protocol, with the aim of positioning it as a scalable and adaptable model for next-generation virtual rehabilitation.

## 2 THEORETICAL RATIONALE

The TERSICORE protocol is grounded in a theoretical framework that integrates principles of neuroplasticity, social neuroscience, and game-based rehabilitation.

Central to its conceptual design is the notion that cognitive recovery following neurological impairment is most effectively supported by tasks that are not only domain-specific and goal-directed, but also emotionally salient, socially mediated, and ecologically valid [11, 12]. From a neurobiological perspective, experience-dependent neuroplasticity is optimally induced when task engagement is meaningful and attentionally sustained, involving both top-down executive control and bottom-up affective arousal [13]. Motivation is a critical modulator of cognitive rehabilitation outcomes: intrinsically motivated behaviors, particularly those associated with creative expression and aesthetic appreciation, have been shown to activate distributed networks across the prefrontal cortex, limbic system, and default mode network—regions crucial for episodic memory, executive function, and narrative construction [14, 15].

TERSICORE leverages these mechanisms through the incorporation of art-based and creative tasks that stimulate higher-order cognitive functions while eliciting social engagement.

Indeed, TERSICORE emphasizes the therapeutic potential of group interaction, operationalized through real-time, multi-patient engagement within immersive or semi-immersive digital environments. Contemporary evidence in social neuroscience highlights how joint attention, interpersonal coordination, and affective synchrony can facilitate neurocognitive rehabilitation by enhancing mentalization processes, turn-taking, shared intentionality, and pragmatic language use. Socially interactive rehabilitation also enhances adherence, agency, and self-efficacy—dimensions strongly correlated with long-term functional outcomes [16].

Crucially, the use of Metaverse-based environments introduces a novel dimension to this protocol: the ability to simulate complex, ecologically rich settings that retain high levels of cognitive demand while offering ecological experiences, shared in real time with other users in a social interactive setting. Unlike static computerized tasks, Metaverse scenarios allow the dynamic reconfiguration of context-specific variables (e.g., spatial layout, narrative flow, collaborative roles), thereby approximating real-life cognitive challenges while preserving clinical safety and adaptability [17].

This ecological realism is essential not only for enhancing transferability of learned skills to daily functioning, but also for embedding cognitive targets within meaningful narratives (see diegetic connectivity [18]) and socially situated problem-solving. By embedding cognitive stimulation within emotionally salient, socially mediated, and ecologically realistic environments, TERSICORE advances a paradigm of "situated neurorehabilitation" [19–23] wherein cognitive functions are treated not in isolation, but as emergent from embodied, relational, and context-sensitive interactions. This approach is particularly aligned with the growing emphasis on integrating affect, sociality, and creativity into evidence-based therapeutic frameworks [24, 25].

## 3 THE PROTOCOL: STRUCTURE AND FUNCTIONALITY

TERSICORE is designed as a flexible, modular system accessible via immersive (Virtual reality [VR] headsets) and non-immersive (tablets) platforms. It enables synchronous multi-user participation, allowing patients to engage in shared virtual activities. Group-based sessions (max. 4 patients per session) are structured to promote interaction and peer feedback.

The protocol supports real-time clinician monitoring and adaptability, making it suitable for both clinical and home-based implementation. Crucially, the number of sessions, their duration, and specific scheduling are determined by the therapist, who operates through a dedicated dashboard interface that enables full oversight and customization of the rehabilitation pathway.

TERSICORE supports both immersive (VR) and non-immersive (tablet) modalities, enabling deployment across various settings and levels of technological access. While VR offers heightened sensory engagement, a stronger sense of presence, and enriched embodied interaction, the tablet-based version retains core interactive elements with a simplified interface suitable for home-based use [26]. Both modalities support therapist supervision and allow adaptation based on individual needs. For each task included in the protocol, specific operational procedures and the metrics used to assess targeted cognitive and functional abilities—along with progress tracking over time— are detailed in the following section.

The TERSICORE protocol integrates four exergames and a fifth separate environment, all available in both immersive (VR) and non-immersive (tablet-based) format, designed for functional pre-post assessment, each developed to target specific cognitive and sensorimotor domains across distinct neurological populations.

Each exergame constitutes a therapeutic activity situated in a digital environment, with tasks designed to simultaneously elicit domain-specific processes and foster engagement through symbolic, affective, and social dimensions. The implementation of multi-user dynamics within these environments allows for synchronous patient-therapist or patient-patient interaction. As already mentioned, all tasks within each exergame have been specifically designed to be delivered in both immersive (VR) and non-immersive (tablet) formats. However, in alignment with current evidence suggesting that tolerability of VR headsets typically ranges between 20 and 30 minutes [27, 28] and considering that standard rehabilitation sessions often last approximately one hour, TERSICORE adopts an alternating modality approach. Within the same session, activities are intentionally distributed between VR and tablet use to minimize the risk of cybersickness and cognitive fatigue, while maintaining therapeutic intensity and continuity. Finally, across all exergames, the system collects quantitative performance data such as task completion time, number of errors, action sequencing accuracy, and language use during task execution. These metrics allow for functional profiling over time and support therapist-guided personalization of the rehabilitation pathway.

### 3.1 Description of the exergames

The exergame Escape Room is designed to target executive functions and complex attention, specifically inhibition, cognitive flexibility, working memory, divided attention, decision-making, and processing speed. Escape Room VR is a multiplayer XR (Extended Reality) game with rehabilitative purposes, designed for two to four players (in even numbers only), who must collaborate to solve a series of tasks in the correct sequence in order to escape the room. This task engages the frontoparietal control network and promotes dynamic task-switching and inhibition control [29]. The cooperative structure promotes metacognitive dialogue and strategic planning, consistent with literature on group-based executive training paradigms [30, 31].

Motor planning and sensorimotor integration are addressed through NeuroTeam. In this exercise, up to two participants are immersed in a realistic virtual art studio, featuring easels, canvases, and soft lighting that evoke the atmosphere of a traditional atelier. At the center of the room, a painting is displayed. In the first phase, the system displays a painting in its original-colored version and presents participants with a multiple-choice selection of colors. Participants are required to select only the colors that appear in the displayed artwork. Correct selection of these colors will allow the creation of each patient's personal palette, designed to be complementary between participants. In the second phase, the artwork is presented in black and white. Each participant, holding a joystick that serves as a virtual brush, is required to restore color to the painting through progressive extension movements of the upper limb relative to the trunk. With each movement, the system gradually restores to the canvas the colors included in the participant's personal palette, created during the first phase. The exercise is considered complete when both participants have covered the entire surface of the canvas, successfully restoring its original colors. The activity emphasizes the importance of coordination and collaboration between participants to successfully complete the task.

This activity is specifically designed to promote upper limb rehabilitation, particularly in post-stroke patients, by encouraging controlled, goal-directed movements, visuomotor coordination, postural control, and proprioceptive feedback. Moreover, selective and sustained attention, visuospatial exploration, and executive functions—including planning, problem-solving, and inhibitory control—are the primary cognitive functions targeted by this exergame.

The exergame Nostalgia Bits is designed to support long-term memory rehabilitation. It is structured for four participants (minimum two) and consists of five sequential phases. Players explore an immersive virtual scene which they are instructed to memorize by evoking autobiographical memories related to elements of the environment. Each participant then creates a digital artifact that visually represents the personal memory associated with the scene. This artifact is automatically saved in the player's virtual memory archive and remains accessible in future sessions. In the following phase, participants engage in a group sharing moment, during which they present their artifacts and explain the associated memory to the others. The final phase consists of a memory quiz task, where players take turns answering questions that require delayed recall of the previously explored scene.

Language and communicative-pragmatic functions are addressed in CreatiVR, an immersive, group-based cognitive rehabilitation session based on visual art tailored for patients. The activity represents a virtual adaptation of the validated ACE-t protocol (Art, Colors and Emotions Treatment) developed by Savazzi et al. [32] originally structured in 14 sessions with the aim of fostering cognitive, behavioral, and communicative abilities through color-themed, artist-inspired creative exercises. Within CreatiVR, this approach is reinterpreted in a fully immersive environment, where participants explore the expressive and emotional potential of color and artistic creation to stimulate verbal and non-verbal communication, and shared emotional reflection in a group setting.

A distinctive feature of the TERSICORE model is the inclusion of a fifth separate environment—Truman Show—conceived as an immersive, ecologically valid scenario for pre- and post-intervention functional assessment. Within a virtual urban village, participants engage in simulated real-life activities. The game unfolds as a typical day, during which the patient navigates a virtual city square populated with shops and commercial venues. They are guided through a sequence of four consecutive tasks, each set within a different store, designed to stimulate and assess four cognitive domains and one motor domain. The overarching objective of these tasks is to contribute to the organization of a birthday party for a loved one, thereby embedding goal-directed behavior in a meaningful social context. Each task is introduced by a 360° video, which provides instructions and contextual cues to enhance understanding and immersion. This scenario is not simply observational but flexible and role-based, enabling the capture of executive, linguistic, and social-behavioral competencies under naturalistic but controlled conditions. Virtual assessment tools have been validated for their capacity to detect subtle deficits that may not emerge during conventional testing, especially in populations with frontal or subclinical dysfunction [33.34].

Taken together, these five exergames articulate a novel therapeutic synthesis based on symbolic action, shared meaning, and multimodal interaction.

## 4 DISCUSSION AND CONCLUSIONS

The TERSICORE protocol proposes a paradigm shift in cognitive rehabilitation by integrating immersive technology, social interaction, and creative activities within a structured, clinically oriented framework. This approach moves beyond conventional individual-based therapeutic models by embedding neurocognitive stimulation in socially mediated and ecologically valid virtual environments. Rooted in principles of experience-dependent neuroplasticity [35, 36], and affective neuroscience [37], TERSICORE aims to foster cognitive recovery through multimodal, emotionally salient, and cooperative task structures. A growing body of evidence supports the hypothesis that socially embedded rehabilitation—particularly when combined with creative engagement—can enhance motivation, increase adherence, and promote broader generalization of cognitive gains [14-16, 25, 25, 32]. The inclusion of narrative and symbolic elements, such as artmaking, memory sharing, and joint problem-solving, activates distributed neural systems across the prefrontal cortex, hippocampus, temporal poles, and limbic structures, supporting integrated cognitive and emotional processing [38]. Moreover, immersive virtual environments have been shown to elicit higher ecological validity and cognitive transfer compared to traditional computerized tasks, particularly when designed to simulate real-world complexity [8, 33]. Despite this theoretical robustness, empirical validation of the TERSICORE framework remains essential. Indeed, during the project design and development phases, research involving stakeholders has been carried out in order to develop TERSICORE with a user-centered perspective [39]. Future research will include feasibility studies assessing usability, perceived engagement, and acceptability across patients and clinicians [40]. Pilot trials employing standardized neuropsychological batteries will evaluate the impact of each exergame on its targeted cognitive domain—such as autobiographical memory [41], executive functions [42], language, and motor-perceptual processing [43]. Secondary outcomes may include measures of quality of life, mood, communicative competence, and social participation—key indicators of real-world functional improvement in neurorehabilitation [44]. Importantly, the protocol's modular structure enables adaptation to diverse clinical populations. Individuals with stroke-related cognitive impairment, Parkinson's disease, multiple sclerosis, and mild to moderate dementia represent initial targets, given the well-documented cognitive and communicative deficits in these populations [45, 46]. Moreover, future development should explore the platform's integration with adaptive and biometric feedback systems. The incorporation of eye-tracking, speech analysis, or physiological markers could enhance clinical monitoring and allow dynamic adjustment of task difficulty based on real-time indicators of cognitive load and emotional state [47]. This would align TERSICORE with the broader paradigm of precision rehabilitation and closed-loop neuroadaptive systems [48]. Finally, TERSICORE's technical flexibility—supporting both immersive (VR) and non-immersive (tablet-based) modalities—positions it as a candidate for hybrid rehabilitation models that bridge institutional, outpatient, and home-based care. In doing so, it responds to the increasing demand for accessible, scalable, and user-centered digital therapeutics within neurorehabilitation ecosystems [49, 50]. In summary, TERSICORE offers a theoretically grounded and technologically innovative model of situated neurorehabilitation. By combining creativity, social dynamics, and immersive technology, it aims not only to improve cognitive function, but also to restore autonomy, identity, and social connectedness—core dimensions of person-centered care.

**Table 1: Description of the exergames included in TERSICORE**

| Name | Targeted motor and cognition function | Targeted patient population | Brief Description |
|---|---|---|---|
| *Escape Room* | Executive functions and complex attention (inhibition, cognitive flexibility, working memory, divided attention, decision-making, and processing speed) | Patients with executive dysfunction and dysexecutive syndrome in early-stage neurodegenerative or mixed (vascular) conditions (e.g., Multiple Sclerosis, Parkinson's Disease, non-amnestic Mild Cognitive Impairment, vascular MCI). | Collaborative task-solving in sequence to escape a virtual room; fosters communication, joint planning, and flexible thinking. |
| *Nostalgia Bits* | Long-term memory, autobiographical recall | Patients with cognitive impairment due to a neurological condition, such as Mild Cognitive Impairment due to Alzheimer's Disease | Memory game in five phases, combining immersive scene encoding, autobiographical memory activation, digital artifact creation, group sharing, and delayed recall in quiz format. |
| *NeuroTeam* | Motor planning, upper limb coordination, visuomotor integration. Cognitive functions: selective and sustained attention, visuospatial exploration and executive functions (planning, problem-solving, and inhibitory control). | Patients with focal brain damage, such as Post-stroke | Cooperative VR painting task set in a virtual art studio; players reconstruct a famous painting by applying complementary color palettes, enhancing upper limb motor control and embodied cooperation. |
| *CreatiVR* | Language, communication abilities, emotional expression | Patients with neurodegenerative disease (i.e, Parkinson Disease) | Immersive art-therapy sessions based on colour, artist biographies, and personal storytelling to stimulate language, affective communication and shared reflection. |
| *Truman Show* | Executive functions, memory, linguistic comprehension, motor planning, social behavior, functional organization | All | Immersive assessment module simulating a typical day in a virtual city square; patients complete four sequential "real-life" tasks to prepare a birthday party, each introduced by a 360° video; designed to evaluate cognition in ecologically valid settings. |

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