Narrative-Driven VR Exergames for Active Older Adults: Examining the Impact of Narrative Styles and Themes on Motivation and User Experience

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Abstract

Older adults often face the dual challenge of insufficient physical activity

and unmet psychological needs. Although exergames can promote physical activity, they often struggle to sustain motivation or adequately support psychological need satisfaction. This work explores the potential of integrating narrative into a VR cycling exergame, focusing on how narrative design can enhance motivation and fulfill psychological needs. Two experiments examined the impact of narrative styles with varying interactivity demands and different narrative themes (hedonic, eudaimonic, mixed-affective) on user experience. Study 1 (N=15) suggested that interactive narrative styles were associated with enhanced autonomy and relatedness, facilitated attentional dissociation from bodily fatigue, and led to higher psychological need satisfaction and lower perceived exertion, albeit at the cost of increased cognitive demands. Study 2 (N=36) compared hedonic, eudaimonic, and mixed-affective narratives. Hedonic narratives appeared to support flow and motivation with relatively low cognitive demands, whereas eudaimonic narratives were linked to deeper emotional and reflective engagement but imposed higher cognitive and emotional demands, leading to reduced replay intention. Mixed-affective narratives, by contrast, presented a potentially more balanced trade-off between motivational benefits and competence satisfaction. Interpreted through a Self-Determination Theory-informed perspective, these findings provide insights into how narrative styles and affective themes may be leveraged to design VR exergames that better align psychological engagement with older adults' physical capacities. Overall, these exploratory findings highlight both the promise and the limitations of narrative-driven exergame design, and they offer implications for the development of adaptive, psychologically informed exergames for older adults.

Keywords: Exergames, Interactive Narratives, Virtual Reality, Older Adults, Physical Activity, Psychological Needs

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1. Introduction

Physical health and psychological needs are interdependent components of healthy ageing [1–3]. This dual demand becomes increasingly critical for older adults, who face compounded challenges as they age. Recognised as a heterogeneous and dynamic population, older adults exhibit substantial variability in physiological, sensory, and cognitive functioning [4]. While definitions of 'older adulthood' vary (e.g., WHO's 60+ vs. 50-55 in parts of Europe [5]), interventions targeting individuals aged 55+ offer a critical win-

dow for preventative health [6]. In this paper, we use "older adults" to refer to individuals aged 55-75. This range covers a preventative window in which physical activity interventions remain feasible, while excluding adults over 75 for safety reasons given the physical demands of the cycling task. Despite these differences, older adults face common challenges, including concurrent declines in physical and cognitive capacities [7–10], as well as difficulties in fulfilling psychological and social needs, which are often exacerbated by retirement and living alone [11, 12].

Digital games have demonstrated potential to address these needs by providing physical, cognitive, and psychological needs [13–19]. However, many existing interventions adopt a compartmentalised approach, targeting physical or psychological domains in isolation. For example, exergames have become a common strategy to promote physical activity (PA) [17, 20–23], offering cognitive and physical training, rehabilitation, and balance improvement [22]. Yet, sustained engagement with exergames is likely shaped by multiple interacting factors. Alongside usability, accessibility, physical capacity, and content variety, insufficient support for players' psychological needs may be one modifiable design-related factor that contributes to disengagement [24].

To operationalise these missing psychological dimensions, we draw on Self-Determination Theory (SDT) [25], which posits that wellbeing and intrinsic motivation depend on the satisfaction of three basic psychological needs: autonomy, competence, and relatedness. Addressing these specific needs is critical for designing effective interventions for older adults [25, 26]. Narrative has been proposed as a promising design approach for supporting engagement and meaning-making in digital games [26, 27], while enabling players to perceive gameplay as meaningful [28]. Through narrative theme design, games can facilitate two distinct types of experiences: hedonic (emphasising immediate pleasure and control) and eudaimonic (associated with meaning, reflection, and moral complexity) [29, 30].

However, integrating narrative into exergames introduces a *Dual Design Challenge* specific to older adults. While prior work has explored narrative in sedentary contexts, such as using animated narratives to promote PA in children [31] or interactive storytelling for moral reasoning in students [32], the tension between physical exertion and narrative processing in older adults remains underexplored. For older adults, digital games with narrative elements offer unique benefits, such as improved engagement in cognitive memory games [28] or satisfying psychological needs through emotionally challenging content [19]. Although these approaches effectively promote PA,

they often give limited attention to users' psychological needs, which have been identified as one important contributor to older adults' exercise motivation and experience [25, 26].

Despite this prior work, it remains insufficiently understood how older adults experience cognitive and emotional demands introduced by interactive narrative during physically active gameplay. Narratives can convey diverse emotional experiences and support a range of gameplay styles, suggesting their potential as a flexible design mechanism for supporting a wide range of player experiences in exergames. Taken together, these considerations point to the need for empirical work that examines not whether narrative 'works' in exergames, but how different narrative designs are experienced under conditions of physical exertion and cognitive constraint in older adulthood. Based on these gaps, we investigated the following research questions:

RQ1 How do different narrative styles (no narrative, auto-narrative, interactive narrative) affect older adults' intrinsic motivation and user experience in VR exergames?

RQ2 How do different narrative themes (hedonic, eudaimonic, and mixed-affective) influence older adults' intrinsic motivation and player experience in VR exergames?

RQ3 What design guidelines can be derived for narrative-driven VR exergames to support physical engagement and psychological need satisfaction in older adults?

In this study, we operationalise narrative style through different levels of interactivity, using variations in user control and decision-making demands to differentiate narrative structures in VR exergames. To address these questions, we conducted two studies. Study 1 (N=15) employed a within-subjects design to examine how different narrative styles (no narrative, auto-narrative, and interactive narrative) shape older adults' intrinsic motivation and player experience. Results indicate that interactive narrative styles enhanced psychological need satisfaction and reduced perceived exertion, while also introducing risks of increased cognitive load. Building on these findings, Study 2 (N=36) adopted a between-subjects design to further investigate how three interactive narrative themes-hedonic, eudaimonic, and mixed-affective-differentially influence motivational and experiential outcomes.

Our results showed that each theme addressed distinct needs: eudaimonic narratives may be suitable for educational contexts that seek to foster ethical reflection and critical thinking, hedonic narratives improved flow and enjoyment while reducing cognitive challenges, and the mixed version offered balanced benefits. Drawing on both studies, we propose design guidelines to inform the future development of such games. We make the following contributions:

1. We present an empirical investigation of how narrative-driven design is experienced by older adults in VR cycling exergames, highlighting how different narrative styles are associated with variations in psychological needs, perceived exertion, and cognitive demands during PA.
2. We systematically examine how interactive narrative themes-hedonic, eudaimonic, and mixed-affective are associated with distinct motivational and experiential profiles in older adults' exergame play.
3. Drawing on quantitative and qualitative findings, we outline a set of design implications for narrative-driven VR exergames that reflect trade-offs between psychological needs, cognitive load, and physical capacity in older adult users.

2. Related Work

2.1. Theoretical Foundation: Narrative and Self-Determination Theory

To examine how narrative design shapes motivation and experience in exergames, we ground our work in Self-Determination Theory. SDT posits that intrinsic motivation and psychological wellbeing depend on the satisfaction of three basic psychological needs: autonomy, competence, and relatedness [25, 26]. Although exergames are effective in promoting PA, they frequently struggle to sustain engagement once the novelty of motion-based interaction diminishes. Prior research has highlighted the importance of varied, enjoyable, socially engaging, and appropriately challenging experiences when designing exergames for older adults [22]. From a self-determination perspective, these qualities may also support autonomy, competence, and relatedness, which provide the theoretical focus of this work.

Narrative has been widely proposed as a promising mechanism for addressing this motivational gap. In interactive systems, narrative is not merely a thematic overlay but emerges through player action and interactivity, distinguishing it from the passive consumption of stories in traditional media

[33, 34]. Narrative can embed gameplay activities within a coherent story context. This reframes repetitive actions as meaningful pursuits, sustaining engagement beyond short-term novelty [35].

SDT provides a useful interpretive framework for examining how narrative elements may be experienced as autonomy-supportive, competence-relevant, or socially meaningful during gameplay. First, narrative can enhance autonomy by situating player actions within meaningful choices and self-endorsed goals. This allows players to experience behaviour as volitional rather than externally imposed [32]. Second, narrative contributes to competence by framing challenges as purposeful obstacles within an unfolding story. Progress and success become narrative advancement rather than isolated task completion. [36]. Third, narrative can foster relatedness through interactions with characters and story-driven relationships, enabling feelings of connection and social presence even in single-player contexts [37]. Thus, narrative functions not merely as an affective overlay, but as a structural mechanism satisfying players' basic psychological needs.

Importantly, integrating narrative into physically active contexts introduces additional cognitive dynamics. Narrative engagement may redirect attentional focus away from bodily sensations of exertion, potentially shaping how physical effort is subjectively experienced, although such effects are likely constrained by cognitive capacity and safety considerations, particularly for older adults [38, 39]. This attentional shift functions as a dissociative strategy, which has been shown to support motivation and perceived exercise enjoyment [40]. However, narrative is not a monolithic construct: different narrative orientations, such as hedonic and eudaimonic narratives, may vary substantially in their cognitive, emotional, and motivational demands. How these differences interact with the satisfaction of SDT needs under conditions of physical exertion remains insufficiently understood, motivating the need for systematic investigation.

2.2. Narrative Styles and Themes in Digital Games

Narrative design in exergames shapes player experience along two closely related dimensions: the style of interaction and the narrative theme. Regarding narrative style, the distinction between non-interactive and interactive forms reflects a fundamental difference in the degree of player interactivity. Non-interactive narratives follow a predesigned, fixed storyline in which players primarily receive narrative content passively. While this format reduces

cognitive demands, it offers limited support for autonomy. In contrast, interactive narratives allow players to influence narrative progression through meaningful choices [41]. Prior work suggests that narrative interactivity can enhance engagement and motivation by supporting a sense of control [32]. However, enabling such narrative interactivity also introduces a critical trade-off: interactive decision-making increases cognitive load. This creates tension in exergames, requiring players to split limited mental resources between narrative processing, motor coordination, and safety [4]. Distinguishing between narrative styles is therefore essential for understanding how narrative-related benefits interact with cognitive demands during PA.

To further conceptualise narrative interactivity in this work, we draw on Interactive Narrative Theory, which characterises digital storytelling as an experience shaped by users' active involvement in the narrative process rather than passive reception [42, 43]. In interactive systems, narrative interactivity manifests not only through the presence of choice, but through the cognitive and attentional demands imposed by narrative-related interactions during ongoing activity. In the context of exergames, these demands are further constrained by physical exertion. Furthermore, for older adults, this trade-off is particularly critical due to age-related cognitive-motor interference, where older adults must consciously prioritise motor control and safety over cognitive tasks [44]. From this perspective, narrative interactivity must be carefully calibrated to support immersive and motivating experiences while avoiding cognitive overload, particularly when striving to maintain optimal experiential states such as flow [45].

Beyond interaction style, narrative themes influence the emotional orientation of the gameplay experience. Hedonic themes emphasise enjoyment, pleasure, and emotional comfort, often featuring lighthearted content and positively valenced outcomes. These themes tend to elicit affective enjoyment while requiring relatively limited emotional and cognitive processing [46, 47]. In contrast, eudaimonic themes are characterised by emotional depth and moral or reflective content, frequently engaging players in dilemmas or personally meaningful situations [29, 48]. While such themes may support experiences related to competence and self-reflection, they typically involve more demanding emotional processing. In physically active contexts, this reflective load may compete with the physiological demands of exercise, potentially leading to overload or reduced engagement.

Consequently, the integration of narrative style and narrative theme requires careful balancing of psychological engagement and physical capacity.

These trade-offs are particularly salient for older adults, who may experience reduced cognitive flexibility or dual-tasking capacity during physical exertion. While interactive narratives paired with hedonic themes may offer a more balanced experiential profile, the suitability of eudaimonic content in active settings remains uncertain. At present, it remains unclear how different combinations of narrative styles and themes shape older adults' psychological need satisfaction and engagement during exergame play, highlighting the need for empirical investigation.

2.3. Bridging Narrative and Exergames for Older Adults

While cycling-based VR exergames have demonstrated effectiveness in improving physical performance metrics [49] and enhancing perceived enjoyment [50], the role of narrative within these systems remains comparatively underdeveloped. Existing studies frequently incorporate narrative as a peripheral or atmospheric element rather than as a core gameplay mechanism. For example, Lu et al. [37] employed narrative primarily as background context. Although such approaches may enrich the experience aesthetically, they do not integrate narrative into moment-to-moment interaction, thereby limiting its potential to support psychological need satisfaction during physical exertion.

Moving beyond passive storytelling, recent research has begun to explore more narrative-driven exergame designs as a means of sustaining engagement. For instance, Freitas et al. [51] suggested that narrative elements may contribute to adherence among physically active older adults. However, their study did not disentangle the effects of narrative content from the effects of narrative interactivity, leaving it unclear whether observed benefits stemmed from the presence of story elements or from the additional interaction demands introduced by narrative-related decision-making. This distinction is particularly critical for older adults, who often face dual demands during exergame play: maintaining physical coordination and safety under exertion while simultaneously engaging with cognitively and emotionally demanding content [52].

This dual-demand context highlights a central design trade-off in narrative-driven exergames. While increasing narrative interactivity may deepen psychological engagement, it also introduces additional cognitive demands that can interfere with physical performance and attentional resources. Empirical evidence for this complexity is provided by Schwarz et al. [53], who found that higher levels of narrative interaction do not necessarily translate into

greater engagement. Such findings suggest that narrative integration alone is insufficient; rather, its effectiveness depends on how narrative interactivity is calibrated to users' cognitive capacities and physical constraints. For older adults, who may experience reduced dual-tasking capacity during physical exertion, this calibration remains poorly understood and empirically underexplored.

Accordingly, this work addresses these gaps by systematically examining how narrative interactivity demands and narrative themes jointly shape older adults' psychological need satisfaction, perceived exertion, and engagement during exergame play. Rather than assuming that narrative integration directly improves health outcomes, we focus on identifying the experiential and motivational mechanisms through which narrative design can support meaningful engagement alongside PA under conditions of physical and cognitive constraint.

3. Player Experience Measures Used in This Research

We conducted two experimental studies employing multiple validated survey scales to investigate player experiences. These scales included measures of different types of perceived challenge in gameplay, the satisfaction of basic psychological needs, players' intrinsic motivation, as well as their perceived physical exertion during exergame play, and flow experience.

Perceived Challenge. We measured perceived challenge using the Challenge Originating from Recent Gameplay Interaction Scale (CORGIS), a 30-item questionnaire covering four dimensions: cognitive, emotional, performative, and decision making challenge [54]. Example items include *"I had to think several steps ahead when playing the game"* (cognitive challenge) and *"The game made me think about real life issues"* (emotional challenge). The CORGIS was selected for its comprehensive coverage of challenge types [55], which is critical for studying narrative-integrated exergames. All items were rated on a 7-point Likert scale (1=Strongly disagree, 7=Strongly agree).

Basic Psychological Needs Satisfaction and Frustration. Basic psychological needs were assessed using the recent validated Basic Needs in Games Scale (BANGS) [56]. The BANGS measures both satisfaction and frustration of autonomy, competence and relatedness across six subscales, each consisting of three items rated on a 7-point Likert scale. We used this questionnaire to evaluate multiple psychological need dimensions related to

player experience and to understand older players' overall satisfaction with our bespoke game.

Intrinsic Motivation. We measured intrinsic motivation using the Intrinsic Motivation Inventory (IMI), a validated tool to assess self-regulation and motivational experience in laboratory settings [26, 57, 58]. The IMI has been widely applied in exercise science [57, 59], with the interest/enjoyment subscale being particularly important for assessing intrinsic motivation in exergame contexts [60]. Although the IMI has been used in longitudinal exercise interventions [61, 62], it indexes subjective motivational experience rather than adherence behaviour; therefore, a single post-session IMI score cannot itself be interpreted as evidence of long-term adherence [57, 63]. In this paper, the IMI was used solely to characterise immediate post-session motivational experience, not as a measure of adherence. We also included three other IMI dimensions: perceived competence, effort/importance, and pressure/tension, which together constituted our measurement of intrinsic motivation. Each item is rated on a 7-point Likert scale.

Perceived Physical Exertion. We assessed perceived exertion during exergame play using the Borg Rating of Perceived Exertion (RPE) scale, CR10 version [64]. The scale has been widely applied in occupational and exercise research [65], capturing subjective perceptions of breathlessness, fatigue, and overall physical effort based on physiological signals such as heart rate and muscle strain. Ranging from 0 to 10 with descriptive anchors, it is intuitive and accessible even for participants unfamiliar with exercise intensity scales. We assessed perceived exertion because our primary interest was in how participants subjectively experienced the physical demands of the exergame under different narrative conditions, rather than in estimating physiological exercise intensity.

Flow. We measured flow using a 9-item flow scale [66]. Example items include *"During the game, the way time passed seemed to be different from normal"* and *"During the game, I had a strong sense of what I wanted to do"*. Flow has been widely used to evaluate gameplay experiences and is strongly related to immersion and intrinsic motivation [67–69]. The items were rated on a 7-point Likert scale (1=Strongly disagree, 7=Strongly agree). This measure enabled us to assess older adults' enjoyment and immersion across game conditions.

4. Study 1: Impact of Narrative-driven Styles on Older Adults' Exergaming Experience

To understand older adults' perceptions of narrative-driven exergames, we first examined how different narrative styles influenced their gameplay experience through three versions of a VR cycling exergame: a baseline version with no narrative, an auto-narrative version where the story unfolded automatically without user input, and an interactive-narrative version that enabled user choices affecting the narrative through dialogue and decisions during cycling. We recruited an initial pool of 18 UK residents via university mailing lists, community websites, and in-person outreach. Three participants withdrew because of severe motion sickness. The final sample for the within-subjects experiment in Study 1 comprised 15 participants (8 female, 7 male; mean age=66, SD=5.7). Each participant played all three versions of the VR exergame. To comprehensively evaluate these versions, we adopted an explanatory mixed-methods approach. Quantitative measures (evaluating perceived challenge, psychological needs, intrinsic motivation, and physical exertion) were used to test specific hypotheses regarding player experience, while qualitative semi-structured interviews were analysed using Reflexive Thematic Analysis to deeply understand the underlying mechanisms and subjective nuances driving these statistical outcomes.

4.1. Design of a VR Cycling Exergame with Three Narrative-driven Types

4.1.1. Implementation of the VR Exergame Environment

We developed a VR exergame environment in Unity, presented from the first-person perspective of an older adult. Specifically, we used the Meta Quest 2 headset and developed the VR environment and in-game gesture interactions with the Meta XR All-in-One SDK and the Meta XR Interaction SDK. The virtual world, modelled on outdoor cycling routes through buildings and forested areas, was constructed with VR-specific assets in Unity Asset Store and the Psychophysical Experimental Virtual Reality Tool [70]. The characters were designed with walking and speaking behaviours to support realistic social encounters. To enhance immersion, the voices of the characters were adapted using AI-generated speech synthesis. The final narrative was presented through both voice-over and on-screen text. The game integrates visual dialogue options that players select through pinch-release gestures. This gesture was chosen because it is intuitive and easy for older

adults to learn [71], while also reducing the risk of mis-selection during physical activity. During pedaling, players can keep both hands on the handles for safety.

4.1.2. A Cycling Exergame with Narrative-driven Elements

To incorporate narrative elements into the VR exergame, we integrated a narrative design featuring emotional challenge by drawing on key design insights - introducing difficult themes or decisions, creating relatable characters, and fostering reflective states or broader emotional experiences [48, 72, 73]. This narrative style was chosen because emotionally challenging games have recently been shown to help older players engage through simple decision-making, while also fostering deeper feelings of autonomy, reflection, and relatedness [19]. Accordingly, narrative choices were designed around moral, social, and consequential dimensions to foster meaningful experiences [74].

As a common form of individual exercise, cycling is an ideal activity for supporting older adults' physical and mental condition [75], and has shown the potential to promote adherence to home-based exercise [76]. Moreover, evidence shows that older adults readily adapt to cycling due to its low-impact nature and reduced pain [52, 75]. Given the advantages of cycling and cycling-based exergames [22, 49, 77], we adopt this modality as a representative form of PA for older adults in our study.

The exergame was integrated with a stationary bike using an automatic path-following system, as the hardware lacked physical steering capabilities and used Bluetooth to transmit pedaling data (e.g., speed and cadence) to control in-game movement. This approach assisted players in navigating turns and reaching narrative decision points, while allowing them to focus on cycling and dialogue interactions. During each game version, participants cycled the same distance, approximately 3 km. The cycling resistance was also held constant across versions, while participants were free to determine their own cycling speed. Cycling resistance was determined through the pilot study. Although one participant with regular cycling habits preferred higher resistance levels, the final setting was set to level 6 (out of 22), which most participants perceived as both enjoyable and physically meaningful.

In the interactive version, seven narrative interaction points are distributed along the path, namely, one dialogue point at the start, one route-selection point, four dialogue points along the path, and the final decision point at the end. The average distance between interaction points is about

480 meters, ensuring cycling intervals of about 1.5 to 2 minutes and preventing frequent interruptions during PA. Conspicuous speed-reduction signs are placed near each interaction point.

Each interaction was designed to last approximately 1 minute. However, no strict time limits were imposed in the game, allowing players to proceed at their own pace. Accordingly, time spent at narrative interaction points did not contribute to the cycling distance, and variation in overall completion time could reflect both self-selected cycling speed and the duration of dialogue interactions.

Players make three to five dialogue choices per interaction. These options are categorised as either meaningful or non-meaningful: the route-selection point and the final decision event influence subsequent narrative progression and outcomes, whereas the remaining options do not affect the storyline. Participants were informed that they could make narrative choices, but they were not told which specific interactions would alter subsequent events.

To assess the suitability of the narrative and interaction design for older adults, we conducted a pilot study with four older adults (three women and one man), all of whom met the study's inclusion criteria. Participants evaluated the narrative content, the clarity of spoken and written information, the feasibility of narrative choices and gesture-based interaction, and the appropriateness of the cycling resistance. The pilot identified several areas for refinement. Participants considered the conflict in the initial narrative design overly intense and noted that such content might be uncomfortable or difficult for some older adults. We therefore reduced the intensity of the conflict. They also emphasised that the narrative should be grounded in familiar, everyday experiences and remain straightforward and easy to follow. Based on this feedback, we simplified and refined the storyline, dialogue, and presentation of narrative choices. Following these revisions, all four participants considered the final narrative engaging and suitable for use in Study 1. The pilot participants did not take part in the main study, and their feedback was used only to refine the study materials and was not included in the formal analysis.

Finally, we developed a VR cycling exergame with narrative-driven elements, presented from the perspective of the protagonist, David (see figure in the graphical abstract). The game begins with players learning about David, a retired man who enjoys cycling and lives with his son, Jim - an avid hiker. One morning, Jim departs early, leaving David alone. Along the way, David learns from a neighbour that his estranged childhood friend Steven



Figure 1: First-person view in the Non-Narrative condition (NNE). The virtual environment features realistic roads with natural scenery, providing a pure cycling experience without narrative elements.

is dying. Environmental cues and conversations reveal David's memories of friendship and conflict, while Jim's missed call remains unanswered. At a final crossroads, players must make a meaningful choice between two divergent narrative paths:

Route A: Check on Jim's safety. Players learn Jim is injured but treated, while Steven dies, leaving David an inheritance. Later, David meets Steven's troubled sister Jenny, and must decide whether to protect or report her.

Route B: Visit Steven one last time. David reconciles with Steven before his death, who asks him to care for Jenny. Meanwhile, Jim becomes disabled and resentful. David later encounters an ill Jenny, forcing a choice between supporting her or preserving ties with Jim.

4.1.3. Three Narrative-driven Types of the VR Cycling Exergame

The three types of narrative-driven VR cycling exergames used in Study 1 are detailed below, each of which had the same duration and virtual map environment.

Version 1: Non-Narrative + Cycling Exergame (NNE). Participants wore a Meta VR headset and pedaled on a stationary bike, cycling along a pre-set route in a virtual gaming environment. As the two routes (Routes A and B) were comparable in length and resistance, Route A was

randomly selected for this version. The environment featured realistic roads with turns, inclines, and declines, immersing players in a purely physical riding scenario (see Figure 1).

Version 2: Auto-Narrative + Cycling Exergame (ANE). Participants pedaled through a VR cycling environment while experiencing an emotional challenge based narrative. The narrative followed a default path (Route B), with all events and dialogues unfolding automatically. The route was randomly selected, as in this version, both routes were designed to be broadly comparable in narrative length, number of dialogues, and the overall intensity of emotional challenges. When participants reached each trigger area for the event, NPCs appeared and initiated dialogues that progressed without any input. Therefore, players were asked to follow the dialogue and storyline passively while continuing to cycle.

Version 3: Interactive-Narrative + Cycling Exergame (INE). In this version, players cycled continuously while sometimes engaging in narrative interactions. Specifically, they wore a VR headset and used simple 'pinch-release' gestures to interact with the in-game UI and make event and dialogue decisions (see Figure 2). Both dialogues and routes were determined by the players, creating a dynamic and participatory experience that ultimately empowered them to shape the development and outcome of the narrative. Participants continued pedalling throughout the cycling task in all three conditions; narrative presentation and interaction in the ANE and INE conditions were therefore not treated as rest periods.

4.2. Participants and Procedure

4.2.1. Participants

We recruited eligible participants using the following inclusion criteria: (a) Aged 55-75 years. This age range ensures a sufficiently broad span of older adults while excluding those above 75 for safety considerations.(b) Fluent in English, capable of fully comprehending experimental instructions and content. (c) Given the physical nature of the study, participants were required to have adequate physical capability to ride a stationary bicycle without associated health risks. (d) Crucially, no prior experience with VR. We specifically selected VR novices who were open to new technologies, aiming to ensure comparable levels of prior experience among all participants. Participants' self-reported habitual physical activity backgrounds are summarised in Table 1.



Figure 2: A participant engaging with the Interactive-Narrative condition (INE) using pinch-release hand gestures to select dialogue options. The participant wears a Meta Quest 2 headset while cycling on a stationary bike.

Based on these criteria, 15 older participants were included in Study 1. An a priori power analysis was conducted to allow for the detection of within-subjects effects of f=0.5, an alpha level of 0.05, and a desired power of 0.80. While the participants represented diverse professional backgrounds (e.g., university professor, church priest, fitness instructor, nursing home caregivers), they all shared a common curiosity regarding VR exergames. The study was approved by the institutional ethics committee, and all participants provided informed consent. Each received a £30 Love2Shop voucher as compensation.

4.2.2. Procedure

Before the experiment, participants received an information sheet, provided informed consent, and completed a short training session in which the experimenter introduced the VR headset and the stationary bike. Participants were explicitly informed that they could withdraw at any time in case of discomfort. Discomfort was monitored through participant self-report and researcher observation throughout each session; a standardised simulator sickness questionnaire was not administered. We adopted a counterbalanced within-subjects design to mitigate order effects. Each participant played the

Table 1: Participants' self-reported habitual physical activity profiles.

Activity profile	n	**Description**
Regular structured exercise	2	One participant cycled approximately 20 miles per week; another cycled regularly and undertook home-based weight training.
Recreational cycling	2	Cycling was reported primarily as a recreational or social activity.
Lifestyle physical activity	11	Walking or strolling was the predominant reported activity. Some participants also reported gym-based exercise, although this was not their primary regular activity.
Total	15	

Note. Participants were grouped according to their predominant self-reported activity. Categories were mutually exclusive and were not derived from a standardised physical activity measure.

three game versions, with each session lasting approximately 15 minutes. After each version, participants rested before completing questionnaires (IMI, CORGIS, BANGS, RPE-CR10), which took about 15 minutes. Upon completing all sessions, participants took part in a 10-20 minute semi-structured interview to reflect further on their experiences. Researchers were present throughout to ensure proper system operation, assist with questionnaires, conduct interviews, and respond to any emergencies.

4.3. Hypotheses

Based on Self-Determination Theory (SDT) and Interactive Narrative Theory, we formulated the following hypotheses regarding narrative styles (NNE, ANE, and INE) for Study 1:

H1: Exergame incorporating interactive narrative elements (INE) improves overall perceived challenge levels compared to games with other narrative styles (NNE and ANE).

H2: The interactive-narrative exergame (INE) fosters higher basic psychological need satisfaction than the auto-narrative (ANE) and non-narrative (NNE) conditions.

H3: Exergames incorporating narrative elements (INE and ANE) promote higher enjoyment as measured by IMI Interest/Enjoyment than the non-narrative condition (NNE).

H4: The interactive-narrative version (INE) promotes lower perceived physical exertion than the non-narrative condition (NNE).

4.4. Quantitative Results: Player Experience

We evaluated the internal consistency of each questionnaire factor using McDonald's ω, which offers a robust estimate of reliability [78]. Prior to the main analyses, Shapiro-Wilk tests were conducted on all dependent variables. Results showed that scores on the CORGIS, BANGS, and IMI questionnaires met the criteria for normality across the three conditions. Therefore, GLM repeated-measures ANOVAs were employed for these data. When Mauchly's test indicated violations of sphericity, the Huynh-Feldt correction was applied. Effect sizes are reported as $\eta^2_{partial}$ for ANOVA tests. As data from the Borg RPE scale did not meet the assumption of normality, this measure was analysed using a Friedman test. All statistical analyses were conducted with a significance level of α=0.05. Significant main effects were followed by Bonferroni-adjusted pairwise comparisons. Tables 2 and 3 present the overall differences across the three game versions for Study 1, while Table 4 reports all Bonferroni-adjusted pairwise comparisons, including both significant and non-significant results.

Table 2: Repeated measures ANOVA results for CORGIS, BANGS, and IMI in Study 1, including the reliability analysis of the variables (McDonald's ω). Descriptive statistics, Means (Standard Deviations), are reported for each variable across three conditions: non-narrative (NNE), auto-narrative (ANE), and interactive-narrative (INE) exergame. F-values, p-values, and $\eta^2_{partial}$ values are included to assess within-group differences.

Scale	McDonald's ω	NNE (SD)	ANE (SD)	INE (SD)	F	p	$\eta^2_{partial}$
CORGIS - Cognitive challenge	0.904	3.43 (1.35)	3.77 (0.92)	4.61 (0.71)	7.612	**0.002****	0.352
CORGIS - Emotional challenge	0.901	2.72 (1.23)	4.32 (1.21)	4.96 (0.86)	24.011	**0.000*****	0.632
CORGIS - Physical challenge	0.923	3.03 (1.59)	3.52 (1.52)	4.51 (1.43)	6.361	**0.005****	0.312
CORGIS - Decision making	0.846	2.07 (1.17)	3.13 (1.49)	5.01 (0.61)	30.042	**0.000*****	0.682
BANGS - Autonomy satisfaction	0.896	3.00 (1.36)	3.27 (0.83)	4.08 (0.54)	8.557	**0.001****	0.379
BANGS - Autonomy frustration	0.633	4.11 (1.30)	4.31 (1.02)	3.64 (1.03)	1.851	0.176	0.117
BANGS - Competence satisfaction	0.935	4.49 (1.41)	3.71 (1.86)	4.96 (1.40)	7.230	**0.003****	0.341
BANGS - Competence frustration	0.846	3.40 (1.39)	3.56 (1.30)	3.36 (1.22)	0.162	0.851	0.011
BANGS - Relatedness satisfaction	0.817	2.60 (1.40)	3.80 (1.45)	4.84 (1.17)	12.930	**0.000*****	0.48
BANGS - Relatedness frustration	0.791	2.71 (1.33)	3.31 (0.80)	2.44 (0.97)	3.265	0.053	0.189
IMI - Interest/Enjoyment	0.945	4.24 (1.62)	3.99 (1.43)	4.71 (1.36)	3.131	0.059	0.183
IMI - Perceived competence	0.941	4.31 (1.24)	3.57 (1.25)	4.05 (1.13)	5.691	**0.008****	0.289
IMI - Effort/Importance	0.901	4.98 (1.24)	4.62 (1.33)	5.40 (0.77)	4.715	**0.017***	0.252
IMI - Pressure/Tension	0.925	4.18 (1.74)	4.58 (1.08)	4.30 (1.34)	0.934	0.405	0.063

Note. Statistically significant adjusted p-values are shown in bold. *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

Table 3: Friedman test results for rating of perceived exertion across three game conditions. Friedman test statistics (χ^2) and the p-value are provided to assess within-group differences.

Variable	**NNE (SD)**	**ANE (SD)**	**INE (SD)**	χ^2	p
Borg RPE scale	2.31 (2.27)	1.69 (2.20)	0.67 (1.08)	11.476	**0.003****

Note. Statistically significant adjusted p-values are shown in bold. *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

Table 4: Bonferroni-adjusted pairwise comparisons between the NNE, ANE, and INE conditions across all quantitative measures for Study 1.

	NNE–ANE		**NNE–INE**		**ANE–INE**	
Measure	**Difference (SE)**	**Adj. p**	**Difference (SE)**	**Adj. p**	**Difference (SE)**	**Adj. p**
CORGIS						
Cognitive Challenge	-0.34 (0.27)	0.669	-1.18 (0.38)	**0.024***	-0.84 (0.27)	**0.024***
Emotional Challenge	-1.60 (0.39)	**0.003****	-2.24 (0.39)	**0.000*****	-0.64 (0.18)	**0.009****
Physical Challenge	-0.49 (0.45)	0.862	-1.48 (0.50)	**0.031***	-0.99 (0.29)	**0.014***
Decision Challenge	-1.07 (0.43)	0.078	-2.95 (0.33)	**0.000*****	-1.88 (0.39)	**0.001****
BANGS						
Autonomy Satisfaction	-0.27 (0.30)	1.000	-1.08 (0.32)	**0.012***	-0.82 (0.17)	**0.001****
Autonomy Frustration	-0.20 (0.34)	1.000	0.47 (0.36)	0.655	0.67 (0.37)	0.275
Competence Satisfaction	0.78 (0.32)	0.091	-0.47 (0.33)	0.525	-1.24 (0.34)	**0.008****
Competence Frustration	-0.16 (0.30)	1.000	0.04 (0.37)	1.000	0.20 (0.43)	1.000
Relatedness Satisfaction	-1.20 (0.51)	0.097	-2.24 (0.49)	**0.001****	-1.04 (0.29)	**0.010***
Relatedness Frustration	-0.60 (0.40)	0.460	0.27 (0.32)	1.000	0.87 (0.32)	0.051
IMI						
Interest/Enjoyment	0.25 (0.24)	0.928	-0.47 (0.36)	0.643	-0.72 (0.26)	**0.048***
Perceived Competence	0.73 (0.26)	**0.044***	0.25 (0.18)	0.539	-0.48 (0.21)	0.117
Effort/Importance	0.37 (0.28)	0.635	-0.42 (0.25)	0.347	-0.78 (0.24)	**0.015***
Pressure/Tension	-0.40 (0.33)	0.754	-0.12 (0.31)	1.000	0.28 (0.25)	0.827
Borg RPE Scale	-0.57 (0.37)	0.362	-1.03 (0.37)	**0.014***	-0.47 (0.37)	0.604

Note. For CORGIS, BANGS, and IMI, differences were calculated as the estimated marginal mean of the first condition minus that of the second condition. For the Borg RPE scale, differences represent pairwise differences in mean ranks following a Friedman test, oriented as the first condition minus the second condition. Standard errors are shown in parentheses. All reported p-values were adjusted using the Bonferroni correction. Statistically significant adjusted p-values are shown in bold. *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

4.4.1. Perceived Challenge

Analysis revealed significant main effects of narrative style across all four challenge dimensions: cognitive, emotional, physical, and decision-making (see Table 2 and Figure 3). As expected, older adults reported significantly higher levels of emotional challenge in both the ANE condition (M=4.32, SD=1.21) and the INE condition (M=4.96, SD=0.86) compared to the NNE condition (M=2.72, SD=1.23). Participants also experienced significantly higher levels of emotional challenge when playing the INE version compared to the ANE version (INE: M=4.96, SD=0.86; ANE: M=4.32, SD=1.21).

Furthermore, players in the INE condition perceived significantly greater challenge levels across all three other CORGIS dimensions compared to both the ANE condition and the NNE condition. Specifically, cognitive challenge scores were higher in the INE condition (M=4.61, SD=0.71) than in the ANE condition (M=3.77, SD=0.92) and NNE (M=3.43, SD=1.40); physical challenge was greater (INE: M=4.51, SD=1.43; ANE: M=3.52, SD=1.52; NNE: M=3.03, SD=1.59); and decision making scores were also higher (INE: M=5.01, SD=0.61; ANE: M=3.13, SD=1.49; NNE: M=3.13, SD=1.49). In contrast, players who experienced the auto-narrative while cycling did not differ significantly from those in the exercise-only condition in terms of cognitive, physical, or decision making challenge.

Overall, INE led to significantly higher levels of perceived challenge across all four CORGIS dimensions compared to both the ANE and NNE conditions. We therefore accept H1.

4.4.2. Basic Psychological Needs in Games

Main effects of the narrative style on the three need satisfaction dimensions were significant (see Table 2 and Figure 4a). Autonomy satisfaction scores were significantly higher in the INE condition (M=4.08, SD=0.54) than in both the ANE condition (M=3.27, SD=0.83) and the NNE condition (M=3.00, SD=1.36). Similarly, participants reported significantly higher levels of relatedness satisfaction when playing the INE version (M=4.84, SD=1.17) compared to the conditions of ANE (M=3.80, SD=1.45) and NNE (M=2.60, SD=1.40). The satisfaction of the competency need was also higher in the INE condition (M=4.96, SD=1.40) than in the ANE condition (M=3.71, SD=1.86). However, no significant differences were observed between the NNE and INE conditions in competence satisfaction. There were also no significant differences between ANE and NNE conditions in the autonomy, competence, or relatedness satisfaction measures. Furthermore,

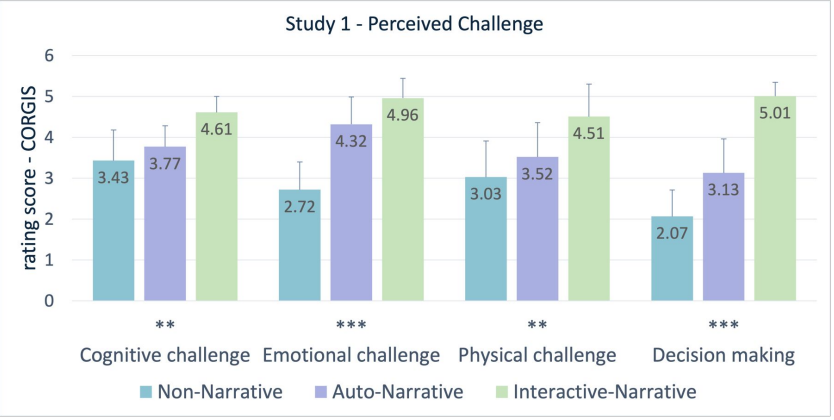


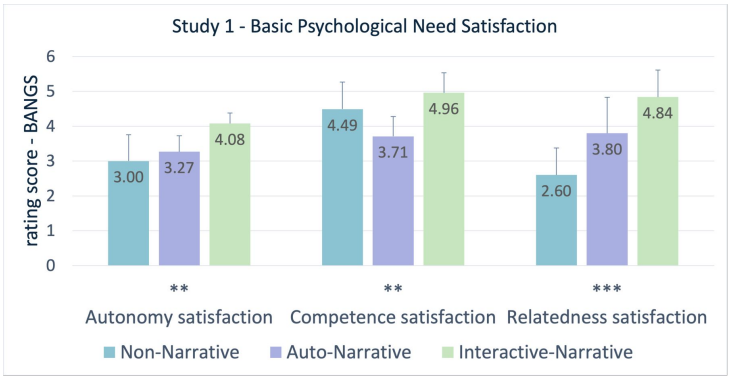
Figure 3: Mean perceived challenge scores across four CORGIS dimensions in Study 1 (N=15). Error bars represent standard deviations. NNE = Non-Narrative Exergame, ANE = Auto-Narrative Exergame, INE = Interactive-Narrative Exergame. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

no significant differences were observed between the three game conditions for the frustration dimensions of autonomy, competence, or relatedness (see Table 2 and Figure 4b).

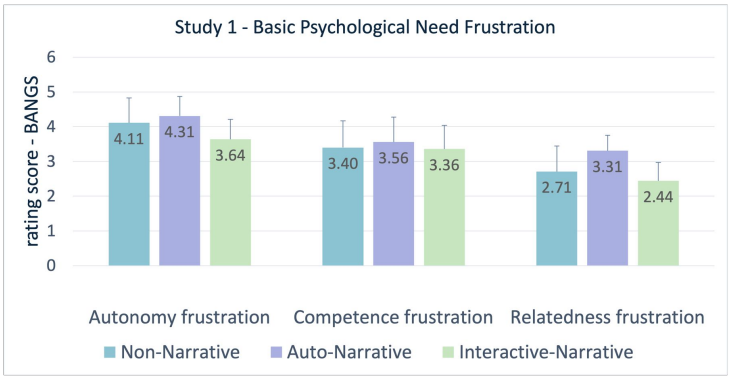
Therefore, H2 was partially supported. We accept H2 with respect to autonomy and relatedness, and note a partial effect on competence.

4.4.3. Intrinsic Motivation

The results indicated significant main effects of the narrative style on perceived competence and effort/importance, while no main effects were observed for interest/enjoyment or pressure/tension (see Table 2 and Figure 5). The effort/importance subscale, which assesses the amount of effort participants invested in the activity and the value they attributed to it, was significantly higher in the INE condition (M=5.40, SD=0.77) compared to the ANE condition (M=4.62, SD=1.33). No significant differences were observed between the NNE condition and the other two conditions on this measure. Participants reported a higher perceived competence in the NNE condition (M=4.31, SD=1.24) compared to the ANE condition (M=3.57, SD=1.25). However, no significant differences in perceived competence were found between the INE condition and either the NNE or ANE conditions, which differs from the results of competence satisfaction observed in the BANGS data. Therefore, we reject H3.



(a) Psychological need satisfaction



(b) Psychological need frustration

Figure 4: BANGS scores for psychological needs in Study 1 (N=15). (a) Need satisfaction across autonomy, competence, and relatedness dimensions. (b) Need frustration across the same three dimensions. Error bars represent standard deviations. Higher scores indicate greater satisfaction (a) or frustration (b). Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

4.4.4. Perceived Exertion

Narrative style significantly affected perceived exertion (see Table 3 and Figure 6). Specifically, participants reported significantly higher perceived exertion when playing the NNE version (M=2.31, SD=2.27) compared to the INE version (M=0.67, SD=1.08). We therefore accept H4. However, no significant differences were observed between the NNE and ANE versions, or between the INE and ANE versions.

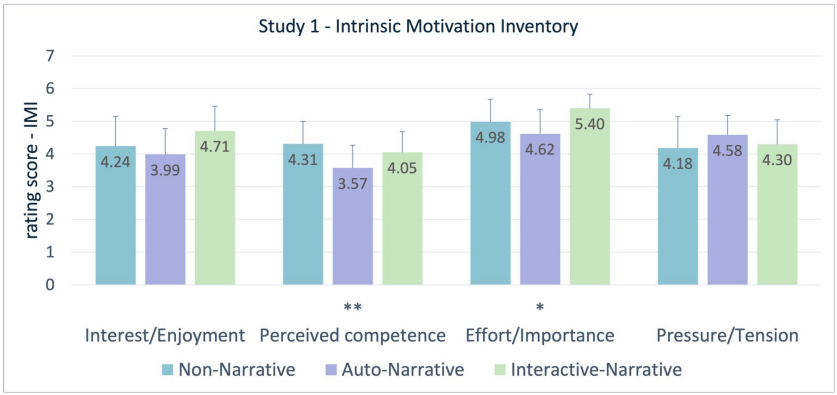


Figure 5: Intrinsic Motivation Inventory (IMI) scores across four subscales in Study 1 (N=15). Error bars represent standard deviations. Higher scores indicate greater interest/enjoyment, perceived competence, effort/importance, and pressure/tension respectively. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

4.5. Qualitative Results: Feedback and Suggestions for Future Game Design

We conducted semi-structured interviews with 15 older adults to explore their experiences with three versions of the game, their perspectives on the exercise-narrative integrated version, and their suggestions for future improvements. The interviews addressed participants' experiences with different versions of the game, potential content and scenarios, as well as issues and recommendations for improvements.

The data from handwritten notes and audio recordings were transcribed to form the basis for coding. Reflexive thematic analysis (RTA) [79, 80] was employed to analyse the data. All interviews were transcribed verbatim by the primary experimenter. Subsequent quality and accuracy checks were performed to ensure the first author (the primary experimenter) developed a comprehensive familiarity with the data. The first and second authors independently coded the data by segmenting the transcripts into smaller units and assigning keywords or short phrases to capture their core meanings, thus generating a set of initial codes. For example, for participant statement (P1), "The storyline was more engaging, but also sad," two distinct initial codes were generated: 1. Deep Affective Engagement. 2. Narrative-Driven Emotional Load (Sadness). Initial codes were then systematically categorised based on their conceptual associations to construct preliminary themes. The two authors held multiple, dedicated consensus meetings to

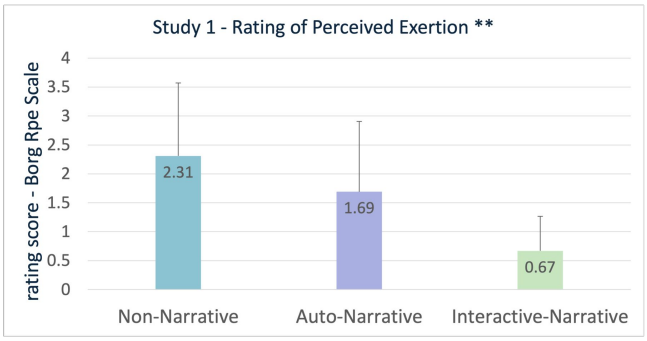


Figure 6: Borg Rating of Perceived Exertion (RPE CR-10 scale) across conditions in Study 1 (N=15). Error bars represent standard deviations. The scale ranges from 0 (no exertion) to 10 (maximal exertion). Lower scores indicate reduced perceived physical effort. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

discuss the themes' conceptual coherence, representativeness, and fidelity to the original data. Through continuous critical discussion and reflexive review, the boundaries and definitions of the themes were iteratively refined. If significant new thematic ideas emerged during the meetings, both authors immediately returned to the full dataset to initiate re-coding. Finally, we identified four themes to illuminate how narrative styles reshape the player experience of exergaming. The themes range from diverse user experiences to critical safety boundaries. Participant references and quotes from the study are identified by the prefix 'P' (e.g., P-01) and the condition code.

4.5.1. Theme 1: Agency as a Prerequisite for Engagement

This theme captures how participants experienced narrative interactivity as part of their engagement with the exergame during physical exertion. One of the main patterns identified in the data was that participants perceived a sense of agency as a core mechanism for enabling engagement and mitigating boredom. Specifically, active decision-making provided participants with a more immersive experience and a valued sense of control, particularly in the interactive conditions. This narrative engagement often acted as a positive distraction, as one participant noted, the game elements helped "distract you from the pain of the exercise or the boredom" (P-12, INE). Even when control was limited, the mere presence of choice was appreciated. For example, one participant mentioned:

> *"I actually enjoyed feeling like I was in control of the bike, even*

> *though I wasn't really in control of the story - I still had a few choices to make"* (P-08, INE).

Conversely, the absence of agency often led to feelings of frustration during gameplay, which participants described as passivity or monotony. In the conditions lacking interaction, participants also tended to feel detached. One participant described the experience as being "just like a passenger," noting that they were just waiting for the ending (P-14, ANE). Similarly, a lack of active involvement may lead to rapid disengagement, with one participant remarking:

> *"This game just has me riding around the whole time, and honestly, it gets a bit boring"* (P-13, NNE).

4.5.2. Theme 2: Motivational Reframing: From Exertion to Meaning

This theme reflects how narrative-driven interaction reshaped participants' motivation and perception of physical effort during exergame play. One key finding was that participants' motivations for exercise were reshaped across the different game versions. Participants reported that the integration of interactive narrative elements fundamentally changed how they perceived exercise, expressing a preference for this mode of engagement. This suggests that interactive narrative-driven designs may mitigate the inherent monotony of conventional exercise, redirecting players' attention from mere physical exertion to the pursuit of higher-level meaning. In contrast, participants' accounts of the ANE version, which featured only non-interactive narrative elements, did not reflect this motivational shift.

This reframing was initially achieved through a psychological shift and load reduction. The interactive narrative elements served as a powerful cognitive distraction. This reduced perceived fatigue and made the activity more enjoyable. For instance, one participant noted directly that "The game makes the exercise more enjoyable and less tiring" (P-12, INE). This successful mental shift allowed exercise to become a subconscious activity, with another participant remarking, "The cycling feels easy. By the end I was doing it without even thinking" (P-15, INE).

Beyond distraction, the narrative design provided a context for multiple value realisation, integrating simultaneous cognitive and physical training. Several participants valued this dual benefit, perceiving the game as providing both mental and physical exercise:

> *"I find that this game provides both mental and physical training, which aligns well with my personal habits"* (P-01, INE)

Others framed this benefit purely as cognitive training, one participant stating, "I think of it as brain training. I play those kinds of games on my phone anyway, and this gives me the exact same feeling" (P-15, INE). Furthermore, the narrative context facilitated deeper engagement, prompting moral reflection. For example, another participant mentioned that "It helps us rethink our behaviour and avoid regrets... it also makes me think more deeply about things" (P-14, INE).

Importantly, the data highlighted the diversity of user motivations, emphasising the potential and the necessity of tailoring interactive narrative-driven exergames for specific populations. For example, the interactive version was found to be a useful cognitive tool for rapid decision-making training by one participant with Attention Deficit Hyperactivity Disorder (ADHD) (P-11, INE). However, this diversity also meant that the value of the exergames varied significantly. For some users, the primary motivation was simply relaxation and low cognitive engagement:

> *"I just want to relax when I play games - sometimes I don't even want to think. This active narrative mode actually feels the most challenging for me"* (P-12, NNE)

Conversely, others saw the value in facilitating highly personalised training, suggesting future features like AI to "tailor its storyline, transforming it into a training tool" (P-14, INE). Finally, the social aspect was a key motivator for older adults. Participants found that the avatar conversation features were helpful for building deeper relationships, similar to cycling with friends (P-02, INE).

4.5.3. Theme 3: The Desire for Flexibility in Modality and Content

This theme highlights individual differences in how participants balanced narrative engagement and PA demands. The analysis highlighted that incorporating diverse game modes and accommodating a wider range of PA forms are essential for broadening the system's appeal. Participants expressed a strong need for the gaming experience to adapt to different social scenarios to strengthen emotional connections. For some, the primary goal was using games as a tool to bond with family at home. The INE version enabled greater variability in gameplay experiences, creating a platform for sharing perspectives and discussing decisions. As one participant explained:

> *"My daughter's in another city, and I think this game would be great for us to play together. We could chat about the choices we made afterward, and I think it'd bring us closer"* (P-14, INE).

Beyond the home environment, other participants suggested that these types of games had significant potential for application in community settings, such as gyms. They envisioned a shift from passive entertainment to interactive group experiences. One participant noted:

> *"As for exercise classes with a VR experience at a gym, I can see why some people would love it - especially compared to just watching movies while working out"* (P-03, INE).

In addition to social context, the data showed that incorporating diverse forms of PA can accommodate users with different physical capabilities. Participants emphasised that future designs should explore alternative exercise options beyond cycling to ensure inclusivity. For instance, suggestions included using "different exercises, like snooker" to consider users "who may not be able to cycle" (P-01, INE). Similarly, others felt the game should cater to less active individuals, noting the game "could benefit from a walking mode" (P-13, NNE).

Finally, for narrative-driven exergames, narrative design may play an important role in sustaining engagement. Specifically, participants desired variety beyond life-like narratives, suggesting that different genres would keep the experience fresh. As one participant noted, 'I'd love to see different kinds of stories, like puzzles or adventures. I think that would be really interesting" (P-02, INE). Several participants who experienced the INE version explicitly expressed a willingness to replay the game. Their accounts reflected two complementary motivations for replay: encountering new narrative content and revisiting the same narrative through different choices. P-02 associated replay with the prospect of a different story, noting, 'If I go cycling again, I'd really like there to be a new story" (P-02, INE). P-01, by contrast, was interested in returning to the same interactive narrative to explore alternative outcomes: 'I'd like to play it again, make different choices, and see how the story turns out" (P-01, INE). This broader willingness to return was also reflected in P-13's response: 'I would like to play this game again" (P-13, INE). Together, these accounts suggest that participants' willingness to replay was associated with opportunities to encounter new narrative content or explore the consequences of alternative choices, rather than simply repeating the same exercise.

4.5.4. Theme 4: Safety Thresholds and Affective Boundaries

This theme captures participants' experiences of cognitive, physical, and emotional boundaries during narrative-driven exergame play. Maintaining appropriate safety thresholds is essential for older adults engaging in narrative-driven VR exergames, including both physiological comfort and emotional boundaries. Any form of physical or psychological discomfort could immediately disrupt the immersive experience. Regarding physiological safety, several participants reported that excessive exertion led to dizziness, particularly in playing the NNE version. However, integrating narrative segments to modulate physiological load presents an effective solution. As one participant noted, the narrative breaks offered a necessary recovery period:

> *"The good thing is, you don't get too dizzy or burnt out. It serves as a little break where you focus on the story and the interactions before getting back into it. It feels like a nice balance"* (P-08, INE).

During narrative-driven exergame play, the optimisation of cognitive load could be closely related to the improved experience. Given older adults' limited cognitive processing capacity, exertion may further constrain their ability to become immersed in the narrative. Too long or complex text could negatively impact the cycling experience. For example, one user found the memory load frustrating: "When I'm cycling, I noticed some sentences are seriously long... They're so long that I actually forget what choice I made at the previous stop. That can be pretty frustrating" (P-06, ANE). Similarly, another participant mentioned: "The story gives you loads of info, and I'm trying to read it while cycling, but some of it is a bit too much for me" (P-01, ANE).

Finally, while incorporating narrative could elicit richer emotional experiences during exergame play, deeply reflective or highly realistic narrative content may also evoke distressing memories. As a participant reported: "Seeing that brings it all back... and it could make them feel really low or upset" (P-07, ANE). This emotion was echoed by another participant regarding older demographics: "I reckon older people who've been through similar experiences might find it even more upsetting" (P-11, ANE). It is suggested that eudaimonic narratives in exergames tend to be more sensitive to users' ethical and affective boundaries. To mitigate this risk, it is essential to evoke positive affect during exertion. Participants explicitly linked positive story elements to higher motivation. As one participant vividly described:

> *"The themes are just too heavy for me... The happier it is, the more energy I have for cycling. But when it gets really sad, I honestly struggle to keep going"* (P-05, INE).

In summary, the above themes illustrate the complex ecosystem of user experience in narrative-driven exergames, highlighting the interplay between agency, motivation, inclusivity, and safety. In combination with the quantitative results, we have synthesised four core findings from Study 1.

4.6. Study 1: Key Findings

Finding 1. Agency Supported Immersion and Interest in Replay. Our qualitative findings show that the INE version fostered a stronger sense of immersion and control. In contrast, users reported that the ANE version needs more interaction, while prolonged playing of NNE felt monotonous. These results suggest that providing players with autonomy is critical for enhancing both immersion and enjoyment in exergames. The study also showed that participants in the INE condition actively reflected on their decisions and expressed interest in replaying the experience to explore alternative narrative outcomes. This pursuit of novelty further shows the potential of interactive narratives that incorporate meaningful choices.

Finding 2. Interactive narratives satisfy deeper psychological needs. Our experimental results showed that the INE condition elicited higher perceived challenges, while increasing need satisfaction. Therefore, although interactive narratives impose greater cognitive and perceived physical demands, rather than hindering players, they effectively produce positive psychological effects on older adults. Semi-structured interviews further showed that interacting with the narrative deepened engagement, enabling participants to focus more actively during exercise. These findings show the critical role of interactive narrative styles in fostering psychological engagement and set the stage for our second study.

Finding 3. Balance between narrative complexity and exercise intensity is essential. Although Study 1 indicated that interactive narratives reduced perceived exertion, qualitative findings suggest that a delicate balance is required. Excessive narrative information risked cognitive overload, raising perceived exercise difficulty and causing confusion. This highlights the importance of aligning the informational density of narratives with the physical demands of exergames, a challenge noted in prior work [81].

Finding 4. Narrative themes influence older adults' motivation for exergaming. Study 1 also showed that narratives incorporating emotional challenge were perceived as overly demanding in the context of physical exertion, potentially evoking negative emotions and reducing future willingness to play. This contrasts with its benefits in sedentary games, which often elicit appreciation and satisfy psychological needs [19, 82]. These results highlight the necessity of exploring how hedonic narratives that emphasise immediate enjoyment shape the experiences of older players. Study 2 was refined to compare eudaimonic, hedonic, and mixed-affective narrative themes within an interactive narrative exergame.

5. Study 2: Effects of Different Narrative Themes on Older Adults' Exergaming Experience

Study 1 demonstrated the potential of an interactive-narrative style in satisfying diverse psychological needs and lowering perceived exertion during exergaming. It also revealed that narrative content influences older adults' intention for continued engagement. Based on these findings, Study 2 was designed to examine the effects of different narrative themes, namely eudaimonic, hedonic, and mixed-affect designs,on the motivation and experience of older adults.

The emotionally challenging narrative design from Study 1 was retained as the eudaimonic version in Study 2. Informed by suggestions of older adults, we integrated joyful and inspiring daily life scenarios to develop a mixed-affective version that combined eudaimonic and hedonic storytelling in a 1:1 ratio. A third version was created with a purely hedonic narrative, incorporating only pleasure-oriented elements and excluding eudaimonic content. Additionally, user feedback also highlighted that cognitive load and emotional risks need to be optimised. Thus, narrative segments across all versions were shortened and simplified to reduce cognitive load while retaining key narrative choices. The total gameplay duration was kept consistent at approximately 12 minutes across the three versions, with identical narrative lengths. Because three Study 1 participants withdrew due to severe motion sickness, and because Study 1 participants described narrative segments as providing a recovery period from continuous cycling, we introduced an additional precaution in Study 2. Specifically, participants in all conditions were instructed to stop pedalling during narrative interaction moments, thereby reducing continuous motion while they attended to and interacted with the

narrative content. Game logs indicated that total non-pedaling time was comparable across the three versions, averaging approximately 4.5 minutes. No participant withdrew from Study 2 because of motion sickness, although isolated discomfort was still reported in the interviews. The overall game process was similar to the INE version from Study 1 and is illustrated in Figure 7.

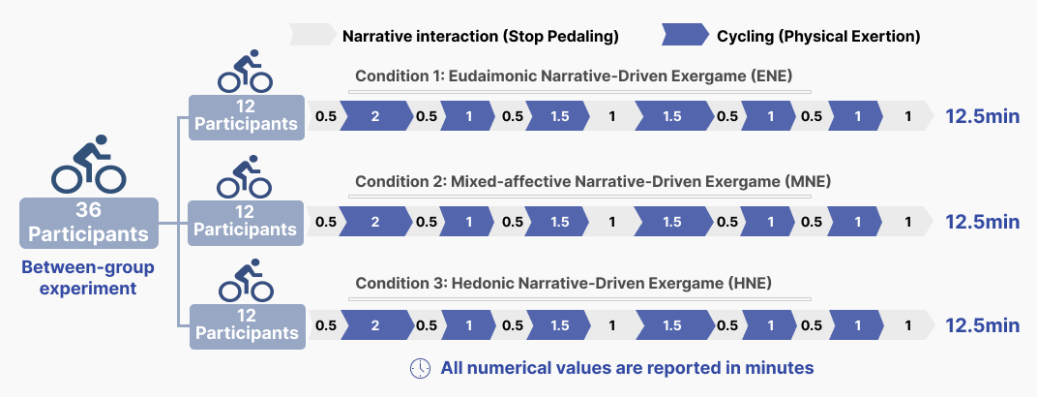


Figure 7: Experimental design structure for Study 2 (N=36, between-subjects). All three conditions (ENE, MNE, HNE) followed identical temporal structures: seven narrative dialogue segments (0.5-1.5 minutes each) interleaved with cycling phases (0.5-1.5 minutes each), totaling 12.5 minutes per session. white segments indicate narrative interaction (stop pedaling); purple segments indicate active cycling. All numerical values are reported in minutes.

5.1. Interactive-Narrative VR Exergame Featuring Three Narrative Themes

The design of the three narrative conditions was motivated by both theory and participant feedback from Study 1. While some older participants expressed a preference for lighter, everyday storylines centred on positive experiences, others valued the emotionally weightier narrative and engaged with it appreciatively. This divergence suggested that a single narrative theme is unlikely to suit all older players. We therefore developed three versions spanning the hedonic-eudaimonic continuum, following established distinctions between hedonic and eudaimonic entertainment experience [29, 46–48].

The core interactive-narrative game style from Study 1 was retained, and three new narrative scripts were developed. Each was tailored to its intended theme so that the versions differed systematically in emotional valence and reflective depth while the environment, cycling task, and choice structure

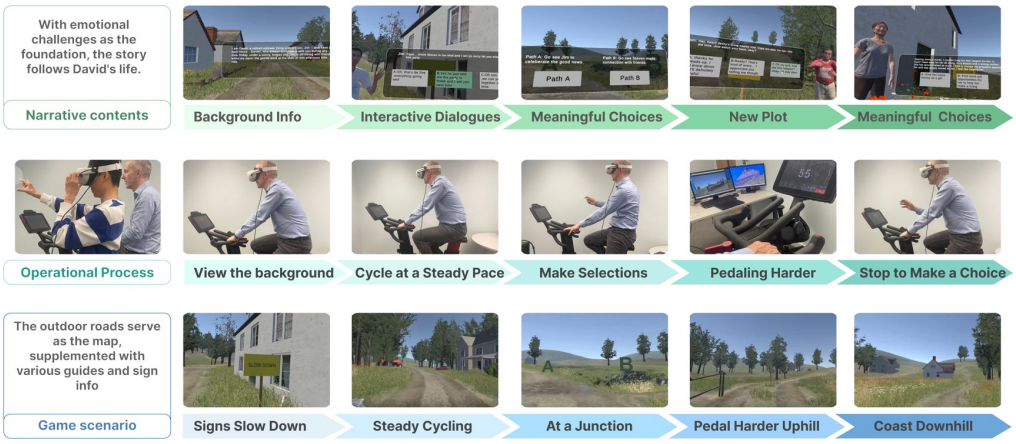


Figure 8: Participant gameplay flow in Study 2. The figure illustrates the complete sequence from baseline instructions through narrative interactions to cycling phases and final choices across different narrative triggers. Each row represents a distinct gameplay phase with corresponding in-game screenshots.

were held constant. Table 5 summarises the design rationale behind each condition. The scripts were constructed deductively from the theoretical definitions above [48]; no manipulation check or expert validation of thematic distinctiveness was carried out before the main study, and the conditions are therefore theory-informed rather than empirically validated.

5.1.1. Condition 1: Eudaimonic Narrative-Driven Exergame (ENE)

The storyline of this version remained largely consistent with the interactive-narrative design from Study 1. However, some dialogues were shortened, and redundant information was streamlined. Overall, the cycling duration in the game was increased while the narrative portion was reduced, with the respective lengths of both kept consistent with the other two versions.

5.1.2. Condition 2: Mixed-affective Narrative-Driven Exergame (MNE)

David, a retired older adult, faces a choice between attending his son Jim's family dinner (Route A) or his friend Steven's recovery party (Route B). During a ride, David meets his neighbor Tom, who invites him to the party, while Jim calls to invite him to dinner.

Route A - Attend Jim's gathering: David misses Steven's party but later finds comfort in shared memories. On his way home, he meets Jenny,

Table 5: Design rationale of the three narrative conditions in Study 2.

	ENE	**MNE**	**HNE**
Design origin	Retained from Study 1; emotionally challenging material valued by a subset of participants	Newly developed to combine both tonal registers	Newly developed in response to requests for lighter everyday content
Theoretical basis	Eudaimonic: meaning, moral reflection, appreciation	Coexistence of hedonic and eudaimonic elements	Hedonic: enjoyment and positive affect
Intended affective quality	Poignant, morally ambivalent	Bittersweet: warmth accompanied by an unavoidable sense of loss	Light-hearted, consistently positive
Central dilemma	Dying friend vs. son in danger	Son's family dinner vs. friend's recovery party	Son's celebration vs. friend's party
Outcome structure	Loss is unavoidable at both decision points	Loss at the first decision point; the second resolves positively either way	No loss at either decision point
Moral weight of choices	High: both decisions require giving something up, and the second concerns the welfare of a vulnerable other	Moderate: the first decision involves an unavoidable loss, while the second is positive either way	Low: both decisions concern social preference, with no adverse consequence
Intended experience	Reflection on relationships, loss, and responsibility	Enjoyment alongside a sense of what was given up	Relaxation and positive mood
Formative evaluation	Piloted with four older adults (1 M, 3 F): narrative appropriateness, text legibility, and pedalling resistance	Not separately piloted	Not separately piloted

Note. ENE = eudaimonic narrative-driven exergame; MNE = mixed-affective narrative-driven exergame; HNE = hedonic narrative-driven exergame. The following elements were held constant across all three conditions: the virtual environment, cycling route and duration, cycling time, and pedalling resistance. ANE and INE were additionally matched on the ratio of cycling to narrative time, the number of NPCs, the number of meaningful binary choice points, and the mode of narrative presentation.

a young woman escaping family violence, and players choose whether David invites her to join community volunteer work or tells her to take good care of herself.

Route B - Join Steven's party: David reconciles with Steven, who urges him to value the present and his relationship with Jim. Inspired, David adopts a positive outlook and later helps Jenny, now recovering, with players choosing whether David gives her some money as a gift or helps her find more job opportunities to make a living.

5.1.3. Condition 3: Hedonic Narrative-Driven Exergame (HNE)

The game's story takes place in a peaceful setting, where David will also make a choice. It's the night of Steven's party, and David had promised to attend. However, David's son Jim also received a new job offer, asking him to celebrate together today. David must choose between attending Steven's party and Jim's celebration.

Route A - Attend Jim's Celebration: David celebrates with Jim and later reconnects with Jenny, who offers to host a gathering. David must then decide whether the final event takes place at his home or Jenny's.

Route B - Attend Steven's Party: David joins Steven's party, strengthening family ties while Jim remains supportive. Later, Jenny invites him to her party, but it coincides with his niece's event, forcing him to choose between attending Jenny's party and his niece's event.

Figure 9 separately summarises how the initial choice determined the subsequent narrative branch and the branch-specific later choices across the three narrative conditions.

All conditions used the same virtual environment and the same physical layout. The two narrative branches differed in the order in which locations were visited: each branch followed a different sequence through the shared map, including a return segment along part of the same path. Figure 10 shows a top-down view of the environment with both traversal sequences indicated, together with the location of each NPC encounter and choice point. Because both branches traversed the same layout, cycling distance and visual complexity were comparable across branches.

5.2. Participants and Procedure

In Study 2, we recruited 36 new participants (17 female and 19 male) using the same criteria as in Study 1 to achieve a power of 0.80 ($alpha$=0.05, f^2=0.25). Participants had a mean age of 65 years (SD=5.4). Participants

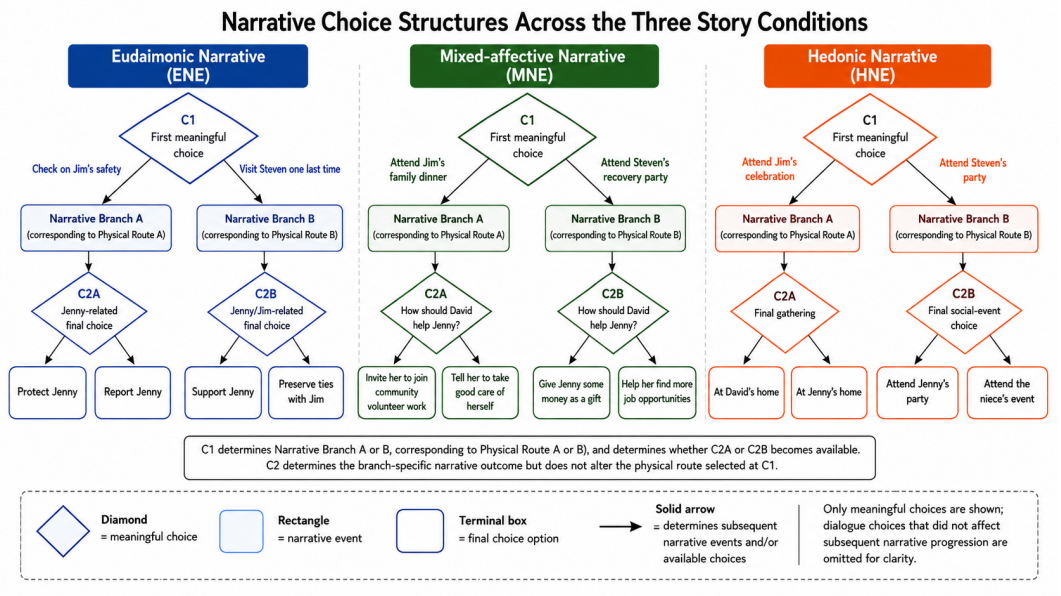


Figure 9: Branching choice structures across the three narrative conditions. The initial choice at C1 determined both the subsequent narrative events and which branch-specific second choice, C2A or C2B, became available. Terminal boxes represent the final options presented at C2. Only meaningful choices are shown; non-meaningful dialogue choices that did not alter subsequent narrative progression are omitted for clarity. Narrative Branches A and B correspond to physical Routes A and B, respectively.

were randomly assigned to one of three groups (12 per group) in a between-subjects design. Each session lasted approximately 40 minutes, for which participants received a £15 Love2Shop voucher. Participants played one version of the game for about 12 minutes, followed by the same questionnaires and interviews as in Study 1, with the addition of a flow scale in the questionnaire and an interview question about replay intentions and preferred contexts (see Figure 8).

Participants are coded as ENE for the eudaimonic narrative-driven exergame, HNE for the hedonic narrative-driven exergame, and MNE for the mixed version, each followed by an identifier (e.g., ENE-01).Baseline physical activity was not formally assessed or controlled for in Study 2.

5.3. Hypotheses

Building on related work and the findings from Study 1, we had the following hypotheses in Study 2:

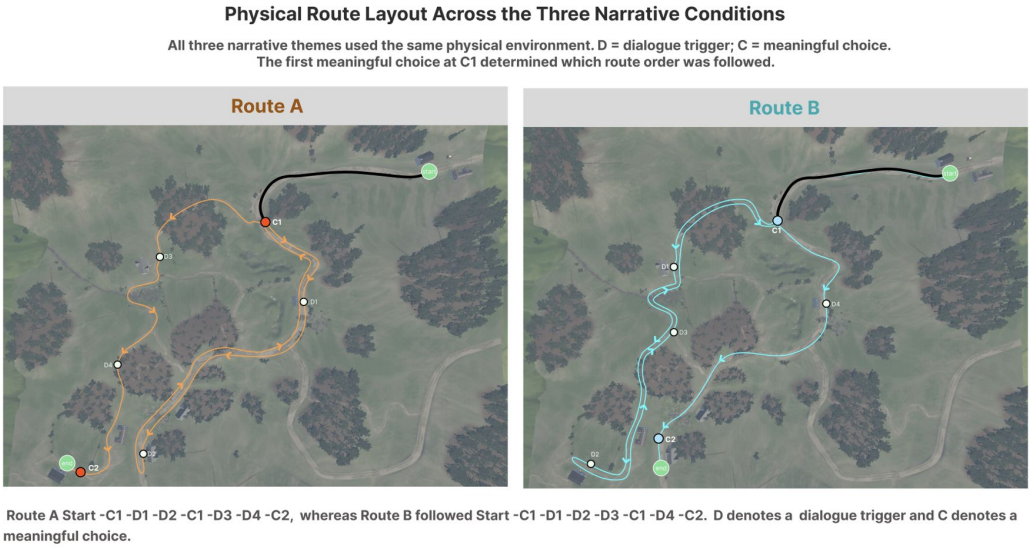


Figure 10: Top-down view of the shared virtual environment used in Study 2, showing the two traversal sequences corresponding to Narrative Branches A and B. Both branches traversed the same physical environment but visited the shared locations in different orders, including a return segment along part of the same path. D denotes a dialogue/NPC encounter, and C denotes a meaningful choice.

H5: Compared with the eudaimonic narrative theme (ENE), the hedonic (HNE) narrative theme provides lower perceived physical exertion during exergame play.

H6: Compared with the hedonic narrative theme (HNE), the mixed-affective (MNE) and eudaimonic (ENE) narrative themes elicit higher competence and relatedness satisfaction during exergame play.

H7: Hedonic and mixed-affective narrative themes (HNE and MNE) improve enjoyment as measured by IMI Interest/Enjoyment in exergames compared to the eudaimonic (ENE) theme.

H8: Hedonic and mixed-affective narrative themes (HNE and MNE) elicit higher flow compared to the eudaimonic (ENE) theme.

5.4. Quantitative Results: Player Experience

Shapiro-Wilk tests showed that the scores on the CORGIS, BANGS, and IMI questionnaires met the assumption of normality, thus a multivariate analysis of variance (MANOVA) was conducted on these data. Where a

Table 6: The MANOVA results for CORGIS, BANGS, and IMI. Means (Standard Deviations) are reported for each variable under the eudaimonic narrative-driven exergame (ENE), mixed-affective narrative-driven exergame (MNE), and hedonic narrative-driven exergame (HNE) conditions. F-values, corresponding p-values, and $\eta^2_{partial}$ values are provided to assess between-group differences.

Variable	McDonald's ω	ENE (SD)	MNE (SD)	HNE (SD)	F	p	$\eta^2_{partial}$
CORGIS - Cognitive challenge	0.896	4.83 (0.89)	4.14 (1.18)	3.78 (0.82)	3.603	**0.038***	0.179
CORGIS - Emotional challenge	0.892	5.21 (0.57)	4.35 (1.05)	3.06 (0.66)	22.713	**0.000*****	0.579
CORGIS - Physical challenge	0.867	4.65 (1.06)	3.52 (1.05)	3.60 (0.88)	4.775	**0.015***	0.224
CORGIS - Decision making	0.736	4.97 (0.73)	4.45 (1.19)	4.83 (0.72)	1.057	0.359	0.060
BANGS - Autonomy satisfaction	0.878	5.06 (1.73)	5.25 (1.17)	5.64 (0.66)	0.659	0.524	0.038
BANGS - Autonomy frustration	0.576	3.92 (1.42)	3.50 (1.03)	3.81 (1.08)	0.395	0.677	0.023
BANGS - Competence satisfaction	0.833	5.39 (0.90)	5.70 (1.00)	4.22 (1.17)	6.824	**0.003****	0.293
BANGS - Competence frustration	0.831	2.58 (0.64)	2.19 (0.85)	3.53 (1.35)	5.737	**0.007****	0.258
BANGS - Relatedness satisfaction	0.887	4.08 (1.17)	4.44 (1.64)	4.47 (1.02)	0.333	0.719	0.020
BANGS - Relatedness frustration	0.737	3.22 (0.95)	1.81 (0.77)	2.33 (0.83)	8.474	**0.001****	0.339
IMI - Interest/Enjoyment	0.877	3.93 (1.07)	5.63 (0.91)	5.17 (0.84)	10.345	**0.000*****	0.385
IMI - Perceived competence	0.912	4.85 (0.94)	5.20 (0.99)	3.78 (1.36)	5.290	**0.010***	0.243
IMI - Effort/Importance	0.759	4.67 (1.19)	5.67 (0.66)	5.46 (0.63)	4.465	**0.019***	0.213
IMI - Pressure/Tension	0.825	4.94 (0.74)	3.63 (1.45)	3.92 (1.29)	3.971	**0.028***	0.194

Note. Statistically significant adjusted p-values are shown in bold. *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

significant main effect was observed, we performed post-hoc tests, and used the Bonferroni method for p-value adjustments. However, the scores on the Flow questionnaire and the Borg RPE scale violated the normality assumption and were thus analysed using the Kruskal-Wallis test. Similarly, for any significant result, post-hoc tests with Bonferroni-adjusted p-values were conducted. Internal consistency of each factor was evaluated using McDonald's ω. All statistical tests were performed with a significance level of α=0.05. Tables 6 and 7 present the overall differences across the three game versions for Study 2, while Table 8 reports all Bonferroni-adjusted pairwise comparisons, including both significant and non-significant results.

Table 7: The table presents the results of the Kruskal-Wallis tests for flow and perceived exertion scores across the three game conditions. χ^2 and p-values are also reported to assess between-group differences.

Variable	McDonald's ω	ENE (SD)	MNE (SD)	HNE (SD)	χ^2	p
Flow	0.829	4.14 (0.76)	5.39 (0.85)	5.14 (0.86)	10.657	**0.005****
Borg RPE scale		4.83 (1.92)	2.32 (1.72)	2.93 (1.98)	8.810	**0.012***

Note. Statistically significant adjusted p-values are shown in bold. *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

Table 8: Bonferroni-adjusted pairwise comparisons between the ENE, MNE, and HNE conditions across all quantitative measures for Study 2.

	ENE–MNE		ENE–HNE		MNE–HNE	
Measure	**Difference (SE)**	**Adj. p**	**Difference (SE)**	**Adj. p**	**Difference (SE)**	**Adj. p**
CORGIS						
Cognitive Challenge	0.70 (0.40)	0.270	1.05 (0.40)	**0.038***	0.36 (0.40)	1.000
Emotional Challenge	0.86 (0.32)	**0.035***	2.16 (0.32)	**0.000*****	1.30 (0.32)	**0.001****
Physical Challenge	1.13 (0.41)	**0.027***	1.05 (0.41)	**0.045***	-0.08 (0.41)	1.000
Decision Making	0.52 (0.37)	0.512	0.13 (0.37)	1.000	-0.38 (0.37)	0.919
BANGS						
Autonomy Satisfaction	-0.19 (0.52)	1.000	-0.58 (0.52)	0.803	-0.39 (0.52)	1.000
Autonomy Frustration	0.42 (0.49)	1.000	0.11 (0.49)	1.000	-0.31 (0.49)	1.000
Competence Satisfaction	-0.31 (0.42)	1.000	1.17 (0.42)	**0.027***	1.47 (0.42)	**0.004****
Competence Frustration	0.39 (0.40)	1.000	-0.94 (0.40)	0.078	-1.33 (0.40)	**0.007****
Relatedness Satisfaction	-0.36 (0.53)	1.000	-0.39 (0.53)	1.000	-0.03 (0.53)	1.000
Relatedness Frustration	1.42 (0.35)	**0.001****	0.89 (0.35)	**0.046***	-0.53 (0.35)	0.416
IMI						
Interest/Enjoyment	-1.70 (0.39)	**0.000*****	-1.23 (0.39)	**0.009****	0.47 (0.39)	0.706
Perceived Competence	-0.35 (0.45)	1.000	1.07 (0.45)	0.075	1.42 (0.45)	**0.011***
Effort/Importance	-1.00 (0.35)	**0.023***	-0.79 (0.35)	0.095	0.21 (0.35)	1.000
Pressure/Tension	1.31 (0.49)	**0.034***	1.02 (0.49)	0.134	-0.29 (0.49)	1.000
Flow	-13.33 (4.29)	**0.006****	-10.42 (4.29)	**0.046***	-2.92 (4.29)	1.000
Borg RPE Scale	-12.25 (4.28)	**0.013***	-9.00 (4.28)	**0.035***	-3.25 (4.28)	1.000

Note. For CORGIS, BANGS, and IMI, differences were calculated as the mean of the first condition minus the mean of the second condition. For Flow and the Borg RPE scale, differences represent pairwise differences in mean ranks following the Kruskal-Wallis tests, oriented as the first condition minus the second condition. Standard errors are shown in parentheses. All reported p-values were adjusted using the Bonferroni correction. Statistically significant adjusted p-values are shown in bold. *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

5.4.1. Perceived Challenge

On the CORGIS scale, significant main effects were found on the dimensions of cognitive, emotional, and physical challenge (see Table 6 and Figure 11). Participants in the ENE condition reported significantly higher scores in both emotional challenge (ENE: M=5.21, SD=0.57; MNE: M=4.35, SD=1.05; HNE: M=3.06, SD=0.66) and physical challenge (ENE: M=4.65, SD=1.06; MNE: M=3.52, SD=1.05; HNE: M=3.60, SD=0.88) compared to the other two conditions. Furthermore, cognitive challenge levels were significantly higher in the ENE condition (M=4.83, SD=0.89) than in the HNE condition (M=3.78, SD=0.82), while no significant difference was observed between the ENE and MNE conditions. In contrast, the MNE condition (M=4.35, SD=1.05) showed a significant increase in emotional challenge compared to the HNE condition (M=3.06, SD=0.66), with no significant differences between the two conditions in cognitive or physical challenge. No main effect was found on the decision making dimension.

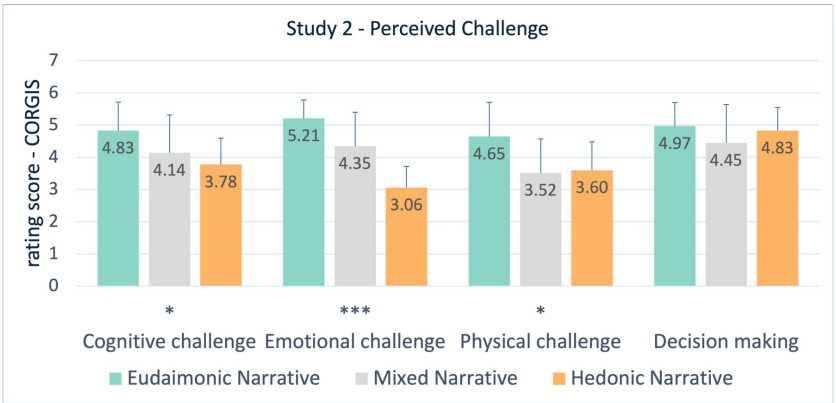


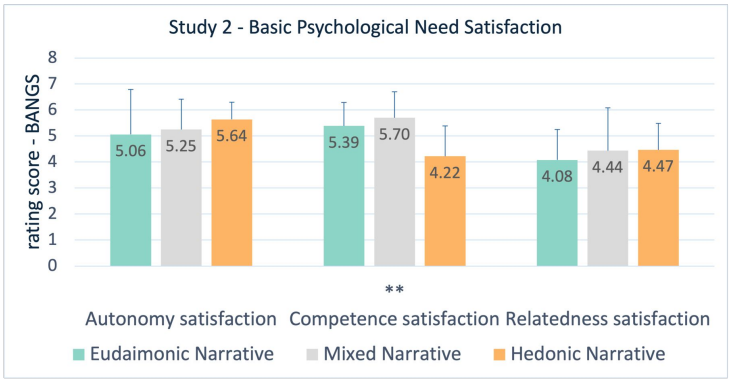
Figure 11: Mean perceived challenge scores across four CORGIS dimensions in Study 2 (N=36, between-subjects). ENE = Eudaimonic Narrative Exergame (n=12), MNE = Mixed-affective Narrative Exergame (n=12), HNE = Hedonic Narrative Exergame (n=12). Error bars represent standard deviations. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

5.4.2. Basic Psychological Needs in Games

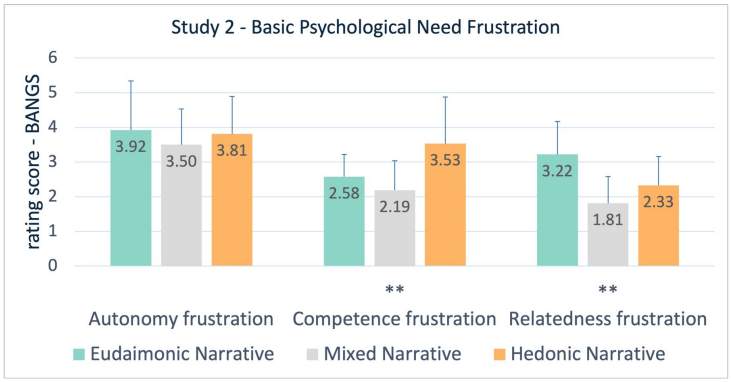
The results of a MANOVA on the BANGS showed significant main effects on the dimensions of competence satisfaction, competence frustration, and relatedness frustration (see Table 6 and Figure 12). The competence satisfaction levels was significantly higher in both the MNE condition (M=5.70,

SD=1.00) and the ENE condition (M=5.39, SD=0.90) compared to the HNE condition (M=4.22, SD=1.17). Competence frustration also differed across conditions, with the HNE condition (M=3.53, SD=1.35) reported significantly higher levels than the MNE condition (M=2.19, SD=0.85). No significant differences were found between the ENE and HNE conditions for competence frustration, nor between the ENE and MNE conditions in competence satisfaction and frustration. In terms of relatedness frustration, the ENE condition (M=3.22, SD=0.95) showed significantly higher levels than both the MNE condition (M=1.81, SD=0.77) and HNE condition (M=2.33, SD=0.83), while no significant difference was found between the MNE and HNE conditions. In addition, no significant main effects of the narrative theme were found on autonomy satisfaction and frustration, or relatedness satisfaction.

Therefore, H6 was partially supported. Specifically, the predicted effect was observed for competence satisfaction, whereas only partial evidence was found for relatedness satisfaction.



(a) Psychological need satisfaction



(b) Psychological need frustration

Figure 12: BANGS scores for psychological needs in Study 2 (N=36, between-subjects). (a) Need satisfaction across autonomy, competence, and relatedness dimensions. (b) Need frustration across the same three dimensions. Each condition n=12. Error bars represent standard deviations. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

5.4.3. Intrinsic Motivation

Main effects of the narrative themes on four IMI subscales were significant (see Table 6 and Figure 13), including interest/enjoyment, perceived competence, effort/importance, pressure/tension. For the interest/enjoyment results, both the MNE condition (M=5.63, SD=0.91) and the HNE condition (M=5.17, SD=0.84) were significantly higher than the ENE condition (M=3.93, SD=1.07), with no significant difference found between MNE and HNE. We therefore accept H7. In terms of perceived competence, the MNE condition (M=5.20, SD=0.99) was significantly higher than the HNE condition (M=3.78, SD=1.36), consistent with the results of the satisfaction of competence obtained in the BANGS scale. No significant differences were found between ENE and HNE or between ENE and MNE on perceived competence. For effort/importance, the MNE condition (M=5.67, SD=0.66) was significantly higher than the ENE condition (M=4.67, SD=1.19). In contrast, the MNE condition (M=3.63, SD=1.45) reported a significantly lower level of pressure/tension than the ENE condition (M=4.94, SD=0.74). No significant differences were found between MNE and HNE or between ENE and HNE on both effort/importance or pressure/tension.

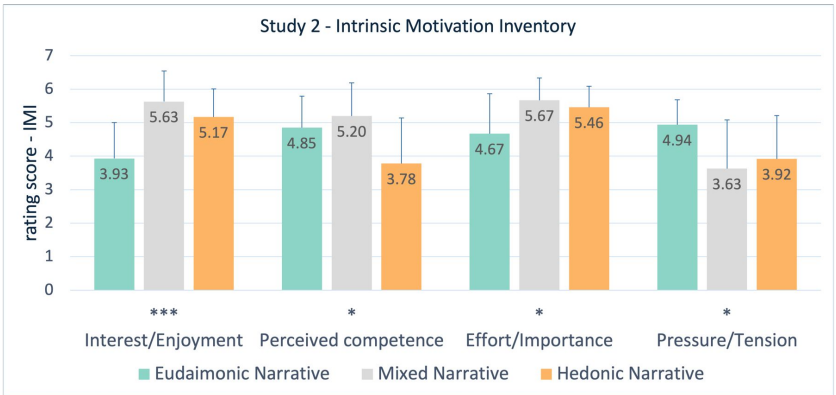


Figure 13: Intrinsic Motivation Inventory (IMI) scores across four subscales in Study 2 (N=36, between-subjects). Each condition n=12. Error bars represent standard deviations. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

5.4.4. Flow

The main effect of the narrative themes on the state of flow was significant (see Table 7 and Figure 14). Specifically, participants in the MNE condition

(M=5.39, SD=0.85) and the HNE condition (M=5.14, SD=0.86) reported significantly higher flow compared to the ENE condition (M=4.14, SD=0.76), while no significant difference was found between MNE and HNE. Therefore, H8 was accepted.

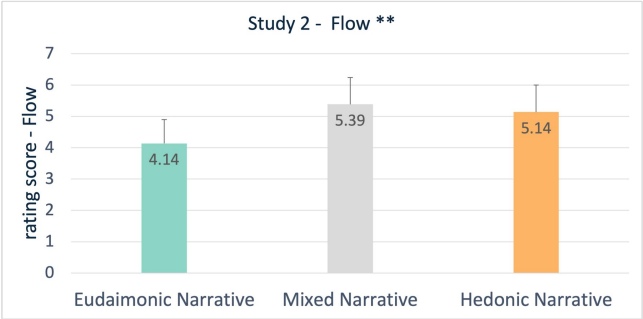


Figure 14: Flow experience scores (9-item Flow Scale) in Study 2 (N=36, between-subjects). Higher scores indicate stronger flow states characterised by immersion and enjoyment. Each condition n=12. Error bars represent standard deviations. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

5.4.5. Perceived Exertion

A significant main effect of the narrative themes was found on the Borg RPE Scale (see Table 7 and Figure 15). Participants in the ENE condition (M=4.83, SD=1.92) reported significantly higher perceived exertion compared to those in the MNE condition (M=2.32, SD=1.72) and HNE condition (M=2.93, SD=1.98). However, no significant difference was found between MNE and HNE. There, H5 was accepted.

5.5. Qualitative Results: Feedback and Suggestions for Future Game Design

Most procedures were consistent with those in Study 1. However, in Study 2, qualitative data was obtained from three different groups of participants. For each group, the first and second authors independently coded the responses to each question. This procedure was designed to capture variations in how different groups addressed the same set of questions. Through the reflexive thematic analysis of the data collected in Study 2, three distinct themes were constructed to examine how narrative exergaming interacts with user needs and physical realities. The analysis reveals a complex dynamic where narrative content is not merely an addition to exercise, but a tool for satisfying diverse psychological and physical needs.

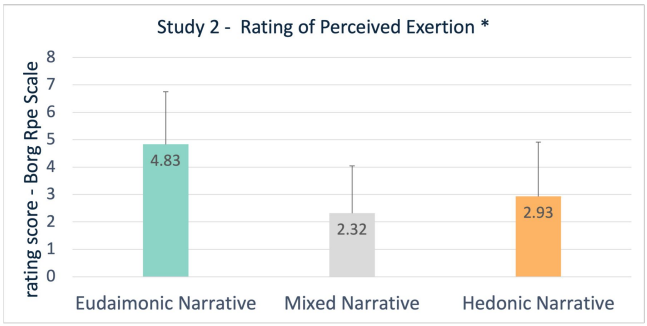


Figure 15: Borg Rating of Perceived Exertion (RPE CR-10 scale) in Study 2 (N=36, between-subjects). The scale ranges from 0 (no exertion) to 10 (maximal exertion). Each condition n=12. Error bars represent standard deviations. Asterisks indicate the significance of the overall test across the three conditions: *** for $p < 0.001$, ** for $p < 0.01$, and * for $p < 0.05$.

5.5.1. Theme 1: Beyond Functionality: From Physical Exertion to Psychological Connection

This theme captures how participants experienced narrative-driven exergames as extending exercise beyond physical functionality to include psychological meaning and connection under conditions of physical exertion. One of the key findings identified in the qualitative data was that participants perceived the game as offering value beyond simple physical functionality, specifically through a shared physical and psychological drive. The analysis suggests that the combination of narrative and exercise created a dual training effect that was significantly more attractive than traditional workouts. Participants noted that this "fresh" experience not only regulated their emotions but also helped maintain focus (ENE-02). As one participant explained, the narrative structure "helped me stay focused, stopping my mind from drifting off to other things while exercising" (HNE-10). This engagement led others to view the system not just as a game, but as having "the potential to become part of a lifestyle" (MNE-09). Across all three narrative versions, the narrative games consistently provided a shared sense of novelty, proving to be more attractive than traditional exercise.

Beyond general engagement, the different version of narrative provided the exercise with deeper meanings, ranging from educational reflection to social connection. Specifically, the eudaimonic elements led older participants to perceive the ethical dilemmas presented in the game as having educational value grounded in real-world relevance. Despite the serious nature of the

story, participants found it beneficial, with one noting:

> *"We should all be thinking about death and morality. Honestly, these games can teach me a lot.They're potentially even helpful tools for certain careers, like if you're a cop"* (ENE-09).

In contrast to the profound moral reflection elicited by the ENE version, the MNE version fostered a more intimate emotional bond. In this case, the value shifted from abstract ethics to personal companionship. Through the narrative's emotional arcs, participants established vivid "social connections", which acted as a buffer against isolation:

> *"The characters in the game almost felt like they were keeping me company... Having a game like this means you can still feel that sense of companionship even if you can't get out"* (MNE-11).

Distinct from other experiences, the HNE version was characterised by playfulness and social appeal. Rather than prompting deep reflection or intimacy, this version boosted the appeal of exercise through pure immersion and entertainment, allowing users to "totally forget" the physical exertion. This lighter tone also sparked a desire for external social interaction: "I'd probably be down to play it with my friends if it was set in a pub... It'd definitely be way more fun to do it as a group" (HNE-07).

5.5.2. Theme 2: Emotion and Pragmatism: Balancing Physical Reality with Narrative Immersion

This theme reflects how participants negotiated narrative immersion in relation to physical comfort, device constraints, and emotional demands during exergame play. The data indicates that user engagement is fundamentally grounded in an 'experience baseline' determined by the interplay between physical device limitations and physiological responses. Issues such as the lack of realistic controls or physiological discomfort were found to hinder the experience. For instance, one participant suggested the need for more complex interactions to mimic reality:

> *"The bike could use more controls. If I could actually turn or do more moves, it would feel way more like real cycling"* (MNE-10).

Others noted that physical side-effects, such as heat or nausea, could disrupt engagement, with one participant stating that the headset "started feeling

pretty hot... and that definitely affected my experience a bit" (ENE-05), while another said: "I struggled with a bit of motion sickness, though... which kinda ruined the experience for me" (HNE-09).

In addition, different narrative themes also appeared to influence participants' sense of immersion. We found that narratives could evoke a range of emotional experiences, and consistent with Study 1, eudaimonic version may trigger negative emotions that users find overwhelming. These negative emotions potentially reduced players' subjective willingness to remain immersed in the game. One participant shared a poignant example where the storyline evoked painful memories:

> *"The game is good, but I don't want to play it again because it reminds me of my wife who passed away"* (ENE-01).

In contrast, when balanced correctly, emotional variability-mixing pragmatic struggles with hedonistic resolution appeared to deepen immersion. Participants described a sense of flow state where "time flies," noting that while the story had "ups and downs," the positive resolution "totally surprised me in a good way" (MNE-08). However, when the experience becomes overly light or purely hedonic, the sense of immersion tends to decline. Some participants felt that without sufficient challenge, the activity lost its appeal:

> *"This game feels a little too easy for me. Everything's going so smoothly right now that it's actually kind of boring"* (HNE-02).

5.5.3. Theme 3: Barriers to Engagement and the Desire for Universality

This theme captures cross-cutting factors that shaped participants' engagement across narrative conditions, highlighting shared constraints and preferences related to interaction complexity, familiarity, and inclusivity. Beyond the differences between game versions, participants across all conditions described aspects of their gameplay experience that related to the optimisation of design details and interaction mechanisms, regardless of the specific narrative content. These data reveal a set of universal design considerations on narrative-driven exergames, which may be closely tied to player motivation and overall experience.

A primary, cross-cutting concern was the need to optimise cognitive load and interaction modes. The data suggested that simplifying the interface and reducing text-heavy dialogue were essential for improving the physical experience, irrespective of the story type. Participants noted that excessive text

was physically draining, as one user explained, "I feel like there's just way too much text in the game. Sometimes it actually makes me feel drained" (ENE-12). Instead of information overload, participants expressed a universal preference for more dynamic engagement, suggesting "fun interactions... or even some meaningful choices" (MNE-11).

To increase engagement further, particularly for older adults, the data highlighted a shared desire for increasing familiarity. Participants across different conditions expressed a wish for game environments that connected to their real lives. Suggestions included blending in real-world locations, such as recreating "our own streets and community" or familiar vacation landscapes, to help users "feel even more connected" (MNE-07). This desire for real-world connection extended to narrative themes, with participants suggesting that including "political topics" would facilitate social discussion among friends (ENE-05).

Regarding gameplay mechanics, participants called for a multi-mode design framework to accommodate diverse preferences found within the broader population. The suggestions ranged from an "exploration mode" focused on puzzle-solving (ENE-07) to competitive modes that trigger motivation, with one user noting they would "speed up just to pass" a rival character (MNE-06). Additionally, participants proposed technological enhancements such as voice input to replace typing, with one stating, "I'd really like to talk to the characters using my actual voice" (HNE-08).

Finally, the analysis emphasised the necessity of cultural localisation and sensitivity as a baseline for universal applicability. To ensure the game is accessible to all demographics, participants emphasised the need for careful language selection. For instance, a community worker pointed out that specific terms could be alienating, noting that "some of the words in the game could upset older adults, stuff like calling people 'old' " (HNE-09).

In summary, these three themes highlight that while narrative-driven exergames have the potential to satisfy physical and psychological needs, the quality of this experience is heavily dependent on the interplay between the narrative's emotional resonance, the user's physical reality, and hardware constraints. The data suggests that different narrative versions serve different motivational needs, while their effectiveness is inevitably shaped by these pragmatic factors. Therefore, to sustain engagement across a wider demographic, future design could prioritise inclusivity, lowering cognitive barriers, and offering diverse interaction modes. Synthesising our results, the following section presents three core findings.

5.6. Study 2: Key Findings

Finding 1. Hedonic narratives suggest higher motivation and lower perceived exertion. Participants in the HNE condition reported higher intrinsic motivation and flow than those in the ENE condition. The hedonic narrative also reduced perceived exertion, making exercise feel easier and more enjoyable. These results suggest that hedonic narratives may encourage broader exergame participation, especially for older adults who lack motivation or prefer a more relaxed experience. Qualitative findings indicated that pleasant, familiar themes, like cycling with friends, increased willingness to continue. However, the lack of tension in this narrative led to the lowest competence satisfaction. Qualitative findings further showed that participants desired more appropriate challenges to support their enjoyment, highlighting a trade-off between accessibility and achievement.

Finding 2. Eudaimonic narratives provide profound experience and moral reflection. In contrast, the ENE condition was associated with higher cognitive and physical challenge, as well as lower willingness to replay the game. Participants also reported lower flow and higher relatedness frustration, indicating more frequent feelings of disconnection and a more negative evaluation of the game. However, this narrative was particularly effective in providing intense emotional experiences and a sense of competence. In addition, it may be particularly valuable in educational contexts that aim to foster ethical reflection and critical thinking, by encouraging users to engage more deeply with morally complex situations.

Finding 3. A mixed-affective narrative is associated with better engagement by balancing motivation and demands. The MNE condition uniquely combined the benefits of both other themes, offering a relaxed cycling experience by reducing cognitive and physical pressure, while maintaining a moderate emotional challenge. Participants reported higher intrinsic motivation and flow compared to the eudaimonic narrative, while also benefiting from parasocial interaction and companionship through hedonic elements. This balance shows that the mixed narrative may achieve positive psychological, emotional, and social outcomes for players without compromising enjoyment or emotional experience.

6. Discussion

This research investigated the role of narrative design in optimising VR exergames for older adults. Our empirical results reveal that the effective-

ness of these interventions relies heavily on balancing narrative interactivity and narrative theme. Study 1 results suggest that interactive narratives can successfully distract from physical exertion and enhance psychological need satisfaction through agency, albeit at the cost of increased emotional and cognitive demand. Study 2 further clarifies that while hedonic themes promote flow and eudaimonic themes foster deep reflection, a mixed-affective approach can offer a more effective trade-off between intrinsic motivation and competence satisfaction. The following sections discusse these findings to examine the interplay between older participants' psychological experiences and self-reported physical experiences.

6.1. The Potential of Interactive Narrative in VR Exergames

Declines in mobility can contribute to social isolation in older adults and limit their participation in group activities [83]. However, cycling-based exergames offer a valuable home-based exercise option. Previous studies indicate meaningful functional and experiential benefits [49, 77, 84] while avoiding reliance on external companions or suitable outdoor environments. Our research provides early empirical evidence that interactive narrative can function as a core design mechanism in VR cycling exergames.

Study 1 indicated that, compared to the non-narrative condition, both styles of eudaimonic narratives elicited higher levels of emotional challenge among older adults. This finding is consistent with Artsch and Hartmann's [85] results in non-exergame contexts. However, our results also highlight that certain eudaimonic narratives can also evoke emotional distress (e.g., painful memories), suggesting the need for careful consideration of emotional safety thresholds during game design. Kümpel and Unkel [82] further reported that eudaimonic experiences in digital games can increase cognitive challenge and relatedness satisfaction. However, our results suggest that within older adults' exergaming contexts, these effects may depend strongly on narrative style. Increases in cognitive challenge and relatedness satisfaction emerged only in the interactive narrative condition, not in the auto-narrative condition. Qualitative findings also imply that interactive choices in INE foster a sense of agency, which could be a prerequisite for the enhanced cognitive engagement and social connection observed.

Moreover, Zhou et al. [19] concluded that emotional challenge-based interactive narrative elements can elevate perceived physical challenge in older adults, which was also manifested in our results. Meanwhile, our findings

suggest that interactive narrative exergames may significantly lower players' perception of physical exertion, as indicated by the lower RPE scores.

This effect may reflect a psychological reframing of motivation induced by the INE experience. Whereas NNE often require players to focus on repetitive body movements [81], INE may draw players' focus toward narrative decisions while exercising, potentially making the exercise feel subjectively easier. However, the present data cannot determine whether the observed differences in perceived exertion reflected differences in participants' actual physical effort, differences in their perception of comparable physical effort, or a combination of both. Prior work has shown that perceived exertion can be influenced by psychological states without corresponding changes in conventional physiological responses [86, 87]. Interactive narratives offer a means of optimising information while maintaining narrative engagement, making it a potentially supportive engagement approach for individuals with cognitive vulnerabilities who may struggle with processing large amounts of information (e.g., older adults with ADHD).

Prior work suggests that narrative content supports exergame enjoyment[31, 53], However, Study 1 did not reveal higher enjoyment or intrinsic motivation in the two narrative conditions. This may align with Waterman and colleagues' [88] view that intrinsically motivated activities are accompanied by both hedonic enjoyment and eudaimonia. Notably, the interactive narrative version produced higher autonomy and relatedness satisfaction, consistent with findings reported by Zhou et al. [19] in non-exertion settings. These results highlight the potential of designing interactive narrative mechanisms for exergames to engage both PA and psychological needs in older adults.

Interestingly, while the INE condition scored higher competence satisfaction on the BANGS scale, perceived competence on the IMI was highest in the NNE condition. Competence satisfaction in BANGS reflects feelings of progress and achievement, while the IMI's perceived competence scale assesses whether the player is good at the game [19]. Therefore, for exergames, interactive narratives may offer a promising means of improving older adults' exercise experiences.

6.2. Understanding Different Narrative Themes in VR exergame

Our research is among the first to explore how older adults' player experience and motivation in a VR exergaming environment relate to interactive narratives on three themes: eudaimonia, hedonia, and a hybrid of

both. Consistent with Bartsch and Hartmann [85], the ENE version provided higher perceived cognitive and emotional challenge. Prior research suggests that eudaimonic experiences can provide greater competence and relatedness satisfaction. However, in the context of exergaming, the ENE condition increased competence satisfaction only. Eudaimonic experiences that emphasise meaning and long-term importance are particularly effective in fostering self-realisation and feelings of competence [29].

Although previous work tended to highlight the positive experiences associated with eudaimonia [89], our results showed that this may introduce physical and relatedness-related challenges within exergame contexts. As qualitative data revealed, the negative emotional experiences sometimes induced by the ethical dilemmas presented in eudaimonic narrative might lead players to feel a sense of rejection or distancing from the in-game characters. Furthermore, simultaneously imposing high cognitive and physical demands may divert older adults' attention away from the storyline and influence their flow state. Understanding narrative competes for resources required for physical execution, while negative emotions may contribute to higher perceived exertion [87]. Participants in the ENE condition also reported lower levels of narrative immersion and a greater tendency to experience dizziness. This finding aligns with Weech et al.'s work [90], which suggests a negative correlation between presence and cybersickness in rich narrative contexts. Given that eudaimonic elements in exergames can elicit strong psychological responses and heightened perceived physical demands, such designs may be well suited to specific contexts (e.g., police training). However, for broader older adult populations, careful calibration is required to avoid demotivation.

In contrast, hedonia emphasises aspects of gameplay related to joviality and serenity [29]. Hedonic enjoyment could arise from the quick and intuitive processing of content that satisfies salient needs and moral intuitions without imposing cognitive conflict [91]. Therefore, games with low cognitive demand may be perceived as more enjoyable than those that require more cognitive effort [85]. Our findings extend this insight to the exergaming context. Consistent with the findings from the INE condition in Study 1, participants in the HNE condition expressed intentions to engage in such games with others in the future. This supports the potential of interactive narratives in multiplayer exergame contexts, independent of specific narrative themes. Our findings further suggested that hedonic themes may amplify this advantage. This trend may stem from the pleasurable experiences such narratives provide, which help reduce perceived participation costs and provide the game

with higher appeal and acceptability. Because competence satisfaction could not be central to hedonic digital experiences [29], players in such exergames perceived relatively low overall levels of challenge. However, Cole et al. [48] concluded that some form of challenge is essential for sustained game engagement. Accordingly, exergames with purely hedonic narratives may face challenges in sustaining sufficient intrinsic motivation and engagement in older adults.

Although the eudaimonic contents in the MNE version elicited stronger emotional challenge than the HNE version, they did not increase cognitive challenge. As a result, the MNE version was also associated with higher enjoyment. This finding suggests that, compared to eudaimonic elements that impose higher emotional and cognitive demands, narratives that maintain a moderate cognitive load and facilitate flow may help reduce perceived exertion. Interestingly, prior research has suggested that both hedonic and eudaimonic experiences are associated with higher relatedness satisfaction [82]. However, our findings show that although the ENE version increased relatedness frustration, relatedness satisfaction did not differ in the three themes. This discrepancy may arise because physical exertion consumes limited attentional resources. This resource scarcity constrains emotional processing, thereby dampening the differential effects of narrative themes on relatedness. Conversely, integrating hedonic and eudaimonic themes may facilitate adaptive emotional regulation [92]. This balance supports attentional allocation, allowing players to draw on hedonic enjoyment to buffer distress and prevent emotional overload that may arise from excessive eudaimonic content.

Existing literature has emphasised the difficulty of integrating narrative with motion-based gameplay in exergaming [81]. Achieving coordination between physical and psychological engagement is considered essential for designing narrative-based exergames. Our observations suggest that MNEs may offer a promising design solution, as they reduce perceived exertion while allowing emotional engagement. Mekler and Hornbæk [29] suggest that hedonic and eudaimonic experiences are not mutually exclusive but can co-exist within a unified design framework. This suggests that combining hedonic and eudaimonic elements may be a useful direction for designing immediate exergame experiences. Whether this balance can support repeated participation over time remains an open question.

6.3. Sustaining Narrative-Driven Exergames Across Repeated Sessions

Both studies examined participants' immediate experiences within a single VR exergame session. For long-term use, narrative themes need not remain fixed across all exercise sessions. However, the dominant affective orientation could be selected according to users' preferences and the intended design goals, while multiple sessions collectively form a short story arc rather than requiring a new campaign for each session. For example, the dominant affective orientation could vary across sessions according to users' preferences and intended design goals, with mixed-affective, hedonic, or eudaimonic narratives serving different purposes. Choices made in one session could be acknowledged in subsequent sessions through variations in NPC dialogue, relationship development, or optional encounters, before the main storyline reconverges. This structure could preserve continuity and agency while keeping the number of authored branches manageable. Different affective content could also be introduced selectively at particular milestones, for example, as optional side episodes or time-limited events, allowing the emotional experience to vary over time without requiring separate full-length campaigns. Large language models may support this structure by generating personalised recaps and low-stakes dialogue variations from curated templates, drawing on users' earlier choices and activity preferences [93]. However, such generated content should remain constrained by human-authored narrative rules and subject to human review. Although this structure may help address the volume of content required, it does not resolve the broader concern that engagement with any single game tends to be time-limited. We note that commercially successful titles may sustain engagement for sixty to ninety days [94]. Narrative-driven exergames may therefore be better positioned to support the initiation of previously avoided physical activity, while whether such engagement contributes to habit formation or longer-term maintenance requires longitudinal investigation.

6.4. Design Guidelines of Narrative-driven VR Exergame for Older Adults

Based on our findings, we offer four design guidelines for integrating narrative elements with the exergame to promote the synergistic physical and mental engagement of the older adults.

6.4.1. Balance Dual Engagement: From Singular Tasks to Holistic Experiences

Effective exergame design for older adults should move beyond the singular goals of physical training toward a model of dual engagement. Given our finding that agency drives engagement, future game designs may leverage branching narrative structures and incorporate meaningful player choices. This can be achieved by integrating critical decision points that steer the narrative's progression. Additionally, introducing options that deliberately diverge from the main plot can enrich game experiences. To balance exertion with immersion, we recommend developing physiologically adaptive narrative systems. For example, when players are energised, the narrative may present more challenging tasks, whereas detection of fatigue could trigger a shift toward lower-intensity, slower-paced content, providing both physiological and cognitive relief. Achieving the balance between narrative engagement and structured exercise is key to fostering both physical and psychological well-being.

6.4.2. Strategically Design Narrative Themes for Targeted Goals

Strategic selection of narrative themes is as critical as including a narrative at all, as different themes serve distinct design goals. Our findings suggest that hedonic narratives are well-suited for lowering entry barriers, particularly for older adults who are less motivated or prefer relaxed experiences. Such narratives can centre on joyful life moments, such as cycling with friends, family trips, or memorable hikes. Furthermore, designers can add some challenges (e.g., some uphill routes or timed tasks) to enhance players' enjoyment and sense of accomplishment during gameplay. In contrast, eudaimonic narratives can be developed around deeper social themes, such as moral dilemmas, regrets, or thought-provoking societal events. Such games could be situated within contexts aimed at easing intergenerational tensions. However, designers should avoid overly heavy themes (e.g., bereavement) or provide a "skip" option to maintain an appropriate balance between emotional and physical experiences. Specifically, given that deep emotional processing consumes substantial cognitive resources, eudaimonic narratives should be paired with low-intensity exercise or longer breaks to prevent cognitive overload. Meanwhile, careful attention to language is essential, terms such as "old" should be avoided to prevent causing offense. Moreover, mixed-affective narrative-driven exergames show promising opportunities for psychological and physical interventions among older adults. By

integrating narratives that mix moving and humorous elements, such games could elicit enjoyment while fostering deeper social reflection and empathy [95]. Providing narrative scenarios tailored to players' activity preferences (e.g., a skiing holiday) may further strengthen hedonic experiences and feelings of self-actualisation, thereby enhancing intrinsic motivation [88].

6.4.3. Minimise Cognitive Load to Ensure a Smooth Experience

Unlike traditional games, exergames require players to manage both physical exertion and information processing. Our findings show that overly complex narratives risk cognitive overload, increasing perceived difficulty and potentially leading to negative experiences for older adults. Designers should therefore simplify narrative understanding to reduce cognitive load, such as using progressive disclosure [96], and incorporating interactive milestones in the interface (e.g., displayed unobtrusively in a corner of the screen), allowing older adults to revisit key events whenever they need support or reassurance. In addition, designers should also simplify narrative understanding by shifting from text-heavy formats to multisensory methods, e.g. using audio cues or color changes to create relaxed or tense atmospheres, or incorporating character relationship diagrams and animations to convey complex backstories. Employing iterative game design frameworks such as the MDA model [97] may further help sustain players' attention, which has been applied in exergame design [60]. Finally, we recommend adopting familiar real-world elements (standard road signs, known destinations) for navigation, effectively minimising memory burden.

6.4.4. Personalised Adaptation for Heterogeneous Capabilities and Engagement

Older adults are a heterogeneous group with diverse physical abilities as well as varying gameplay and narrative preferences. Effective exergames must therefore offer adaptable options to accommodate these individual differences. Designers should provide adjustable exercise intensity, ranging from low-impact modes (e.g., walking [98, 99]) for less active individuals to higher-intensity settings (e.g., VR boxing [100]) for those seeking greater challenge. Furthermore, the game should support multiple modes (e.g., solo roaming, cooperation, competitive) and scale from single-player to synchronous multiplayer. Session structure should be equally flexible: daily routines can be concise, presenting a single chapter per session, whereas professional training could span a full storyline, requiring players to collaborate with a virtual

coach whose personality can be customised. Moreover, incorporating nostalgic themes [101] or familiar real-life settings can strengthen players' emotional resonance, and designs could further enable players to create their own stories or share memories. Finally, integrating natural interaction modalities such as voice dialogue [102], or even allowing users to integrate their own voice, could reduce the learning curve and foster a stronger sense of mastery and enjoyment.

6.5. Limitations

First, our participants were predominantly 'younger-old' adults with intact cognitive function. Consequently, our findings are most relevant to this specific demographic and should be generalised with caution. We acknowledge that the dual-task demands of interactive narratives may prove detrimental for those with cognitive impairments (e.g., MCI), where excessive cognitive load could compromise engagement or safety. Future designs for vulnerable groups should therefore prioritise minimised cognitive friction.

Second, we acknowledge the limited sample size, particularly in the between-subjects design of Study 2 (N=36). While we observed certain statistical trends, the quantitative results should be interpreted as preliminary indicators rather than definitive population parameters. To mitigate this limitation, we employed a mixed-methods approach; qualitative insights derived from reflective thematic analysis provided contextual depth to our quantitative observations, offering a more holistic understanding of user experience trends despite the statistical constraints. In addition, the Study 2 narrative themes were theory-informed but were not independently validated, limiting our ability to confirm that participants perceived the intended thematic distinctions.

Third, our prototype relied on a stationary bike, which may constrain the applicability of the design outcomes. Thus, we encourage future research to explore a wider range of exergame genres and interactive systems to investigate how these principles might be applied to a broader spectrum of physical activities, thereby enhancing their overall value.

Finally, as an exploratory study, our investigation relied on a single-session evaluation and self-report measures. Therefore, our findings primarily reflect acute subjective experiences, such as perceived exertion and immediate motivation, rather than sustained physiological or health benefits. Without objective measures (e.g., heart rate, cycling power, or cadence), we cannot distinguish actual from perceived effort. Simulator sickness in

Study 1 was monitored through participant self-report and researcher observation rather than a standardised questionnaire, limiting systematic assessment of symptom severity. In Study 2, baseline physical activity was not formally assessed or controlled, and potential baseline differences may therefore have influenced perceived exertion and motivation. Future longitudinal studies should combine subjective and psychophysiological measures to assess whether these effects translate into long-term health outcomes.

7. Conclusion

This research explored design strategies for narrative-driven exergames and their potential to address both the PA and psychological needs of older adults. Through a within-subjects experiment in Study 1 (N=15), we observed that participants reported broad psychological need satisfaction when playing the VR exergame in an interactive-narrative style. This style was associated with positive engagement despite perceived higher cognitive and physical demands compared to non-narrative and auto-narrative conditions. Our findings further highlighted the potential influence of narrative theme and complexity on older adults' motivation and experience in exergames. Based on this, the exploratory findings from a between-subjects experiment in Study 2 (N=36) suggested that eudaimonic narratives may foster strong emotional experiences and support competence satisfaction, while hedonic narratives were associated with higher flow, intrinsic motivation, and lower cognitive load. Mixed-affective narratives appeared to offer balanced benefits across emotional, physical, and social domains, potentially promoting older adults' engagement. Together, these initial insights illustrate how hedonic, eudaimonic, and mixed-affective narrative approaches could serve different design contexts. To bridge these findings with practical application, we propose four core design guidelines: (1) balancing dual engagement through adaptive narrative exergame systems; (2) strategically selecting themes aligned with specific motivational goals; (3) minimising cognitive load through multisensory and familiar interaction designs; and (4) enabling personalised adjustments to accommodate older adults' diverse physical and cognitive abilities. These guidelines can assist game designers and healthcare professionals in developing more inclusive and psychologically informed digital interventions that motivate older adults to exercise while supporting their needs for autonomy, competence, and social relatedness.

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