

From Lab to Living Room: Creating Sustained Engagement in Cognitively Beneficial Exergames through Pattern Languages

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Exergames are among the most consistently promising cognitive interventions for older adults. Unfortunately, the promise of exergame success in laboratory studies falls short in widespread adoption. Lab-created intervention games lack the features of mainstream games that drive player engagement. Collaboration between game designers and cognitive scientists is rare, in part because they lack a common tongue to negotiate design problems. We consider pattern languages as a modern Rosetta Stone that enables clear communication between cognitive scientists and game designers. Here, we engaged game designers, cognitive scientists, and HCI researchers in generating a pattern language for designing exergames. We derived 14 design patterns from a corpus of cognitively beneficial commercial games and categorized them into an exertion framework. The resulting pattern language is legible to both cognitive scientists and game designers, allowing them to create fun and engaging exergames that are designed to provide cognitive benefits and engage players beyond standard laboratory settings.

CCS Concepts: • **Do Not Use This Code** → **Generate the Correct Terms for Your Paper**; *Generate the Correct Terms for Your Paper*; *Generate the Correct Terms for Your Paper*; *Generate the Correct Terms for Your Paper*.

Additional Key Words and Phrases: Exergame, Older Adults, Embodied Interaction, Design Pattern

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1 Introduction

An exergame is a video game that leverages bodily motion as the primary input mechanism [47]. Representative examples include Wii Sports [44], Dance Dance Revolution [67], and Beat Saber [9], where players engage in whole-body interactions to simulate tennis gameplay with virtual opponents, perform choreographed movements synchronized to musical rhythms, or execute sword-swinging motions. These applications integrate elements of balance, coordination, and cognitive challenge within virtual environments. For instance, in Beat Saber, players must not only execute precise sword-swinging movements but simultaneously process visual cues, anticipate block sequences, and make rapid strategic decisions about optimal cutting angles and timing—engaging executive function, working memory, and attention alongside physical exertion. This combination constitutes a form of combined physical-cognitive training that has gained traction as an intervention for mitigating age-related cognitive decline.

Research over the past two decades has shown that the benefits of exergames compare favorably to conventional exercise interventions for a wide range of populations, including older adults [3, 27]. These benefits include both physical and cognitive health outcomes [39, 41, 48, 63]. The engaging nature of exergames makes them inherently more appealing than traditional cognitive training methods, while their digital format overcomes common barriers such as

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53 space limitations and transportation issues common to exercise interventions [10]. Additionally, exergames typically
54 offer valuable social elements through multiplayer options and community engagement [38].

55 However, the literature reveals that many exergames used as cognitive interventions [12, 68] were developed in
56 laboratory settings and are not publicly accessible, making it difficult to understand their underlying game mechanisms.
57 This significantly prevents the widespread translation of cognitive-beneficial exergames from research labs into
58 community settings. Furthermore, even when lab-developed exergames are accessible, they often lack the engaging
59 components necessary to sustain long-term player interest and motivation [58, 64, 65]. This means that research-based
60 games may demonstrate cognitive benefits in controlled studies, but their limited entertainment value hinders practical
61 adoption beyond laboratory contexts.

62 Fortunately, we have found that some exergames have not only achieved commercial success within communities
63 but have also moved from living rooms into laboratories. Popular exergames such as Wii Fit have been used as health
64 interventions in clinical randomized controlled trials, and several of these studies have shown effective cognitive
65 benefits for older adults [5, 36, 40, 49, 50, 53]. These exergames that are both engaging and effective provide us with
66 an opportunity to understand the game mechanisms of exergames with cognitive benefits. We can examine whether
67 specific design patterns exist among these cognitively effective exergames. If such patterns exist, they can provide
68 designers and researchers with tools to explore the effectiveness and community scalability of exergames in improving
69 cognition [18, 21, 22].

70 To identify such game design patterns, one possible approach is to use game analysis frameworks to reverse-engineer
71 the design patterns that frequently occur in exergames with evidenced health benefits. A pattern language [55],
72 originally proposed by Christopher Alexander [55] and adapted into a variety of fields [33], provides a structured
73 framework for capturing and communicating design knowledge across disciplines. This makes it particularly valuable
74 for interdisciplinary collaboration between game designers and cognitive scientists. Pattern language methods have
75 also been applied in game design [8]. Unlike traditional design guidelines that focus on single aspects (i.e., accessibility,
76 engagement, or effectiveness), a pattern language captures the relationships between design elements and their
77 contextual applications, enabling designers to understand not just what works, but why and when specific design
78 decisions are effective.

79 In this study, we tried to reverse-engineer the hidden design code that exists in commercial exergames with cognitive
80 benefits to facilitate cognitive-beneficial exergame design collaboration between game designers and cognitive scientists.
81 We aim to investigate the following research questions:

- 82 • RQ1: What are the game design patterns among exergames? Are certain patterns applied more frequently in
83 games with cognitive benefits than other patterns?
- 84 • RQ2: What design insight can we draw from evaluating these design patterns within current game frameworks?
85 / How well do current game frameworks explain design patterns generated from exergames with cognitive
86 benefits?

87 To answer the research questions, we applied pattern languages to exergame design by identifying games from
88 popular game platforms and cognitive research literature and by collaborating with game professionals and cognitive
89 scientists through pattern generation workshops. Additionally, to validate how our patterns were applied to games, we
90 categorized patterns with an exertion game framework [42] to evaluate whether the proposed perspectives from the
91 Exertion Framework have been captured by our design patterns. This paper details our process of adapting a pattern
92 language approach into exergame design. From initial exergame selection through pattern identification, analysis and
93

105 evaluation, applying a pattern language and exertion framework to analyze exergames represents a novel methodological
106 contribution that provides a structured framework for interdisciplinary collaboration in health-focused game design.
107

108 We present the design patterns observed collaboratively by HCI researchers, game designers and cognitive scientists,
109 providing insights into the feasibility of this interdisciplinary approach. This analytical pattern approach can create a
110 shared vocabulary for exergames designed with cognitive promotion as a goal, facilitating communication between
111 game designers who prioritize player experience and researchers who focus on cognitive outcomes. Second, patterns
112 encode both the functional requirements (cognitive benefits) and experiential qualities (engagement) within unified
113 design solutions, helping to bridge the research-practice gap. Third, the hierarchical nature of pattern language allows
114 for scalable application—from individual interaction mechanisms to complete game architectures—making it valuable
115 for both researchers developing targeted interventions and designers creating comprehensive gaming experiences,
116 thereby supporting broader community adoption and dissemination.
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121 2 Related Work

122 2.1 Pattern Language for Game Design

123 An approach that assigns value to that bigger picture is a pattern language (PL). The concept of a PL emerged in the late
124 1970s from Christopher Alexander as a response to mainstream architecture's focus on edifices and lack of emphasis
125 on the people who would be using the space [2]. Alexander contends that a pattern language in architecture allows
126 designers to create constructs that are harmonious with people, nature, and the universe as a whole.
127

128 PL has been both a topic and a method in HCI research since the mid-1980s. As Pan [51] pointed out in their
129 study interviewing with HCI-PL experts, unlike its success in programming and computational areas, PL in HCI
130 has attracted significant attention over the past four decades while not becoming more widespread in practice. Key
131 challenges identified by previous research that contribute to this issue include the extensive amount of time required
132 to produce high-quality patterns, and the need for designers to be specialized and trained to generate patterns [51].
133 Some researchers outside of HCI have attempted to optimize the process of creating PL through collaborative pattern
134 mining [1] and clustering activities [32].
135
136
137

138 Among the most prolific adapters of Alexander's philosophy and practice is Takashi Iba [33], who expanded the
139 application of pattern languages beyond their original architectural context into diverse fields of human activity and
140 creativity. His most distinctive contribution lies in systematically developing pattern languages as tools for understanding
141 and supporting creative processes across multiple domains. A key insight from his work is that creative activities
142 contain recurring successful solutions to common problems that can be codified into digestible and actionable patterns.
143
144

145 Although Alexander's pattern language philosophy has been applied to several disciplines, most notably through
146 Iba's work, the most pertinent to the present research is its application to game design. *Pattern Language for Game
147 Design*, a textbook designed to help game developers create a unified language to solve problems in game design,
148 leverages the philosophy of Alexander's to achieve design goals in game design [6]. In this textbook, the author presents
149 39 game design patterns that were generated from analysis of a broad spectrum of game genres, themes, control
150 schemes, and purposes. The result is a somewhat generalized collection of patterns a practitioner can use to enhance
151 components of their designs. Furthermore, the author also invites readers to generate their own patterns through a
152 collection of exercises throughout the book, and to contribute them to a centralized "Pattern Library," which is visible to
153 other practitioners and can help improve game design decision making [6, 7].
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2.2 Exertion Game Framework

We employ the Exertion Framework [42] to analyze our identified patterns across eight dimensions, combining body-centric perspectives with game design schemas. Originally developed by Mueller et al. for designing and analyzing exertion games—digital games where physical effort predominantly determines outcomes [42]—this framework provides a vocabulary for examining how bodies engage in digitally-mediated physical experiences.

The framework consists of "lenses" that draw from Jacob et al.'s reality-based interaction work [34, 35]. It proposed a "four lens view" for analyzing bodily interactions with non-keyboard controlled devices, informed by van Manen's phenomenological approach to lived experience [66]. The four original lenses examine: the Responding Body (internal physiological responses to exertion, such as heart rate and fatigue), the Moving Body (muscular repositioning and movement characteristics through space), the Sensing Body (perception and interaction with physical and virtual objects in the environment), and the Relating Body (social connections and relationships mediated through exertion).

The framework complements these body lenses with three game schemas drawn from game design literature [57]: Rules (formal game structures and mechanics), Play (experiential aspects and player engagement), and Context (immediate environmental and situational factors). Together, these create a 2-dimensional analytical space that enables comprehensive examination of how exertion game patterns engage both physical and cognitive elements—particularly valuable for analyzing motion games designed to support older adults' cognitive health.

2.3 Cognitive Outcomes of Exergames

Exergames represent a compelling form of combined physical-cognitive training that has garnered substantial empirical support over the past two decades. The cognitive benefits of exergaming are thought to arise from sustained physical activity that elevates cardiovascular function, in turn promoting neuroplastic changes associated with improved cognitive performance [17, 24, 29]. Multiple clinical studies have demonstrated that exergame-based interventions yield cognitive gains for older adults that are comparable to, or exceed, those achieved through traditional single-domain or combined physical-cognitive training programs [4, 30, 60]. Commercial platforms such as the *Nintendo Wii* and *Xbox Kinect* have been shown to elicit physical effort on par with moderate-intensity conventional exercise [39, 41, 48, 63], and emerging virtual reality exergames have demonstrated even greater energy expenditure [20].

A growing body of research has begun examining which cognitive domains benefit most from exergame play, including executive function, working memory, attention, and processing speed [16, 46, 61]. However, these studies typically attribute cognitive outcomes to broad categories—such as game genre or training modality—rather than to specific design features within the games themselves [59]. As a result, the field has accumulated considerable evidence that exergames *can* improve cognition, but lacks a clear account of the "active ingredients" that make a given game both highly playable and cognitively beneficial. Without a structured approach to identifying and communicating these design elements, researchers designing interventions must rely on intuition or wholesale adoption of existing commercial titles, while game designers working on health-focused games lack evidence-based guidance on which mechanisms to prioritize. This gap motivates our pattern language approach: by identifying recurring design patterns across exergames with evidenced cognitive benefits, we aim to make these active ingredients explicit—providing a shared vocabulary that enables researchers and designers to collaboratively create exergames that are both engaging and therapeutically effective.

Participant	Gender	No. of Move-Games Played	Background	Experience of Pattern Language
P.1	Female	13	HCI researcher studying the integration of games into cognitive interventions for older adults	Has read one or more pattern generation books before participating in study.
P.2	Male	10	Game designer and HCI researcher enrolled in a Game Design Science graduate program	Has taken one or two pattern generation courses and has practical experience with pattern generation for games
P.3	Female	12	Self-identified gamer and research assistant working in a cognitive science lab for older adults	Has read one or more pattern generation books before participating in study
P.4	Male	7	Has mixed game development and human-computer interaction backgrounds; currently working in a lab focused on senior gamers	Has taken one or two pattern generation courses and has practical experience with pattern generation for games
P.5	Male	10	Game developer enrolled in a Game Design Science graduate program	Has taken one or two pattern generation courses and has practical experience with pattern generation for games
P.6	Female	8	HCI researcher studying the integration of games into cognitive interventions for older adults	Has had years of experience teaching pattern language and has publications on pattern language
P.7	Male	9	Teaching professor with expertise in game design, pattern language-generation, and senior game development experience	

Table 1. The pattern language and exergaming experience of workshop participants

3 Methods

3.1 Participants

We convened two collaborative workshops with seven researchers and game designers who possessed expertise in exergame design and pattern generation. Collaborators were invited through professional networks based on their expertise in at least two of the following areas: game design/development, exergaming, game pattern generation, or research on older adults' cognition.

To document the collaborative team's expertise, collaborators reported their backgrounds in pattern generation and exergaming. All collaborators had experience playing exergames and possessed knowledge of game design pattern generation. Four had taken game design pattern generation courses and had practical experience with pattern generation for games, while three had previously studied pattern generation literature; see Table 1.

The collaborative team included: two game designers enrolled in a Game Design Science program; two researchers studying the integration of games into cognitive interventions for older adults; two researchers with mixed game

Game Name	Genre	Cognitive Benefits
Fitness Boxing 2	fitness	[15]
Fitness Circuit	fitness	unkown
Supernatural VR fitness	fitness	unkown
Wii Fit	fitness	[5, 36, 40, 49, 50, 53]
Ring Fit Adventure	fitness	unkown
FitXR	fitness	unkown
Les Mills Bodycombat	fitness	unkown
Knockout Home Fitness	fitness	unkown
Mario Tennis Ace	sports	[70]
Home Sports - Oculus	sports	unkown
Mario and Sonic Olympics games	sports	[40]
Nintendo Switch Sports	sports	unkown
Wii Sports Resort	sports	[52]
Wii Sports	sports	[40, 56]
Just Dance 3	music	[45]
Dance Dance Revolution	music	[15]
Synth Riders	music	unkown
Beats Saber	music	[37]
Zumba Fitness: World Party	music	[70]
Fruit Ninja VR	action	[31]
Sweet Surrender	action	unkown
Dragon Fist: VR Kung Fu	action	unkown
Asgard's Wrath 2	action	unkown
Arms	action	unkown
The Thrill of the Fight	action	unkown

Table 2. The list of selected exergames and clinical-evidence references

development and human-computer interaction backgrounds working in a lab focused on senior gamers; one self-identified gamer and research assistant working in a cognitive science lab for older adults; and one teaching professor with expertise in game design, pattern language generation, and senior game development experience. This collaborative research approach was approved by the Research Ethics Advisory Group at X University.

3.2 Collaborative Pattern Generation Workshops

All collaborators engaged in two structured workshops. The first workshop focused on pattern mining and clustering through collaborative observation and analysis. The second workshop emphasized pattern crafting, where collaborators proposed patterns and received expert-led training on pattern writing. Following the workshops, collaborators had 2-3 weeks to complete pattern generation using the Game Pattern Library template [7]. This design enabled the extraction of design patterns from existing exergames while leveraging expert knowledge to ensure practical applicability for game development.

3.2.1 Game Search Strategy and Selection. As part of the workshop preparation, a list of popular commercial exergames and general exergames was selected for pattern generation (Table. 2). Games were identified using the keywords "Fitness (games)," "Exercise (games)," "Motion (games)," or "Movement (games)" via the search function of major game platforms, including Steam, Nintendo, Xbox, Meta, and PlayStation websites.

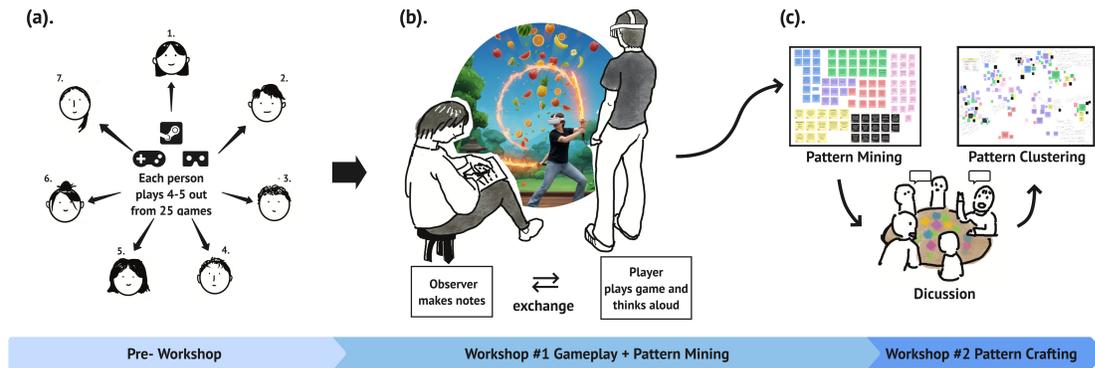


Fig. 1. The progress of collaborative pattern generation for exergames.

The criteria for selecting games included: (1) The game must be listed on game platforms as either an exergame or general movement-controlled game; (2) The game must be available for download; (3) The game must have a favorable rating or review from game evaluation websites (e.g., Metacritic and Meta Quest). Common reasons for exclusion included games that did not require physical movement for gameplay (e.g., brain exercise games, sports games with joysticks) and games targeting only young children (under 12 years old). For exergames with multiple versions (e.g., Fitness Boxing and Just Dance), only the most well-received version was included.

Rating scores were documented and used as a selection criterion for determining whether a game was "successful" or "recommended" by players. Most rating scores were extracted from Metacritic, a professional game critic website that uses "a weighted average of reviews from top critics and publications for a given movie, TV show, video game, or album" [62, p.1]. Metacritic scores are also used by Steam, one of the largest digital game distribution services, for game recommendations. For Meta Quest exclusive games unavailable on Metacritic, ratings were obtained from the Meta Quest platform, which uses user star ratings (1 to 5). A Metacritic critic score above 70 was used as the threshold, as this aligns with the platform's classification of "favorable reviews"[62, p.1]. Similarly, a Meta Quest rating above 4.0 (out of 5) was used as the equivalent threshold for platform-exclusive games.

3.2.2 Pattern Generation Process and Workshop Structure. We conducted two collaborative pattern generation workshops (Figure. 1). Prior to the first workshop, collaborators were assigned four to five exergames to play based on a provided game list and their previous exergaming experience. Only the games that collaborators had never played were assigned to them. After initial individual gameplay on assigned games, followed by two workshops for the collaborative pattern generation, the workshops encompassed pattern mining, clustering, and crafting phases. The first workshop lasted four hours and was conducted in chronological order as described below:

- (1) A detailed explanation of pattern mining and clustering processes. At the beginning of the workshop, the lead researcher and pattern expert presented a 20-30 minute introduction to the study, the workshop agenda, and the process of performing pattern mining and clustering to workshop collaborators.
- (2) Paired gameplay observation between collaborators. The gameplay session lasted 45 minutes, and the collaborators were split into three groups in which each group included two or three collaborators. Each group was asked to experience at least two games in addition to the game they were assigned prior to the workshop within

365 45 minutes. One collaborator would act as a player to play the game and talk aloud about the perceived game
366 design, while another collaborator would act as an observer and take notes. Then, they were asked to switch
367 roles.
368

- 369 (3) Discussion of observations. Collaborators were given 20 minutes to post all of their observations from the
370 gameplay experience to a Miro board, followed by a 30 minute discussion to share their observations and ask
371 for clarifications.
372 (4) A collaborative pattern mining and clustering activity. After all observation notes were added to the first board,
373 collaborators were instructed to place their observations into an affinity diagram, where observation notes
374 relating to each other were placed closer together. Collaborators were also instructed to focus on the hidden
375 meanings, and the goals that the game design sought to solve, instead of superficial elements, such as how
376 the game appears visually. The clustering activity continued until there were no notes left on the first board.
377 Collaborators engaged in a clustering practice round first, which resembled the following:
378
379

380
381 *Host: "Collaborator No.1 please randomly select an observation note, then move to the second board."*
382

383
384 *Host: "Collaborator No.2 please select one observation note from the first board that is different from one that
385 collaborator No.1 chose. Please place the note far from the board based on how different you think they are."
386*

387
388 *Host: "Collaborator No.3 please select another note from the first board that you think is different from previous
389 two notes that were placed on the second board. Similarly, place the note in a position on the board based on how
390 different you think it is from other two."
391*

392
393 The second workshop lasted three hours and focused on pattern crafting (also called pattern writing practice),
394 where collaborators proposed potential patterns identified from the clustering activities, followed by a pattern writing
395 demonstration led by a pattern generation expert. Following the workshops, collaborators were given 2-3 weeks to
396 complete and generate game patterns based on the results of clustering activities.
397
398

399 3.3 Data Analysis 400

401 3.3.1 *Evaluating Patterns on Games.* All patterns generated from the workshops were organized using a game pattern
402 template format [7], which includes pattern name, problem statement, solution, and examples. These patterns were
403 documented in a Microsoft Word file and shared with the researchers conducting the evaluation. Before evaluation
404 began, two researchers conducted a quality control exercise. During this process, redundant patterns were merged into
405 single patterns, and low-quality patterns with vague descriptions or patterns that applied only to specific technology
406 challenges rather than game design were excluded from evaluation. Quality control assessment was done independently
407 and discussed between the first and second authors until agreement was reached.
408
409

410 After the quality control assessment, two researchers independently evaluated each game (N=25) against all identified
411 patterns. For each game, researchers were asked to play the game for at least 60 minutes and evaluate all patterns
412 for one game at a time. Researchers documented their evaluations independently in separate documents, recording a
413 yes/no decision for each pattern's presence, and providing specific examples of game features that demonstrated the
414 pattern's application.
415

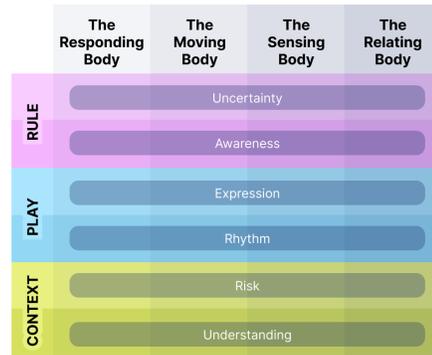


Fig. 2. The Exertion Framework Proposed by Mueller et al. 2011 [42]

After completing independent evaluations, the two researchers compared their results. A pattern was considered present in a game only when both researchers agreed on its application. Upon disagreement, the nature of the disagreement was first identified. If the disagreement stemmed from different interpretations of the pattern definition, a consultation was initiated with the pattern author to clarify the pattern’s intended meaning, and the pattern was revised for high quality by the first and second authors. If the disagreement arose from different observations of game features, a third researcher was involved to evaluate the game and reach agreement through a majority vote. The final agreed-upon results, including the presence or absence of each pattern and the corresponding game feature examples, were stored in an Excel worksheet for subsequent analysis.

3.3.2 Descriptive Pattern Frequency Analysis. Pattern occurrence frequencies were calculated across three analytical levels. At the first level, the absolute count and percentage of each pattern’s occurrence were computed across all 25 games in the corpus. Pattern frequency was determined by dividing the number of games containing each pattern by the total number of games analyzed, yielding a percentage that represented overall pattern prevalence in 25 exergames. At the second level, the dataset was revised to include only the 11 exergames with evidenced cognitive benefits. Pattern frequencies were recalculated within this subset using the same computational procedure. At the third level, games were categorized by genre (e.g. Fitness, Sports, Music, and Action), and pattern frequencies were computed separately for each genre category. For each genre, the occurrence count of each pattern was divided by the total number of games within that genre, producing genre-specific frequency percentages.

3.3.3 Pattern Co-occurrence Analysis. To investigate relationships among design patterns of exergames with cognitive benefits, a co-occurrence analysis was conducted using the Jaccard similarity coefficient [25]. This calculation was performed for all possible pattern pairs, yielding 91 pairwise comparisons (14 patterns × 13 patterns / 2, excluding self-comparisons). The resulting Jaccard scores ranged from 0 to 1, where 0 indicated that two patterns never co-occurred in any game, and 1 indicated that the patterns appeared together in every game where either pattern was present. The similarity matrix was visualized as a heatmap with color intensity mapped to Jaccard score magnitude. The Jaccard coefficient was selected over raw co-occurrence counts because it normalized for differences in individual pattern frequencies, thereby distinguishing genuine design synergies from spurious associations arising solely from high pattern prevalence.

3.3.4 *Categorize Patterns with Exertion Game Framework.* The Exertion Game Framework (Figure 2) [42] was used as a guideline for pattern categorization. This framework was selected because it comprehensively addresses both bodily and gaming dimensions relevant to exergame design, providing a structured lens for understanding how patterns function across different aspects of the exertion experience. The extended framework includes four perspectives on the body (Responding Body, Moving Body, Sensing Body, and Relating Body) and three perspectives on gaming (Rules, Play, and Context), creating a 4×3 grid with 12 cells representing the intersection of bodily and gaming dimensions. The four body perspectives are defined as follows:

- **Responding Body:** Emphasizes how corporeality and temporality are at the heart of people’s experience of exertion, focusing on how the body responds and changes during physical activity.
- **Moving Body:** Focuses on participants’ muscular repositioning of body parts relative to one another during physical activity, combining temporality and spatiality through movement.
- **Sensing Body:** Describes how the body senses and experiences the world, often through physical objects that shape the exertion activity (e.g., balls, rackets).
- **Relating Body:** Encompasses the ways bodies and people relate to one another through digital technology, including social interactions mediated by roles such as co-players, opponents, and audiences.

The three gaming perspectives are defined as follows:

- **Rules**
 - **Rules - Uncertainty of exertion:** Addresses how uncertainty contributes to suspense and surprise in games through random or chance events (e.g., a ball dancing on the net in tennis, adverse weather changes in golf).
 - **Rules - Awareness of exertion:** Focuses on how digital technology can selectively reveal or hide bodily information, allowing players to benefit from increased awareness (e.g., comparing energy expenditure to motivate effort) or decreased awareness (e.g., using music as distraction from physical discomfort).
- **Play**
 - **Play - Expression of exertion:** Highlights exertion as a form of self-expression and the expressive power of the human body, including performative interactions such as celebratory gestures and dances.
 - **Play - Rhythm:** Describes how systems support uniform or patterned recurrence of beats in bodily action, where rhythmic synchronization to music or partners can regulate arousal, improve performance, and dissociate from exercise discomfort (e.g., Dance Dance Revolution’s movement-music synchronization).
- **Context**
 - **Context - Risk of exertion:** Addresses the vulnerability of the body to overexertion and injury, including experiences of being injured, recovering, and discussing injuries as prominent elements of sports.
 - **Context - Understanding:** Refers to systems’ potential to support development of knowledge and skill about the exerting body through bodily exploration, practice, and appropriate challenge matching that facilitates kinaesthetic literacy and bodily awareness (e.g., learning about heart rate to plan effort investment, or exploring safe strike intensity).

Two researchers independently categorized each pattern by assigning it to the most appropriate cell in the grid, representing the intersection of one body perspective and one gaming perspective. Each researcher documented their categorization decisions in separate documents. After completing independent categorizations, the two researchers compared their results. Upon disagreement, the nature of the disagreement was first identified. If the disagreement

stemmed from different interpretations of the framework definitions, researchers consulted the original framework paper [42] to clarify the intended meaning. If the disagreement arose from different judgments about pattern fit, a third researcher was involved to evaluate the pattern and reach agreement through a majority vote. This process continued until all patterns were categorized with alignment. The final categorization results were documented in the grid, with each pattern placed in its agreed-upon cell representing the intersection of its primary body and gaming perspectives.

4 Outcomes

4.1 Exergame Design Patterns from Pattern Generation Workshops

4.1.1 *Pattern #1: Chain the Basics.*

Design Problem: How can we change the difficulty of the exergame to keep players engaged while not increasing the complexity of the movement actions required from the player?

Pattern Description: Use a combination of basic movements to make the game harder. The perceived difficulty of completing a movement can be tied to the given time to complete an action and the complexity of the movement combo. Thus, adjusting the dynamics of these two elements can contribute to changing the game difficulty even with basic movements. Adding different combinations of basic movements can increase the difficulty of the action, which likely motivates players to challenge themselves both mentally and physically. Shortening the time gap to give less reaction time in response to the target can also increase the physical and mental effort from the player.

4.1.2 *Pattern #2: Progress Tracking.*

Design Problem: How do you encourage the player to want to repeatedly and routinely engage with an exergame?

Pattern Description: Scoreboards, whether individual or community-based, reward repeated attempts at game stages or tasks with personal and peer validation. Many forms of analog exercise (running or weightlifting, for example) emphasize personal records and individual progress. In-game scoreboard mechanics provide an in-game version of PR-tracking alongside extrinsic motivation to improve through peer recognition. In-game calendars, records, or rankings that automatically track and visualize progress will support a sense of self-competence and personal growth.

4.1.3 *Pattern #3: Multi-sensory Feedback.*

Design Problem: How can games help players stay focused and maintain fast reaction times when physical activity competes for attention and sensory processing?

Pattern Description: Exercise games often require players to track fast-paced, interactive elements while their bodies are in motion. Relying solely on visual cues can overwhelm players or slow their response, especially during strenuous activity or when the screen is crowded. By layering synchronized multi-sensory signals, including flashing lights, rhythmic sounds, and tactile vibrations, it helps players to converge on key game moments or targets. These aligned cues can distribute the cognitive load across different senses instead of relying on only one, improving reaction time and reducing missed actions by allowing players to see, hear and feel at the same time.

4.1.4 *Pattern #4: Competition.*

Design Problem: Physical fitness requires exertion beyond one's current capabilities—a necessary discomfort that drives growth. This creates a critical balance: fitness gains on one side, physical discomfort on the other. If discomfort becomes too intense, players burn out and abandon their fitness goals. How can game designers calibrate challenge levels to maintain this balance and sustain long-term engagement?

Pattern Description: Introducing competitive elements to a game that involves exercises leverages the natural synergy

573 between physical exercise and friendly competition. This synergy is most obvious in physical games, such as soccer,
574 track and field, or American Football. In short, introducing a competitive element gives another benefit to the positive
575 side of the scale, re-weighting it in a manner that could encourage players to push through the innate discomfort of
576 physical exertion. It also brings a sense of relatedness and recognition for the expended effort.
577

578 4.1.5 **Pattern #5: Reward the Physical Effort.**

579 *Design Problem:* In games centered around physical movement, how can you encourage players of different fitness
580 levels to push themselves to their personal physical limits for maximum exercise benefit?

581 *Pattern Description:* Create a direct relationship between physical effort intensity and in-game performance or rewards,
582 where greater exertion produces proportionally better outcomes without imposing an upper limit. Rather than capping
583 performance at a fixed threshold that all players must reach, design mechanics where the harder players push themselves
584 physically—whether through faster movements, more repetitions, or greater force—the more they achieve in-game.
585 This continuous reward structure allows each player to self-regulate based on their own capabilities while providing
586 ongoing incentive to increase effort within their personal comfort zone.
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590 4.1.6 **Pattern #6: Leverage People’s Mental Model.**

591 *Design Problem:* Digital games assume literacy in controllers, avatars, and visual conventions that alienate non-gamers
592 from potential benefits like fitness, wellbeing, and meaningful experiences. How can designers create intuitive exergames
593 accessible to players regardless of gaming background?

594 *Pattern Description:* Design game interactions, controls, and environments that mirror real-world experiences and objects
595 that players already understand. Since people share common mental models of how the physical world works, leveraging
596 these existing schemas allows players to intuitively know how to interact with the game without extensive tutorials
597 or prior gaming knowledge. The closer the game’s core mechanics resemble familiar real-world activities, the more
598 seamlessly players can transfer their existing knowledge into gameplay. For example, using the environment or objects
599 to give implicit hints about possible movements creates a more immersive gaming experience while eliminating the
600 need for disruptive tutorials. This approach reduces barriers to entry, maintains immersion, and allows the environment
601 to provide implicit guidance about possible actions.
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606 4.1.7 **Pattern #7: Rhythm.**

607 *Design Problem:* In games that aim to encourage full-body physical activity, how do you motivate players to move with
608 greater enthusiasm and consistency?

609 *Pattern Description:* Incorporate dynamic, rhythm-driven background music and tightly integrate physical movement
610 mechanics with the musical beat. Humans naturally respond to rhythm, and tapping into this instinct can boost player
611 motivation and create a sense of flow and enjoyment in movement.
612
613

614 4.1.8 **Pattern #8: Link Gameplay to Game Theme.**

615 *Design Problem:* Sometimes, a theme is paramount for digital games. In bigger franchises like Halo, the theme (epic
616 space warfare) is crucial to delivering the story and the aesthetic experience intended by the designers. In other games,
617 like Tetris, the theme is almost non-existent, yet they deliver an engaging experience in their own right. With such
618 extremes, how can designers confidently settle on a theme and how much to express that theme in their digital game?

619 *Pattern Description:* One manner of sifting through potential themes and theme salience is by considering how gameplay-
620 centric the design is. For example, a visual novel is more focused on the content and compelling writing, whereas
621 a heavy strategy game like chess is much more focused on the interplay between opponents at the gameplay level.
622
623

625 A strong and prevalent theme may serve a visual novel better than Chess. A designer can select the theme and the
626 salience of that theme based on how much they want the player to focus on gameplay – a stronger theme is likely to
627 draw attention away from the gameplay and towards the narrative or art, and an abstract or minimalist theme is more
628 likely to draw the player’s attention to the gameplay itself.

630
631 **4.1.9 Pattern #9: Too Busy To Get Bored.**

632 *Design Problem:* When your game relies heavily on simple, repetitive mechanics (such as a single core loop or repeated
633 movements in an exergame), how can you prevent players from getting bored?

634 *Pattern Description:* Layer cognitive challenges or reactive decision-making tasks on top of repetitive physical actions
635 to occupy players’ mental bandwidth. By requiring players to process information, make strategic choices, or react
636 to dynamic stimuli while performing physical movements, the mental engagement distracts from the monotony of
637 the underlying repetition. This dual-task approach—combining physical execution with cognitive processing—keeps
638 players focused on the mental challenge rather than dwelling on the repetitive nature of their movements, thereby
639 sustaining interest and immersion.

642
643 **4.1.10 Pattern #10: Leverage the Randomness.**

644 *Design Problem:* Unlike traditional games where leveling up increases character power, exergames increase difficulty to
645 demand greater physical effort. Yet human physical capacity has inherent limits. How can designers sustain long-term
646 engagement once players master movements without relying on endless physical escalation or repetitive actions?

647 *Pattern Description:* When the main interaction is associated with the game interactables, to increase the unpredictability
648 of the interactables can encourage the dynamics of the body movements. In this situation, even if the player may
649 already master the movement itself, it requires more cognitive efforts to deal with the dynamic changes of the game to
650 be able to act accurately and timely. By taking advantage of the requirement of more cognitive investment, it gives the
651 opportunity to keep players engaged to be rewarded.

654
655 **4.1.11 Pattern #11: Link Physical Impact to Gameplay.**

656 *Design Problem:* Unlike traditional game characters controlled by buttons, where individual force or physical fitness
657 does not influence the gameplay experience significantly, exergames create a direct association between a player’s
658 physical ability and their in-game performance. How can designers make physical capabilities—force, speed, movement
659 quality—visibly impactful in the game world, creating tangible embodied agency?

660 *Pattern Description:* Use sensory devices to capture the nuanced, analog qualities of players’ physical movements and
661 translate them into proportional, non-binary in-game effects. Rather than reducing physical input to simple binary
662 states (on/off, hit/miss), measure and respond to the continuous spectrum of physical effort—the scale and direction of
663 force, speed of movement, angle of motion, or intensity of exertion. The data collected from sensors is transmitted
664 into gameplay in ways that reflect the richness of human kinesthetic awareness. For example, rather than having a
665 static melee attack with a fixed animation regardless of how the player swings, the attack should reflect factors like
666 input angle, speed, and force, providing feedback that communicates these variations back to the player. This creates a
667 responsive system where subtle differences in physical execution produce meaningfully different gameplay outcomes.

671
672 **4.1.12 Pattern #12: Strategic Memorization.**

673 *Design Problem:* How can you add a layer of mental engagement to physically repetitive exercise games while encouraging
674 players to focus on strategic execution rather than getting distracted by trying to remember basic controls?

675 *Pattern Description:* Design gameplay systems where memorizing sequences, patterns, or combos becomes essential
676

677 for mastery. Rather than recalling basic controls, players develop strategic depth by internalizing optimal action
678 sequences—attack combos or movement chains. The cognitive challenge becomes "what's the best combo for this
679 situation?" instead of "what button do I press?" Players who master these patterns execute them fluidly, shifting focus
680 from controls to decision-making. This creates satisfying progression: initial struggle to remember sequences, then
681 automatic execution through practice, and finally mastery through knowing which patterns to deploy when.
682
683

684 4.1.13 **Pattern #13: Planted Player Stance.**

685 *Design Problem:* When users are immersed in virtual environments, misalignment between virtual first-person locomotion
686 and physical movement causes nausea. Exergames that encourage intense physical activity while incorporating
687 virtual locomotion risk amplifying motion sickness, directly undermining their health benefits. How can designers
688 enable engaging virtual locomotion without triggering discomfort during physical exercise?
689

690 *Pattern Description:* To address this issue, it is crucial to balance virtual locomotion with physical body movements.
691 Rather than requiring players to move toward targets using a controller, making the targets moving toward the players
692 logically restricts players' virtual locomotion, allowing them to focus on their physical movements and significantly
693 reducing the potential for nausea.
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696 4.1.14 **Pattern #14: No Cheat, Just Sweat!**

697 *Design Problem:* Players often exploit game systems to achieve intended effects with minimal physical effort, directly
698 undermining exergames' core purpose of promoting movement. How can designers create mechanics that ensure
699 meaningful physical engagement while preventing low-effort exploitation?
700

701 *Pattern Description:* To naturally reduce the chance of players "cheating," exergames can leverage the platform's extensive
702 body tracking capabilities to mimic real-life arm movements and gestures, thus encouraging more intensive physical
703 effort and minimize the opportunity for users to cheat.
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705

706 4.2 The Frequency of Design Pattern Usage

707 4.2.1 Overall Pattern Usage Frequency.

708 The analysis of pattern occurrence across all examined games reveals varying levels of adoption among the 14 identified
709 design patterns (Fig. 3). P2 *Progress Tracking* and P3 *Multi-sensory Feedback* emerged as the most widely implemented
710 patterns, each with 88% adoption in all games. This demonstrates that tracking mechanisms and multi-modal sensory
711 integration are considered foundational to exergame design. P6 *Reward the Physical Effort* closely followed at 84% overall
712 adoption, while P11 *Link Physical Impact to Gameplay* showed 72% overall adoption, indicating strong emphasis on
713 connecting physical exertion to meaningful game outcomes. P1 *Chain the Basics* appeared in 64% of games, suggesting
714 difficulty progression through movement combination is a widely recognized design principle.
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717 Patterns with middling frequency included P8 *Link Gameplay to Game Theme* at 56%, P4 *Competition* and P12 *Strategic*
718 *Memorization* both at 52%, and P13 *Planted Player Stance* at 48%, indicating these address more specialized design
719 contexts. The least adopted patterns were P14 *No Cheat, Just Sweat* at 44%, P7 *Rhythm* and P10 *Leverage the Randomness*
720 both at 40%, suggesting genre-specific rather than universal applicability.
721
722

723 4.2.2 Pattern Usage Frequency in Exergame with Cognitive Benefits.

724 We see the similar ranking in pattern usage in terms of high-frequency and low-frequency patterns in exergames with
725 cognitive benefits compared to overall result; however the rank of mid-tie patterns are very different. In high-tie, P2
726 *Progress Tracking* (90%), P6 *Leverage Mental Model* (90%), and P3 *Multi-sensory Feedback* (81%) are still the top three
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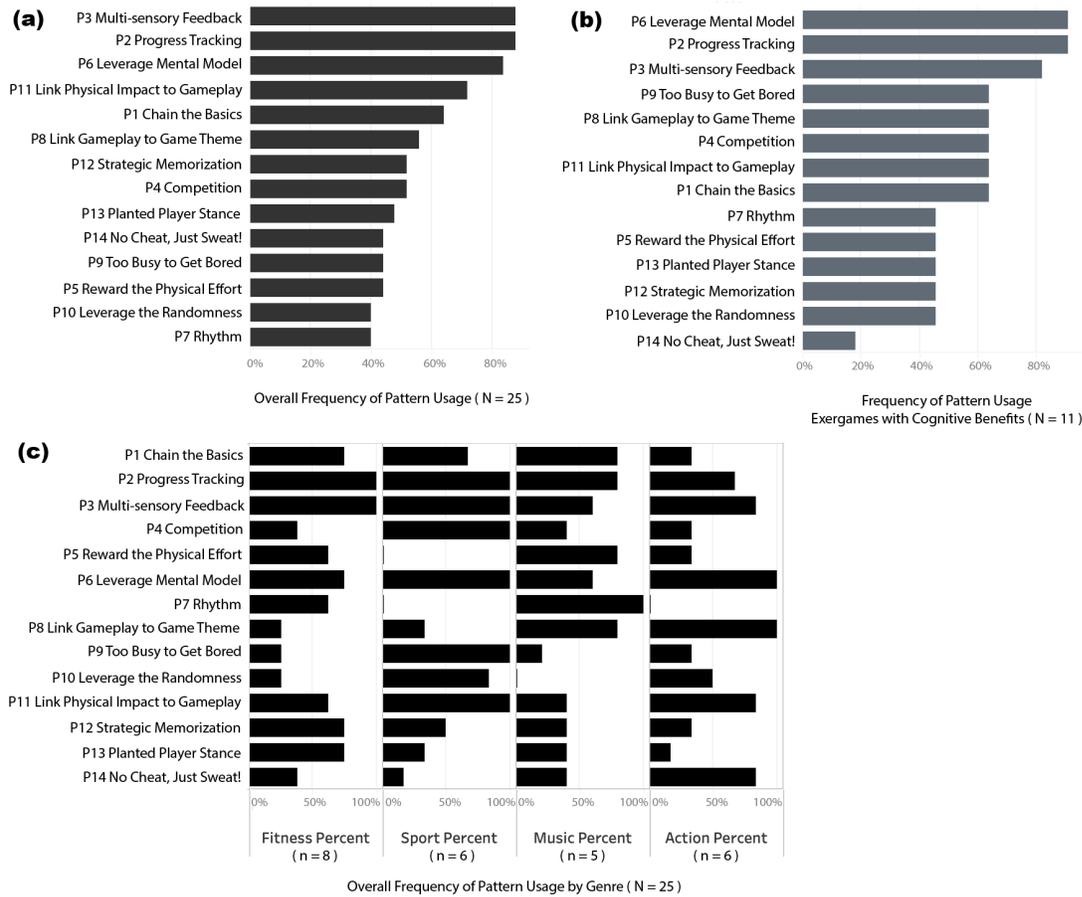


Fig. 3. The Frequency of Design Pattern Usage

most used patterns in exergames with cognitive benefits, although *P6 Leverage Mental Model* and *P2 Progress Tracking* are more commonly used than *P3 Multi-sensory Feedback* in exergames with cognitive benefits. This supports the idea that efforts-reward matching, tracking mechanisms, and multi-modal sensory integration are core game mechanisms to exergame design.

In middling-frequency pattern usage ranking, *P4 Competition*, *P8 Link Gameplay to Game Theme*, and *P11 Link Physical Impact to Gameplay* are all at adaption of 64% exergames with cognitive benefits, suggesting a widely recognized design principle in more than half of the exergames. *P5 Reward the Physical Effort*, *P7 Rhythm*, *P10 Leverage the Randomness*, *P12 Strategic Memorization*, and *P13 Planted Player Stance* are at 45.5%. *P14 No Cheat, Just Sweat!* is the least common used pattern only adapted in 18% of exergames with cognitive benefits.

When we compare how four cognitive challenge related patterns *P8 Link Gameplay to Game Theme*, *P9 Too busy to get bored*, *P10 Leverage the Randomness*, *P12 Strategic Memorization* were used in exergames with cognitive benefits versus overall, we found three of four were used more frequent. Notably, *P9 Too busy to get bored* demonstrated a notable differential adoption with 64% in exergames with cognitive benefits versus only 45% in overall exergames, highlighting

its particular importance for maintaining mental engagement during physical activity. P12 *Strategic Memorization* was the only cognition-related pattern that dropped by 7%.

4.2.3 Pattern Usage by Game Genre.

Genre-specific analysis reveals distinct pattern adoption profiles across Fitness, Action, Music, and Sport game categories.

Fitness games demonstrated a wide but heterogeneous adaption to all patterns and some patterns are more selective adoption. With 100% implementation frequency limited to only *Progress Tracking* (P2) and *Multi-sensory Feedback* (P3). Strong but not universal adoption appears in *Chain The Basics* (P1) at 75%, *Leverage People’s Mental Model* (P6) at 75%, *Strategic Memorization* (P12) at 75%, and *Planted Player Stance* (P13) at 75%, while mid-tier patterns include *Reward Physical Effort* (P5) at 62.5%, *Rhythm* (P7) at 62.5%, and *Link Physical Impact to Gameplay* (P11) at 62.5%. Notably, fitness games show relatively low adoption of cognitive complexity patterns with *Too Busy To Get Bored* (P9) at only 25%, *Link Gameplay To Game Theme* (P8) at 25%, and *Leverage The Randomness* (P10) at 25%, alongside *Competition* (P4) at 37.5% and *No Cheat, Just Sweat* (P14) at 37.5%. This profile reflects the genre’s primary emphasis on measurable progress and accessible sensory feedback while revealing surprising gaps in cognitive engagement and thematic integration patterns.

Sport games showed wider adoption with 100% implementation of multiple patterns, including P2 *Progress Tracking*, P3 *Multi-sensory Feedback*, P4 *Competition*, P6 *Leverage Mental Model*, P9 *Too Busy to Get Bored*, and P11 *Link Physical Impact to Gameplay*, alongside 83% for P10 *Leverage The Randomness*, emphasizing competitive dynamics and unpredictable challenge progression inherent to sports gameplay. Interestingly, sports games show 0% adoption of both P5 *Reward Physical Effort* and P7 *Rhythm*. This seems to show that sports games derive their reward structure from competitive outcomes (winning/losing) rather than effort quantification, and they resist rhythm constraints that would feel artificial in sports contexts where timing emerges organically from gameplay rather than external musical cues. The strong presence of *Too Busy to Get Bored* (100%) in sports games suggests cognitive challenge may emerge naturally from reading opponents, predicting ball trajectories, and making split-second strategic decisions—cognitive demands inherent to sports rather than artificially layered atop movement (compared to the ones in Music genre).

Music games exhibited the most specialized profile with perfect 100% adoption of P7 *Rhythm* as expected, alongside strong implementation of P1 *Chain The Basics* at 80%, P2 *Progress Tracking* at 80%, P5 *Reward Physical Effort* at 80%, and P8 *Link Gameplay To Game Theme* at 80% reveals how music games build complexity: rather than introducing new movement types or mechanics, they create difficulty through increasingly complex timing combinations and stronger integration between musical elements and physical actions. Notably, music games show a lower adoption of cognitive complexity patterns like P9 *Too Busy To Get Bored* at only 20% and 0% for P10 *Leverage The Randomness*. It seems music games prioritize flow states achieved through rhythmic synchronization over cognitive challenge through unpredictability. Randomness would disrupt the genre’s core appeal—the satisfaction of perfectly timed movements synchronized to predictable musical beats.

Action games displayed the most balanced and moderate adoption across patterns, with 100% implementation of Reward the P6 *Physical Effort* and P8 *Link Gameplay To Game Theme*, 83% P3 for *Multi-sensory Feedback*, P11 *Link Physical Impact To Gameplay*, and P14 *No Cheat, Just Sweat!*, but notably 0% for P7 *Rhythm*, reflecting action games’ core design principle focusing on immediate, visceral feedback connecting player actions to game outcomes. The complete absence of P7 *Rhythm* (0%) distinguishes action games from music games, freeing players to respond reactively to game events rather than predictably to musical beats. This flexibility allows action games to accommodate diverse movement patterns and player strategies, making them particularly valuable templates for researchers seeking to embed cognitive

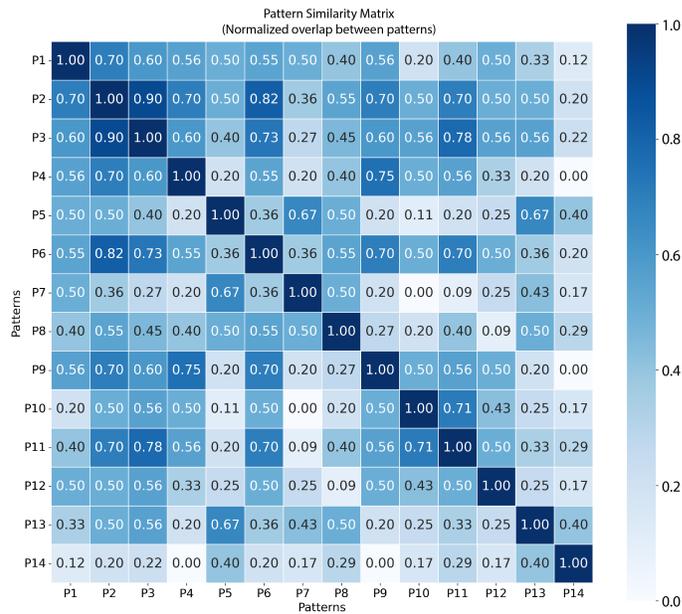


Fig. 4. Heatmap of pattern co-occurrence. The heatmap displays normalized similarity scores (0-1 scale) between all pattern pairs across 25 motion-controlled games. Darker blue indicates stronger associations, where patterns frequently co-occur relative to their individual frequencies. Diagonal values equal 1.0 (perfect self-similarity). High Jaccard scores (>0.7) reveal patterns that consistently appear together, suggesting synergistic design relationships.

challenges within intrinsically engaging moment-to-moment gameplay rather than long-term progression systems or competitive structures.

4.3 Pattern Co-occurrence

The Jaccard similarity analysis examined 91 unique pattern pairs across the 14 identified patterns that used in exergames with cognitive benefits. Jaccard coefficients ranged from 0.00 to 0.90 (Mean = 0.43, SD = 0.20), indicating substantial variability in pattern association strength. The distribution revealed that 8 pattern pairs (8.8%) exhibited very high similarity ($J \geq 0.70$), 15 pairs (16.5%) showed high similarity ($0.60 \leq J < 0.70$), 33 pairs (36.3%) demonstrated moderate similarity ($0.40 \leq J < 0.60$), and 35 pairs (38.5%) displayed low similarity ($J < 0.40$).

Eight pattern pairs exhibited very high similarity ($J \geq 0.70$), representing the strongest design associations in the corpus. The highest similarity was observed between P2 *Progress Tracking* and P3 *Multi-sensory Feedback* ($J = 0.90$), followed by P2 *Progress Tracking* and P6 *Leverage Mental Model* ($J = 0.82$), and P3 *Multi-sensory Feedback* and P11 *Link Gameplay to Game Theme* ($J = 0.78$).

Additional high-similarity pairs included P4 *Competition* and P9 *Too Busy to Get Bored* ($J = 0.75$), P3 *Multi-sensory Feedback* and P6 *Leverage Mental Model* ($J = 0.73$), P10 *Leverage the Randomness* and P11 *Link Physical Impact to Gameplay* ($J = 0.71$), P1 *Chain the Basics* and P2 *Progress Tracking* ($J = 0.70$), and P2 *Progress Tracking* and P4 *Competition* ($J = 0.70$). Notably, P2 *Progress Tracking* appeared in five of the eight highest-similarity pairs, followed by P3 *Multi-sensory Feedback* and P6 *Leverage Mental Model*, each appearing in three high-similarity pairs, suggesting these patterns serve as structural hubs in exergame design.

885 Conversely, several pattern pairs exhibited minimal co-occurrence. The lowest similarity was observed between
886 P4 *Competition* and P14 *No Cheat, Just Sweat* ($J = 0.00$), P7 *Rhythm* and P10 *Leverage the Randomness* ($J = 0.00$),
887 and P9 *Too Busy to Get Bored* and P14 *No Cheat, Just Sweat!* ($J = 0.00$), indicating these patterns typically function
888 independently across the analyzed games. Additional weakly associated pairs included P10 *Leverage the Randomness*
889 and P5 *Reward the Physical Effort* ($J = 0.11$), P1 *Chain the Basics* and P14 *No Cheat, Just Sweat!* ($J = 0.12$), and P10
890 *Leverage the Randomness* and P14 *No Cheat, Just Sweat!* ($J = 0.17$). P14 *No Cheat, Just Sweat!* appeared in six of the ten
891 lowest-similarity pairs, suggesting this pattern represents a distinct design approach that is rarely combined with other
892 cognitive or challenge-related patterns in current exergame implementations.
893
894

895 4.4 Pattern Categorization with Exertion Framework

896 We used the exertion framework to analyze the identify patterns, combining body-centric perspectives with gaming
897 schemas, see Fig. 5, which motivated us to examine how well current exertion frameworks capture the cognitive
898 dimensions of exergame design. Across game schemas, patterns cluster heavily in Rules (7 patterns) and Context (6
899 patterns), with only 1 pattern addressing Play experiences directly. The Rules schema encompasses both uncertainty-
900 based patterns (randomness, movement chaining) and awareness-focused patterns (mental models, competition, game
901 theme, cognitive occupation, cheating prevention), while Context patterns concentrate on understanding mechanisms
902 like reward systems, physical impact linkage, feedback modalities, progress tracking, and memorization support, with
903 risk mitigation through planted stances.
904

905 *The Moving Body* lens accounts for the highest concentration with 5 patterns, reflecting the fundamental challenge
906 of translating physical movement into engaging gameplay through mechanisms such as chaining basic movements,
907 preventing cheating behaviors, rhythm integration, and linking physical impact to game outcomes. *The Responding*
908 *Body* (2 patterns) addresses how players react to game stimuli through planted player stances and effort-based rewards,
909 while both *the Sensing Body* (2 patterns) and *the Relating Body* (2 patterns) support engagement through multi-sensory
910 feedback, progress tracking, competition, and strategic memorization mechanisms.
911

912 Four patterns that related to cognitive challenges, P8 *Link Gameplay to Game Theme*, P9 *Too Busy to Get Bored*, P10
913 *Leverage Randomness*, and P12 *Strategic Memorization* did not fit neatly into the original taxonomy (Fig. 2).
914

915 5 Discussion

916 This study sought to unlock the hidden code in exergames with high cognitive benefit potential and merge it with the
917 secret sauce from commercial game designers who make highly appealing games. Our novel and collaborative approach
918 used pattern language methodology to generate evidence-based design solutions through workshops involving both
919 game designers and cognitive scientists. By identifying design patterns that consistently appear across exergames with
920 evidenced cognitive benefits [12, 46, 61, 68] and observing the frequency of pattern usage and co-occurrence of patterns,
921 we provide a shared vocabulary and explicit framework for documenting design rationale, pattern generation enabled
922 game designers and cognitive scientists to synthesize diverse expertise efficiently. The resulting patterns encode not
923 just design solutions but the contextual reasoning behind the design decision, creating reusable building blocks that
924 can inform future design decisions across different projects and teams.
925

926 Through collaborative pattern generation workshops involving seven game designers, HCI researchers, and cognitive
927 scientists, we identified 14 recurring design patterns across 25 exergames. These patterns demonstrated varied applica-
928 bility: some patterns were specific to exergames (e.g. P13 *Planted Player Stance* and P14 *No Cheat, Just Sweat*), while
929 others exhibited broader transferability to general game design (e.g. P4 *Competition* and P2 *Progress Tracking*). Pattern
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		The Responding Body	The Moving Body	The Sensing Body	The Relating Body	The Thinking Body
RULE	Uncertainty		Chain the Basics			Leverage Randomness
	Awareness		Leverage People's Mental Model No Cheat, Just Sweat!		Competition	Game Theme Too Busy to Get Bored
PLAY	Expression					
	Rhythm		Rhythm			
CONTEXT	Risk	Planted Player Stance				
	Understanding	Rewards the Physical Effort	Link Physical Impact to Gameplay	Multi-sensor Feedback	Progress Tracking	Strategic Memorization

Fig. 5. Patterns Categorization with Extended Exertion Framework. We extend this framework by adding a fifth lens: the Thinking Body, which addresses cognitive processes including attention, memory, and decision-making during exergaming.

applications further clustered into functional categories—those directly enhancing user experience and accessibility (P6 *Leverage People’s Mental Model*), and those introducing cognitive challenge (e.g. P9 *Too Busy to Get Bored*, P10 *Leverage Randomness*, and P12 *Strategic Memorization*). This diversity demonstrates that interdisciplinary collaborative workshops can effectively capture multifaceted design solutions spanning accessibility, engagement, and therapeutic effectiveness.

Interestingly, several identified patterns aligned with established empirical findings from behavior and neuroscience literature. P3 *Multi-sensory Feedback’s* emphasis on synchronized visual, auditory, and haptic cues corresponds with research demonstrating that multisensory feedback significantly enhances motor task performance and reduces reaction time in virtual environments [19, 28]. P2 *Progress Tracking’s* implementation of visible achievement systems mirrors exercise adherence research showing that self-monitoring through training logs and progress visualization substantially increases motivation and exercise persistence by providing concrete feedback and enabling individuals to recognize improvement over time [69].

Pattern frequency and co-occurrence analyses revealed that P2 *Progress Tracking* (88%), P3 *Multi-sensory Feedback* (88%), and P6 *Leverage People’s Mental Model* (90% in cognitively beneficial games) not only appeared in the vast majority of exergames but frequently co-occurred, suggesting these patterns function as foundational design elements in exergame architecture. When comparing pattern adoption between games with evidenced cognitive benefits and the overall corpus, P9 *Too Busy to Get Bored* exhibited particularly distinctive usage patterns—appearing in 64% of cognitively beneficial games versus only 45% overall. This pattern, which layers cognitive challenges atop repetitive physical actions to occupy mental bandwidth and distract from exertion discomfort. This differential adoption provides researchers with a concrete mechanism for intensifying cognitive demands while maintaining engagement, potentially offering a detection strategy for identifying design elements that promote cognitive enhancement.

Genre-specific pattern analysis revealed distinct design preferences and mechanisms inherent to different game categories. P7 *Rhythm* appeared in 100% of music games but 0% in sports and action games, while P10 *Leverage Randomness* was absent from music games yet present in 83% of sports games. These genre-specific preferences reflect fundamental differences in gameplay philosophy: music games prioritize flow states through predictable rhythmic synchronization,

989 whereas sports games derive engagement from unpredictable challenge progression. For designers, strategically se-
990 lecting patterns based on target genre conventions may enhance design efficiency by leveraging established player
991 expectations and proven mechanics within each category.
992

993 In addition, our framework-based categorization reveals both the utility and limitations of current exertion frame-
994 works for analyzing cognitive exergames. Mueller et al.'s Exertion Framework was created to provide design and
995 analytical insight for the creation and discussion of exergames. The original exertion framework, developed primarily
996 for physical activity games, provides insufficient vocabulary for discussing cognitive design intentions. When we began
997 analyzing the patterns in the context of this framework, we determined that four patterns did not fit neatly into the
998 taxonomy: P8 *Link Gameplay to Game Theme*, P9 *Too Busy to Get Bored*, P10 *Leverage Randomness*, and P12 *Strategic*
999 *Memorization*. P8 is about leveraging a theme to improve engagement, P9 is about increasing cognitive load to reduce
1000 mental bandwidth and distract from exertion, P10 is about constantly asking the player to apply what they have learned
1001 to new situations, and P12 is about centering gameplay around pattern recognition and recall for combinations. Each
1002 of these patterns engages with an element that is underrepresented in Mueller et al.'s exertion framework: cognitive
1003 engagement.
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1006 Digital games demand cognitive engagement inherently [11], and have been widely adapted for cognitive training to
1007 enhance brain functions [3, 13]. It is unsurprising that several patterns focus more on engaging mental efforts over
1008 physical efforts. This innate cognitive engagement inspired studies on how digital games could be used to evaluate and
1009 train many cognitive functions, such as executive function, global cognition, attention, memory, processing speed, and
1010 visuospatial skills [16]. Since our research specifically examines cognitive engagement within exergames for older adults,
1011 we extend this framework by adding a fifth lens: *the Thinking Body*, which addresses cognitive processes including
1012 attention, memory, and decision-making during exergaming. Considering the four lenses from the Exertion Framework,
1013 the complementary aspects of gameplay, and our addition of the Thinking Body lens, we categorized the patterns as
1014 depicted in Fig.5.
1015
1016
1017

1018 5.1 Contributions to Design Practice and Research

1019 Our approach provides a replicable model for capturing and synthesizing design knowledge across disciplines, particu-
1020 larly valuable for serious games and health-focused interactive systems where technical, clinical, and design expertise
1021 must be integrated [14, 23].
1022

1023 Our findings challenge conventional genre-based approaches to understanding cognitive benefits in games. Current
1024 research often attributes cognitive outcomes to broad game genres—suggesting [59], for example, that "Puzzle games
1025 improve working memory." or "Strategy games improves decision making." However, this approach risks oversimpli-
1026 fication and potential misapplication, as not all puzzle games engage executive function equally. Our pattern-based
1027 approach reveals that cognitive benefits likely emerge from specific design elements and mechanisms rather than
1028 genre conventions. By identifying patterns like *Strategic Memorization* or *Too Busy to Get Bored* that appear across
1029 multiple genres yet consistently in cognitively beneficial games, we suggest that these discrete design elements—not
1030 genre categories—drive cognitive engagement. This granular perspective opens new possibilities: designers could
1031 potentially transplant cognitive-benefit-conferring elements from one genre into another, creating novel combinations
1032 that maintain genre-specific appeal while incorporating evidence-based cognitive training mechanisms.
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1035 Second, these patterns offer actionable solutions to recurring challenges for designers. Rather than prescriptive rules,
1036 these patterns function as a shared vocabulary enabling designers to communicate design intentions and trade-offs when
1037 balancing playability, accessibility, and cognitive challenge. For cognitive researchers, the patterns illuminate which
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commercial game features consistently appear in games demonstrating cognitive benefits, providing evidence-based starting points for intervention design. The differential adoption of cognitive engagement patterns (*Too Busy to Get Bored*, *Strategic Memorization*, *Leverage Randomness*) between cognitive and general games provides researchers with concrete mechanisms for intensifying cognitive demands while maintaining engagement.

Most importantly, these patterns bridge disciplinary vocabularies: where cognitive scientists might discuss "dual-task paradigms," game designers recognize "Too Busy to Get Bored"; where researchers reference "variable practice schedules," designers implement "Leverage Randomness." This translation enables genuine collaboration rather than parallel development, potentially accelerating the translation of laboratory-validated interventions into engaging, community-deployable games that older adults will actually play long-term.

6 Limitations and Future Directions

Several important limitations constrain the generalizability and immediate applicability of our findings. First, our pattern generation and validation involved only 25 exergames, a relatively small sample that may not capture the full diversity of design approaches in this rapidly evolving space. The patterns identified represent recurring solutions within this specific corpus but should not be considered universally applicable design principles without further validation across broader game collections.

Second, our study examined games that have been tested for cognitive effectiveness alongside popular commercial exergames, but the absence of a pattern in untested games does not indicate those games lack cognitive potential. Many commercially successful exergames have simply not yet been evaluated in clinical studies with older adults, and the reverse is equally true—some patterns we identified may appear in games that ultimately prove ineffective for cognitive outcomes when rigorously tested. The correlational nature of our analysis cannot establish causation between pattern presence and cognitive benefit.

Third, while our collaborative pattern generation methodology proved productive for capturing design knowledge, these patterns require validation with end-users and designers outside our workshop context [26]. The theoretical soundness of the patterns must be tested through practical implementation in real game development projects to assess their effectiveness in creating engaging, accessible, and beneficial movement-based experiences for older adults. Empirical validation of pattern effectiveness through controlled development studies would strengthen the empirical base for design decisions in this critical application domain [51]. The broader challenge of increasing genre diversity in exergaming also warrants investigation. Research exploring how complex gameplay mechanics can be effectively adapted to movement-based interfaces could expand the therapeutic and engagement potential of these systems beyond current limitations.

In addition, we analyzed games for general cognitive benefits without distinguishing between specific cognitive domains (working memory, attention, executive function, processing speed) [54]. Future research should examine relationships between specific patterns and particular cognitive outcomes, enabling more targeted intervention design. For instance, *Strategic Memorization* might specifically support working memory while *Leverage Randomness* might preferentially engage cognitive flexibility and executive function. Such domain-specific pattern analysis would allow researchers to deliberately compose pattern combinations targeting specific cognitive deficits rather than relying on broad "cognitive benefit" classifications.

While our diverse expertise produced comprehensive patterns, spanning multiple dimensions of game design, the specific knowledge domains represented by participants directly shaped the types of solutions identified. The relative scarcity of cognitively focused patterns suggests that meaningful interdisciplinary pattern generation requires

more balanced representation of domain expertise, particularly when addressing specialized applications such as health interventions. Future pattern generation efforts should ensure a more balanced interdisciplinary representation, particularly including more clinical and cognitive intervention specialists [43].

Finally, while existing framework may have limitations in analyzing and designing exergames for cognitively benefits, presenting research opportunities for developing new frameworks in the future. Additionally, it is worth noting that neither Mueller’s framework nor our extended framework explicitly addresses dimensions of accessibility and user experience for special populations (such as older adults and individuals with disabilities). Future scholars need to focus on developing population-specific game design frameworks, particularly as game-for-health research must consider how accessibility impacts long-term game engagement.

7 Conclusion

This study investigated the hidden code behind the potential cognitive benefits of exergame design by adapting pattern language methodology to capture design knowledge through interdisciplinary collaboration. Through collaborative pattern generation workshops with game designers and cognitive researchers, we identified 14 evidence-based design patterns spanning eight perspectives combining body-centric perspective with gaming schemas, demonstrating the methodology’s efficiency in synthesizing diverse expertise within structured time frames. This work contributes to the design community by providing empirical evidence of research-to-practice gaps in health-focused gaming, introducing collaborative pattern generation as a viable methodology for interdisciplinary design projects, and delivering concrete design guidelines that enable both researchers and practitioners to create more engaging, accessible, and therapeutically effective exergames for older adults while establishing a foundation for expanding exergaming beyond its current genre limitations.

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