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The Impact of Game-Based Interventions on Adult Cognition: A Systematic Review

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ABSTRACT

This 10-year systematic review examines the impact of game-based interventions (GBI) on adult cognition, covering game-based learning and training, serious games, gamification, and exergames. The research followed PRISMA guidelines and Cochrane recommendations for bias assessment. We reviewed 1,398 articles and selected 42 studies (26 randomized trials, 16 non-randomized). Our findings highlight the influence of contextual factors on GBI, such as culture and individual traits. We emphasize the predominance of digital over analog applications, reflecting GBI's connection to Human-Computer Interaction (HCI). This review underscores GBI's interdisciplinary nature and the need for high-quality research standards. We examined 23 outcome categories and found positive effects in areas like Satisfaction, Flow, Learning, Motivation, and Perception, though with varying bias risks. On average, GBI designs incorporated nine game elements. Most interventions used Puzzle and Simulation genres, were single-player, 2D, and computer-based. Innovations in neurophysiological tools, movement monitoring, and virtual reality offer promising HCI research avenues.

KEYWORDS

Games; gamification; adult cognition; interdisciplinary projects; human-computer interaction

1. Introduction

This systematic review explores the impact of game-based interventions (GBI) on healthy adult cognition. Games, once for entertainment, are now part of the ludification of culture (Carvalho & Coelho, 2022; Raessens, 2006). Games and their different applications have been studied for years by researchers from different fields, i.e., education science, game studies, neuroscience, information science, and human-computer interaction (HCI) (de Freitas, 2018; Dias et al., 2022), leading to an interdisciplinary area (Landers et al., 2018). Different settings (e.g., work, education, healthcare, and others) justify game use, digital or non-digital (Coelho & Abreu, 2023; Soo & Aris, 2018). GBI have become increasingly popular for incorporating games into various settings to enhance cognitive, behavioral, and motor outcomes (Krath et al., 2021; López-Nava et al., 2023). GBI are also valuable for HCI, enhancing user experiences in digital environments by supporting feedback, perceived value, motivation, enjoyment, information quality, engagement, ease of use, entertainment, and positive interactions (de Sales et al., 2022; Putri & A, 2022). GBI encompasses various game-based approaches such as game-based learning, training, serious games, gamification, and exergames, by promoting skill development and behavioral improvement through engaging and playful processes (Ferreira-Brito et al., 2019), with each approach offering distinct benefits.

Game-based learning integrates games into educational curricula (Prensky, 2001; Ragni et al., 2023), offering three approaches: student involvement in game design, development of specific games for teaching, and integration of existing games into learning (Ragni et al., 2023; Van Eck, 2015). Game-based training utilizes games to encode and train specific skills, enhancing their real-world application (Wang et al., 2021). Serious games are full-fledged games (Deterding et al., 2011, 2013) created initially in 1987 for educational purposes, aiming beyond mere entertainment to educate, motivate, and simulate real-life scenarios (Abt, 1987; Min et al., 2022). Unlike serious games, gamification is not a full-fledged game, but the use of its elements in non-game contexts (Deterding et al., 2011, 2013), aiming to transform real-world contexts into engaging experiences (Landers et al., 2018). Finally, game-based exercises, or exergames (Phirom et al., 2020), merge physical activity with gaming, enhancing engagement and enjoyment while promoting bodily movement (Huang et al., 2022; López-Nava et al., 2023).

This systematic review emphasizes the cognitive impacts of GBI. Cognitive psychology investigates how we acquire and represent knowledge about ourselves and the world, and how this knowledge guides behavior, while cognitive neuroscience examines the intricate relationship between brain function and cognitive processes (D'Esposito et al., 2012; Kihlstrom & Park, 2018). Both disciplines study various cognitive domains, focusing on mental processes and their neural foundations, such as perception, attention, memory, learning, imagery, problem-solving, decision-making, executive functions, reasoning, language, sensorimotor, and emotions (Anderson,

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2020; Friedenberg et al., 2021; Poeppel et al., 2020). Nonetheless, rather than focusing on specific cognitive domains, here we aim to broadly investigate the overall cognitive outcomes of GBI in healthy adults, in order to consider the previously cited cognitive domains, as well as other identified outcomes in the literature as influential on cognition.

Systematic reviews clearly define the questions being addressed and their relevance to key concepts. For interventional studies, this typically involves using the PICO framework (Participants, Interventions, Comparisons, Outcomes), which aids in formulating specific search terms and keywords associated with the topic under investigation (Pati & Lorusso, 2018). Considering the above, our main research question was established based on the PICO framework (Table 1), specifying the target population (healthy adults), interventions or exposures (game-based intervention), comparators (non-game-based intervention), and relevant outcomes (cognition outcomes).

In addition to the main research question (i.e., what is the impact of GBI on healthy adult cognition?), we examined four secondary objectives concerning the literature about GBI and adult cognition: (1) What is the risk of bias in these studies?; (2) What are the population characteristics and types of GBI used?; (3) What literature and theories are referenced in the studies?; and (4) What game characteristics are implemented in GBI?

2. Material and methods

Our systematic review adhered to the PRISMA guidelines (Page et al., 2021). Before initiating the review process, we registered the study protocol in PROSPERO (registration number CRD42021282683). Before initiating this review, we searched the PROSPERO database, and no other similar protocol was found (October 2021).

2.1. Eligibility criteria

Concerning the inclusion criteria, we contemplated the topics illustrated in Table 2, according to the PICO and research question.

Concerning the exclusion criteria, we contemplated the topics illustrated in Table 3.

2.2. Information sources and search strategy

The systematic search strategy was devised in collaboration with skilled librarians from our local University and it was carried out in June 2022 in the following databases: Web of Science, Scopus, ERIC, PubMed, APA, and ACM Digital Library. Therefore, studies from 2012 through June 2022 were considered. Our query was elaborated according to PICO, but without any specific reference to the population (adults), as this could substantially restrict the results. Thus, we opted to manually identify the study samples. Further, as we mentioned above, we chose inclusive terminology to encompass a wide range of cognitive outcomes, rather than focusing narrowly on specific domains. Moreover, we added a research design criterion to filter in the pertinent articles. These criteria were:

Intervention and Control: (gamification OR gameful OR gamified OR "game-based" OR "serious game" OR "game-like");

Outcomes: (cognition OR cognitive);

Research design: (experiment* OR quasi-experimental OR rct OR randomized OR non-randomized OR trial OR "control group").

The final query was: (gamification OR gameful OR gamified OR "game-based" OR "serious game" OR "game-like") AND (cognition OR cognitive) AND (experiment* OR quasi-experimental OR rct OR randomized OR non-randomized OR trial OR "control group"). All the primary searches were conducted by attending to the query in the title and abstract.

2.3. Selection process

The study selection process began with database searches conducted with the assistance of UCP librarians. Retrieved

Table 2. Inclusion criteria.

Inclusion criteria	Description
Population	Only studies concerning neurotypical healthy adults (more than 18 years old without any kind of impairment).
Intervention	Only studies that used gamification, game-based training, game-based learning, serious games, and exergames as an intervention.
Control	To ensure the effectiveness of the intervention, we included only original non-randomized control trials and randomized control trials with an active control group. The control groups had to receive a similar intervention but without the use of gamification, game-based training, game-based learning, serious games, or exergames.
Outcomes	Only studies related to cognition.

Table 3. Exclusion criteria.

Exclusion criteria	Description
Publication date	Studies before 2011, to contemplate the most recent data.
Type of study	Studies that were not peer-reviewed, i.e., conference papers, books, Master and Ph.D. dissertations, protocols, and workshops, to contemplate data from studies with more scientific rigor and quality.
Intervention	Studies that used commercial video games as intervention, as we focused on game-based intervention, i.e., game-based learning, training, exercises, serious games, and gamification.
Language	Studies that were not English-language, selecting only studies from international journals.

Table 1. Research question (PICO).

PICO	Population	Intervention	Comparator	Outcome
Research question	Healthy adults	Game-based intervention	Non-game-based intervention	Cognitive outcomes

studies were managed using Zotero and then imported into Rayyan for screening (Ouzzani et al., 2016). The first and third authors reviewed titles and abstracts, removing duplicates and applying inclusion/exclusion criteria. Any uncertainties were marked as "maybe" for further analysis. Disagreements were resolved with input from the second author. The Rayyan tool data are illustrated in Appendix A (Coelho et al., 2024b).

2.4. Data collection process and items

The first and third authors created and fulfilled an extraction sheet to systematize and analyze data from all included studies, according to the criteria from Table 4.

2.5. Reporting aims

This systematic review aims to evaluate how GBI affect healthy adult cognition. We have also considered four secondary objectives, as previously cited. Thus, Section 3 (Results) is divided into five parts, aligned with the five research objectives (the main objective and the four additional ones). The first part covers data selection and bias assessment, introducing extracted studies and categorizing them based on the risk of bias. The second part discusses general study characteristics like nationality, gender, age, and types of GBI examined. The third part explores literature and theories referenced in the studies to justify GBI use. The fourth part, related to the main objective of this systematic review, analyzes outcomes from all studies, comparing intervention (IG) and control groups (CG) across various variables to assess GBI effectiveness. Lastly, the fifth part examines GBI characteristics, i.e., their game elements and features, identifying patterns and disparities in their impact on adult cognition.

2.6. Study risk of bias assessment

The risk of bias assessment followed Cochrane Collaboration's guidelines (Higgins et al., 2023). All articles were analyzed and judged firstly by the first and third authors and then by the second author when necessary. For randomized trials, we used the Risk of Bias tool for randomized trials (RoB 2.0). We analyzed and scored six domains as high risk, low risk, or some concerns. The domains were: (1) Randomization process; (2) Deviations from intended interventions; (3) Missing outcome data; (4) Measurement of the outcome; and (5) Selection of the reported results (Higgins et al., 2023). For non-randomized trials, we used the Risk of Bias Tool In Non-randomized Studies of Interventions (ROBINS-I). We analyzed and scored seven domains as low, moderate, serious, or critical risk. The domains were: (1) Confounding; (2) Selection of participants; (3) Classification of interventions; (4) Deviations from intended interventions; (5) Missing data; (6) Measurements of the outcome; and (7) Selection of the reported results (Sterne et al., 2016). Visual representations were generated using the Robvis tool (Figures 2–5) (McGuinness & Higgins, 2021). In addition, the studies' external and model validity were analyzed using the External Validity Assessment Tool (EVAT©) (Khorsan & Crawford, 2014) and further described in another study (Coelho et al., 2024a). According to this analysis, half of the studies provided insufficient descriptions of recruitment, and the majority lacked clarity regarding participation, impacting the generalization of results. Conversely, model validity was well addressed in most studies, enhancing understanding of staff, locations, and facilities utilized.

Table 4. Extraction criteria.

Main categories	Subcategories
General data	(1) Study design; (2) Goals; (3) Sample size; (4) Age of participants; (5) Sex of participants; (6) Country of research; (8) Main literatures and theories; (8) Game-based category; (9) Type of training; (10) Cognitive domain; (11) Procedures; (12) Intervention group; (13) Control group; (14) Data availability; (15) Source of funding; (16) Journal of publishing; (17) Context of research
Outcome data (main research question)	(1) Intervention group; (2) Control group; (3) Category of outcome; (4) Measure type; (5) Outcome measure; (6) Significance; (7) Effect; (8) Reverse or not reverse result
GBI characteristics	(1) Game-based project; (2) Description; (3) Game-based theory; (4) Game-based literature; (5) Game-based project development; (6) Game elements interpretation; (7) Game elements used; (8) Genres; (9) Social mode; (10) Design; (11) Technological interaction

2.7. Effect measures and synthesis methods

We tabulated and analyzed all studies based on predefined criteria. In the fourth part of Section 3 (Results), we used significance expression (Table 5) to compare outcomes between IG (GBI) and CG (non-GBI), following statistical guidelines for *p*-values (Arsham, 1988). We focused on comparing outcomes between GBI and non-GBI groups, not within them. Some outcomes were treated as "reverse," indicating opposite consequences, such as "disengagement" to measure "engagement" and "cognitive bias" to measure "cognitive bias mitigation."

2.8. Reporting bias assessment

We used the risk of bias assessment (RoB 2.0 and ROBINS-I) to evaluate outcome certainty and quality. In Section 3 (Results), we provided a comprehensive analysis of all studies, without distinguishing based on bias, except in the fourth part focusing on outcomes and significance, where we used multiple (stratified) analyses of studies (Higgins et al., 2023). We stratified studies into three bias groups: (1) All studies, (2) Low risk, and (3) Moderate to serious bias. This stratification helped assess outcome significance relative to study quality, enhancing the credibility of the data analysis in the ensuing Section 3 (Results) and Section 4 (Discussion).

3. Results

3.1. Selection data and bias assessment

A total of 1398 articles were obtained from the databases. We eliminated 615 duplicate records and screened 783 titles and abstracts, according to the inclusion and exclusion criteria. Thus, 66 reports were sought for retrieval, from which

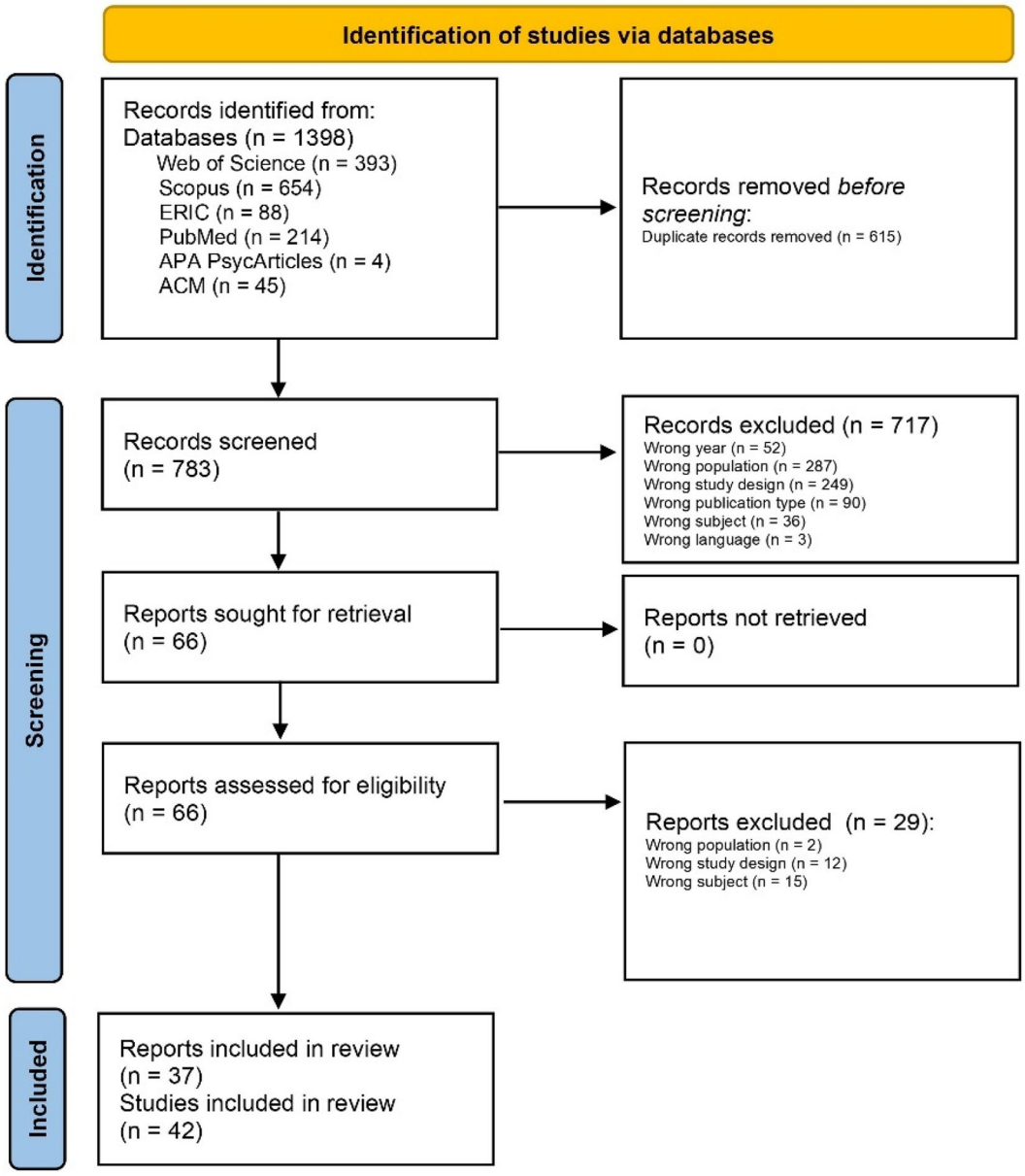


Figure 1. Prisma flow diagram.

37 were included in this review after the full-text analysis. There was one report that included three different studies, and three reports that included 2 different studies, totaling 42 studies. The PRISMA flow diagram with this process is illustrated in Figure 1.

Considering the 42 studies, 26 adopted a randomized control trial method (62%) while 16 followed a non-randomized control trial method (38%). The studies list is shown in Appendix B (Coelho et al., 2024b). By using the RoB 2.0 tool for the randomized experiments, we classified nine studies as low-risk (35%) and 17 had some concerns (65%). Most biases were related to the randomization process, followed by the measurement of the outcome. For the non-randomized experiments, we used the ROBINS-I tool and we classified seven as low-risk (44%), four had moderate-risk (25%) and five had serious risk (31%). The evaluation of the quality of the randomized and non-randomized studies is illustrated in Figures 2 and 3 and in Figures 4 and 5, respectively.

3.2. General characteristics

3.2.1. Nationality

We contemplated the nationality of the participants in the study, as the authors could be from different countries, and such analyses could lead to bias. We found that the studies were mainly from the USA (11), followed by Germany (7), Taiwan (7), the Netherlands (3), China (2), South Korea (2), Malaysia (2), Switzerland (1), Poland (1), Czech Republic (1), Canada (1), Greece (1), Thailand (1), Brazil (1), and Japan (1). The illustrative map is in Figure 6.

3.2.2. Gender

Concerning gender, four studies did not report it (Bakri et al., 2021; Luengvilai et al., 2021; Rhodes et al., 2017). The remaining 38 studies totalized 5318 participants, combining 3058 women (57.50%), 2258 men (42.46%), and 2 others (0.04%), as illustrated in Figure 7.

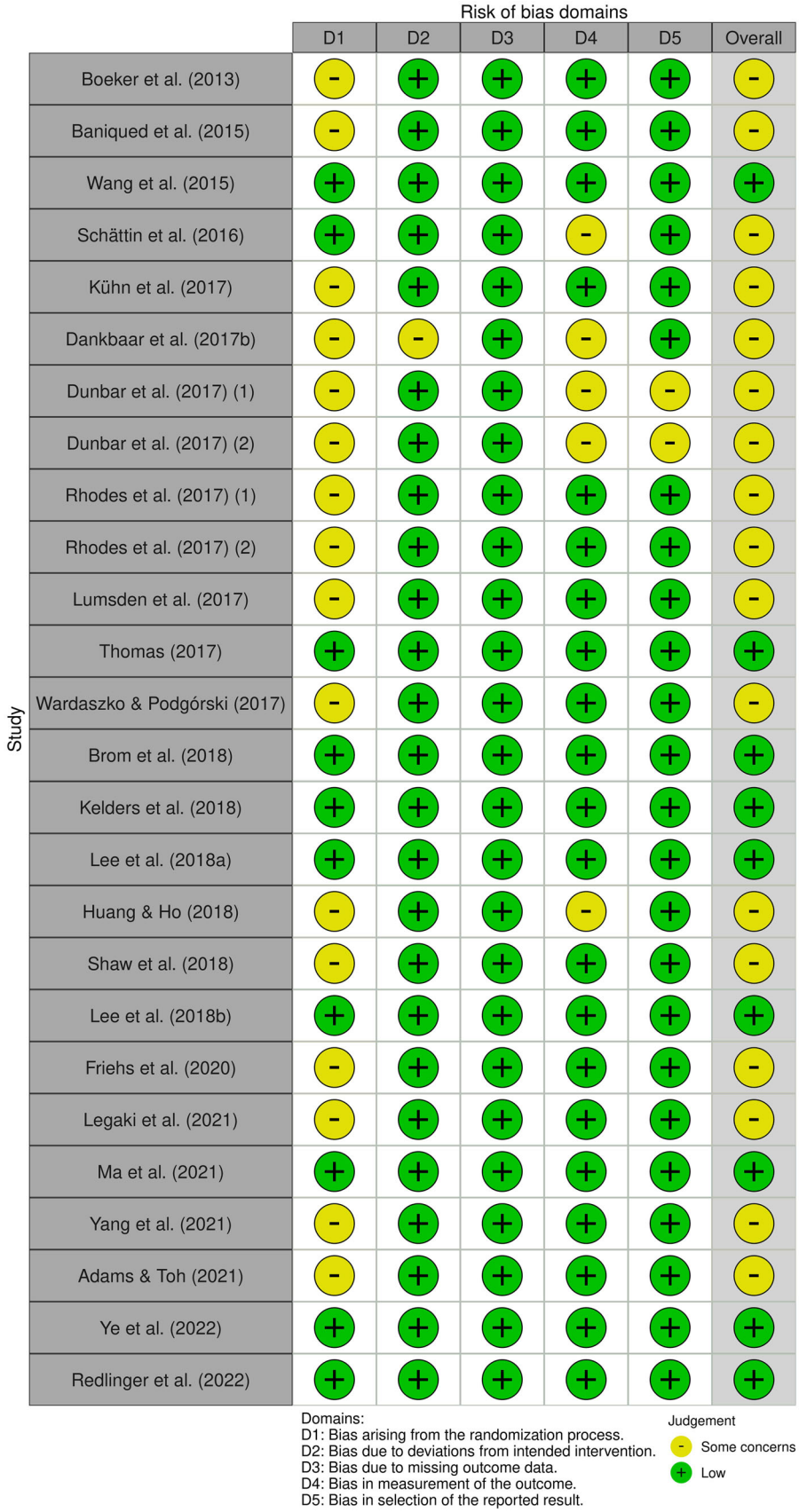


Figure 2. RoB 2.0 (Traffic Light Plot).

3.2.3. Age

We considered the minimum, maximum, and average age of each study, with some considerations. Five studies (Chan et al., 2021; Chang et al., 2017, 2018; Huang & Ho, 2018; Ye et al., 2022) only described the age average, so there was no range between the lowest and highest age. Eight studies

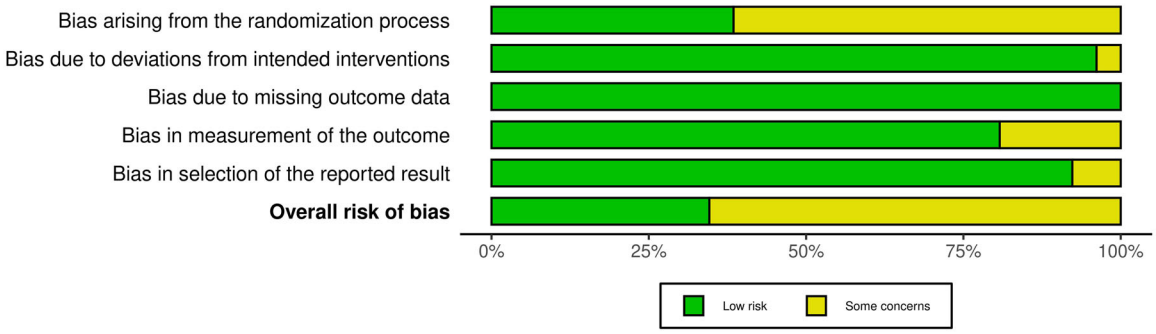


Figure 3. RoB 2.0 (Summary Plot).

described the participants only as college students (Bakri et al., 2021; Boeker et al., 2013; Luengvilai et al., 2021; Oo, 2022; Rhodes et al., 2017; Wang et al., 2015; Wu, 2018) and one study described them as college and MBA students (Legaki et al., 2021). The other 28 studies showed complete age data (minimum, maximum, and average). Thus, considering these 28 studies, plus the five ones that reported only the average age, the participants' average age was 28.85 years old, with a minimum of 18 and a maximum of 83 years old, and the median was 31 years old, as shown in Figure 8. The nine studies that presented the participants only as college or MBA students were excluded from this age analysis due to the lack of information. However, they were included in all other analyses.

3.2.4. Type of game-based intervention

Concerning the type of GBI, 15 studies used gamification as an intervention (36%), 12 studies used game-based learning (29%), nine studies used serious games (21%), five studies used game-based training 12%), and 1 study used exergames (2%). From these interventions, 34 were general digital applications (81%), four were digital applications with a focus on mobile (10%), two were digital and analogic, i.e., non-digital applications (5%), one was analogic only (2%), and one application was digital with a focus on mobile and virtual reality (2%). Figure 9 illustrates this data.

3.3. Literature and theories

We categorized the literature and theories used in the studies into two groups: (1) Main literature, providing foundational context for the study, and (2) Game-based literature, used to develop the games in the research design. The main literature often referenced Games theories, Psychology, Cognition, and Learning. Among these, Games theories were the most prevalent, featured in 39 studies, followed by Psychology, Cognition, and Learning, each appearing in 22 studies. These findings are summarized in Table 6, and visually represented in Figure 10.

Regarding the Game-based literature, only 22 studies used theories to justify the games used in the research design, while 20 studies did not use any. Figure 11 illustrates this.

Concerning those 22 studies that sustained games with literature, the most frequently encountered references were related to Games theories, featured in 8 studies. Following this, we observed references to Psychology in 8 studies; Learning in 6 studies; Cognition in 4 studies; Instructional Design in 3 studies; and User Experience in 2 studies. Table 7 provides a breakdown of the studies per reference, and Figure 12 visually represents all the literature and theories categorized by their respective subjects.

3.4. Outcomes

Due to varying bias levels, we conducted stratified analyses of studies (Higgins et al., 2023), categorizing them into three groups: (1) All studies, (2) Low risk, and (3) Moderate to serious bias. Then, we categorized all the studies' outcomes into 23 categories, according to their subject. Table 8 summarizes our findings within each outcome category.

Our analysis focused on comparing the performance of GBI against non-GBI across various outcomes, emphasizing significant findings. We only considered IGs using GBI and CGs employing non-GBI for comparison. We used outcome measures, particularly *p*-values, to determine significance, as detailed in Section 2.6 (Material and Methods – Effect measures and Synthesis methods). We examined whether the IG, compared to the CG, exhibited a higher (IG > CG), equal (IG = CG), or lower (CG > IG) outcome value with significant results. We grouped all outcome analyses into the specified categories outlined in Table 8, based on the descriptions and related concepts from the studies. These categories were divided into two types: cognitive outcomes and cognitive-related outcomes. The cognitive outcomes include those commonly discussed within cognitive psychology and neuroscience (Anderson, 2020; Friedenberg et al., 2021; Poeppel et al., 2020), such as the cognitive domains mentioned in Section 1 (Introduction). The cognitive-related outcomes include categories not intrinsically tied to those domains, but also relevant to cognition. By combining the outcome descriptions from the analyzed studies with the classification frameworks from cognitive psychology and neuroscience literature, we created a comprehensive list of outcome categories, with the details of the outcomes used within the studies (Table 8). Further explanations of the key details and concepts within each outcome category will be provided in Section 4 (Discussion). This approach allowed us to explore the cognitive outcomes in the literature comprehensively, facilitating diverse reflections on the broad impact of GBI. Refer to Appendix C for detailed outcomes (Coelho et al.,



Figure 4. ROBINS-I (Traffic Light Plot).

2024b). Notably, comparison results do not imply superiority but rather indicate significant differences in specific outcomes, to be discussed further in Section 4.4 (Discussion – Outcomes).

Finally, we summarize outcome categories based on three credibility levels: (1) Strong credibility (results from low bias studies), (2) Medium credibility (results from a mix of low and moderate to serious bias studies), and (3) Weak credibility (results from moderate to serious bias studies).

3.4.1. Analysis of studies

We divided the analysis of studies into (1) All studies, (2) Low risk of bias, and (3) Moderate to serious risk of bias. Table 9 illustrates all the data from all outcome categories divided into these three different analyses. Percentages indicate the proportion of outcomes within each category that showed a higher (IG > CG), equal (IG = CG), or lower (CG > IG) value between the IG and CG, all with statistically significant results ($p < 0.05$).

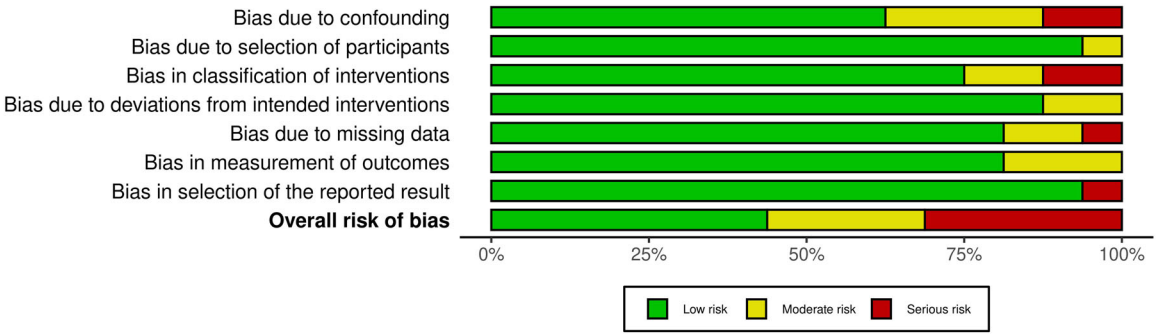


Figure 5. ROBINS-I (Summary Plot).

Table 5. Significance expression.

Significance	*p*-Value
Significant	≤0.05
Very significant	≤0.01
Extremely significant	≤0.001

The analysis of all studies showed that the outcome categories with the highest proportion favoring the IG (IG > CG) were Perception and Satisfaction, both at the same percentage (67%), as illustrated in Figure 13.

When analyzing only low-bias studies, Flow had the highest proportion favoring the IG (100%), followed by Satisfaction (67%), as shown in Figure 14.

Finally, for moderate to serious bias studies, Perception (67%) had the highest proportion favoring the IG, followed by Reasoning (33%), as illustrated in Figure 15.

3.4.2. Summary and credibility of outcomes categories

We categorized outcome categories based on the studies' credibility. Strong credibility outcomes were solely from low bias studies, including Cognitive load and Satisfaction. Medium credibility outcomes stemmed from studies with varying bias levels (low to serious), including Attention, Brain activity and plasticity, Effort, Emotions, Engagement, Flow, Learning, Motivation, User experience/Usability, and Working memory. Weak credibility outcomes were solely from studies with moderate to serious bias, including Cognitive bias mitigation, Perception, and Reasoning. Some categories showed no significant results (IG = CG) and were not classified: Eye fixation and movement, Inhibition control, Intelligence, Long-term memory, Mental health, Spatial Visualization, Spatio-temporal gait, and Visuomotor Coordination.

3.5. GBI characteristics

3.5.1. Game elements

According to gamified learning theory and gamification science framework (Landers, 2014; Landers et al., 2018), game elements provide a means to assess the impact of interventions on psychological states and behaviors, thereby influencing outcomes. Although the use of game elements is more commonly associated with gamification interventions, we also extracted this information from other types of GBI, such as serious games. To evaluate these other GBI employed, we analyzed all the GBI descriptions and visual representations in the studies, attempting to deconstruct the GBI into their game elements. This approach allows for more effective comparisons and analyses across all GBI by organizing them within the same game element framework. Although there are several different frameworks and theories to classify game elements, as will be further discussed in this study, we categorized the game elements based on terminology from a systematic review of gamification (Klock et al., 2020), enabling us to synthesize the data from all the studies in this review, and are illustrated in Table 10. It is important to note that several studies included more than one game. Therefore, a total of 56 games were analyzed across the 42 studies considered.

The games analyzed utilized a minimum of 5 game elements and a maximum of 16 elements, averaging 9 distinct game elements each. The most frequently employed included "Emotions" (presented in 100% of the studies), "Feedback" (96% of the studies), "Single-player" (93% of the studies), "Narrative" (77% of the studies), "Choice" (75% of the studies), "Level" (50% of the studies), and "Signposting" (50% of the studies). Notably, certain game elements such as "Anarchy," "Anonymity," "Easter Egg," "Gifting," "Honor system," "Learning," "Lottery," "Social discovery," and "Voting" were not identified in the studies. It is important to note that because the game element "Emotions" is abstract and broad (Table 10), we included all GBI wherein the intervention was designed to make the experience more playful, according to literature (Ferreira-Brito et al., 2019). Figure 16 provides a visual representation of all the game elements that were examined.

3.5.2. Features

To better understand how the GBI were implemented, we also classified the same 56 games analyzed across the 42 studies into four features based on descriptions and visual representations in the studies: (1) Genres; (2) Social mode; (3) Design; and (4) Technological interaction.

Genre classification organizes works by distinct characteristics, helping audiences find new content and providing creators with a framework for production, playing a crucial role in the media process (Clarke et al., 2017). Game studies focus on defining genres to classify video games, thus we based our analysis on static classifications from existing research, despite the evolving landscape (Faisal & Peltoniemi, 2018). We assessed which GBI aspects aligned

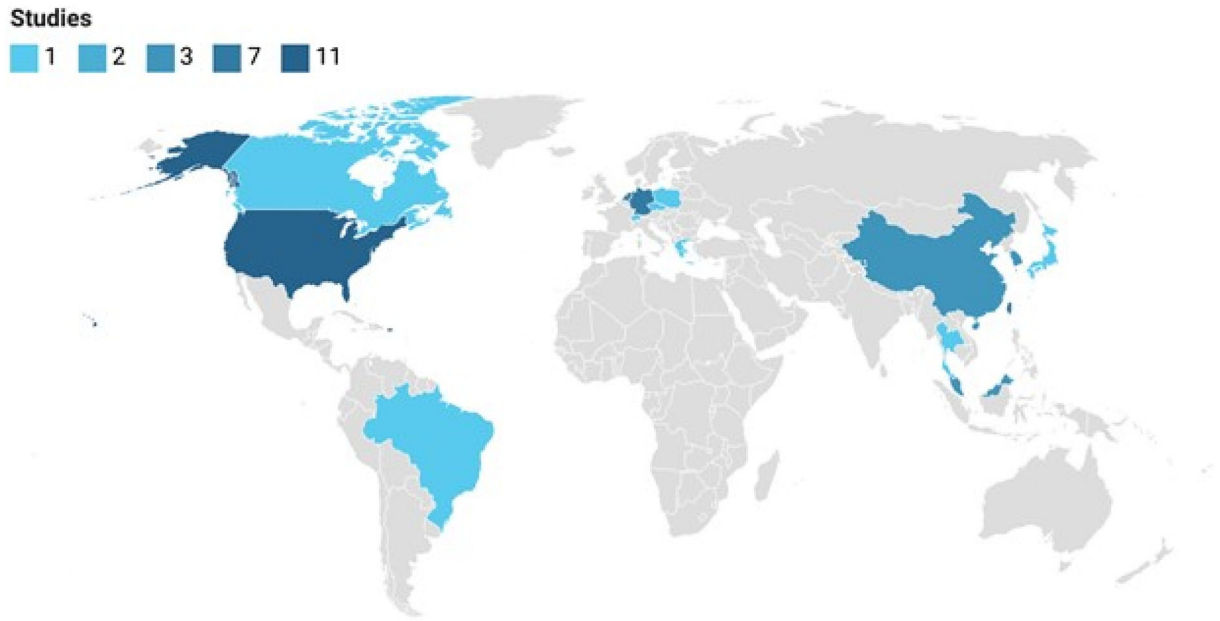


Figure 6. Number of studies by participants' nationality.

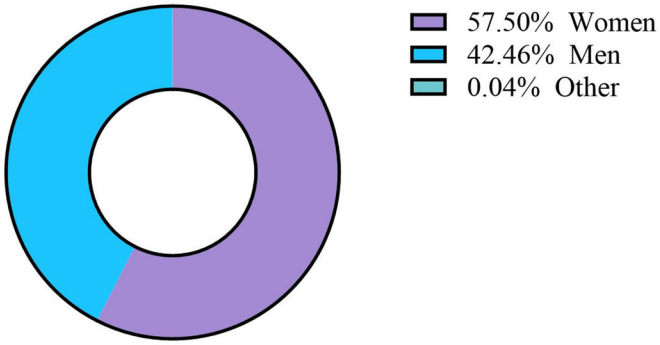


Figure 7. Gender.

with specific genre characteristics, noting that some interventions, like gamification, are game-like but not full-fledged games. We identified the influence of four distinct game genres in the GBI. Action games focus on physical challenges and require motor skills for interaction; Adventure games are driven by a narrative, guiding players through a series of quests; Puzzle games involve solving problems to reach objectives; while Simulation games let players engage with virtual environments that mimic real-world scenarios (Khenissi et al., 2016; Qaffas, 2020; Vargas-Iglesias, 2020). Most GBI were based on Puzzle genre elements (57%), followed by Simulation (34%). Figure 17 illustrates the genre classification.

The second feature, Social mode, refers to whether the game is single-player or multiplayer (Apperley, 2006). Multiplayer games can be classified as competitive, where players aim for personal success; collaborative, where individual success is replaced by group achievement; cooperative, where players pursue personal goals within a group, benefiting from mutual support, (Sánchez et al., 2012), or a mix of cooperative or collaborative with competitive. Most GBI were single-player (73%), followed by competitive multiplayer (18%). We did not detect any collaborative social mode. Figure 18 illustrates this classification.

The third feature, Design, refers to the virtual space and movement dimensions required for user interaction within the game, whether through a 2D, i.e., two dimensions of gameplay – XY, or 3D interface, i.e., three dimensions of gameplay – XYZ (Kim et al., 2017). Non-digital GBI, such as board games, were classified as analog. Most GBI used 2D designs (54%), followed by 3D designs (25%). Regarding design, some GBI were not described or visually presented in the studies (18%). Figure 19 illustrates this classification.

The fourth feature, Technological interaction, focuses on the platform used to run the game, including hardware, software, and operating systems such as personal computers (PC), consoles, tablets, and smartphones (Hu et al., 2023; Romero Hernandez et al., 2016). This feature also encompasses other interactive technologies used by the games to collect data for the gameplay, like biofeedback devices that measure neurophysiological data, e.g., finger sensors to measure skin conductance and heart rate (Dankbaar et al., 2017), pressure-sensitive plates that track movements (Schättin et al., 2016), or head-mounted display for virtual reality (Redlinger et al., 2022). Most GBI used a PC (keyboard and mouse) for interaction (63%), followed by tablets (14%). Concerning technological interaction, some GBI were not described or visually presented in the studies (2%). Figure 20 illustrates this classification. For a comprehensive breakdown of each game element and feature per study, refer to Appendix D (Coelho et al., 2024b).

4. Discussion

This systematic review explores the impact of GBI on adult cognition, compiling findings from 42 selected studies out of 1398 articles. Among these, 26 utilized randomized control trials, and 16 employed non-randomized control trials.

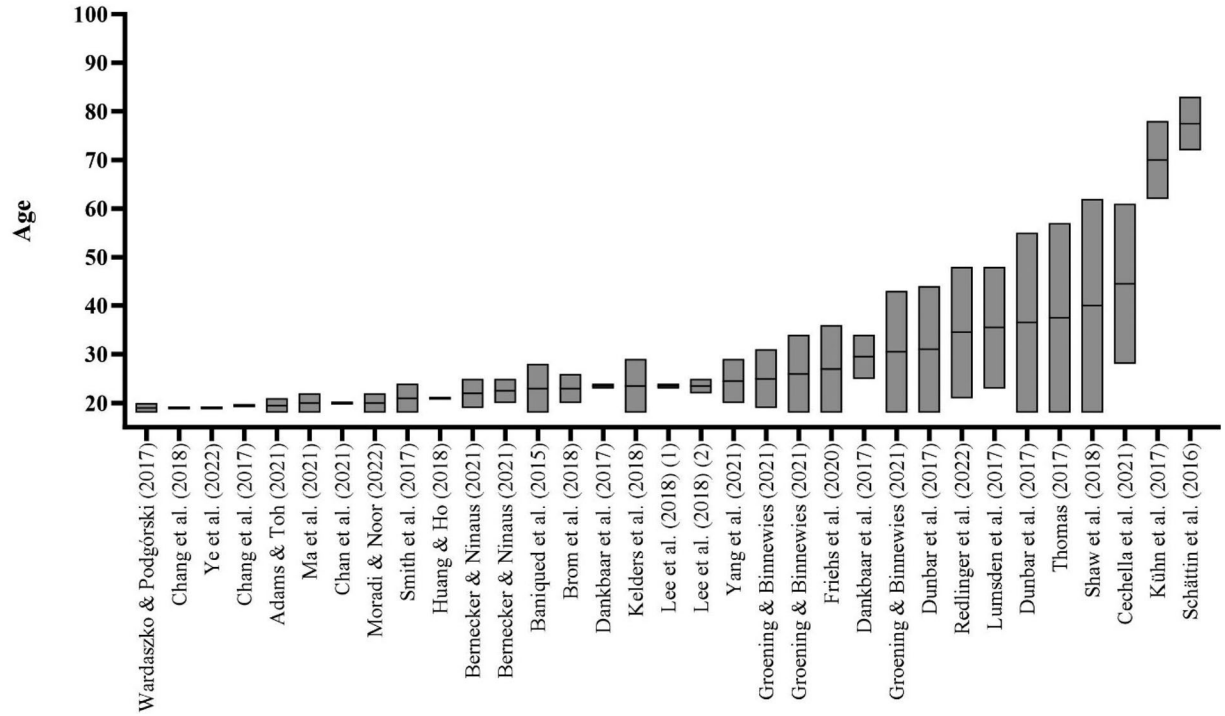


Figure 8. Age.

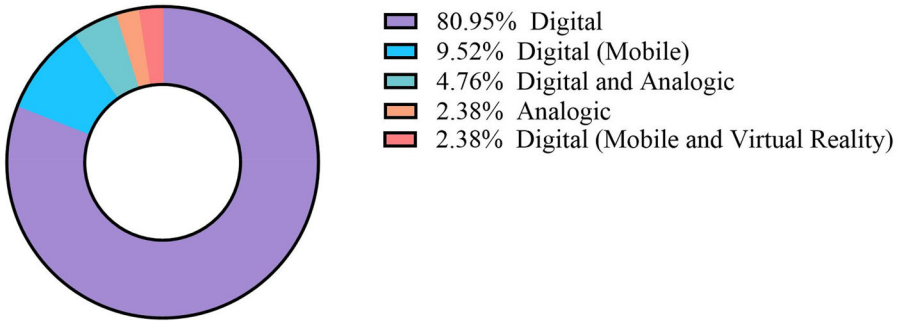


Figure 9. Interventions.

Despite methodological challenges, these studies play a crucial role in a growing scientific field and contribute significantly to the field, offering the potential for improving adult cognition. We discuss contextual factors influencing GBI usage, examine 23 outcome categories related to cognition targeted by these interventions, and explore the game elements and features used, structured according to the data analysis in Section 3 (Results).

4.1. Selection data and bias assessment

It is noteworthy that we identified several bias issues in both randomized and non-randomized controlled trials, as detailed in Section 3 (Results). However, the ones discussed in this section were the most prominent.

The analysis using RoB 2.0 identified a prevalent source of bias in randomized controlled trial studies related to the "bias arising from the randomization process" category. Many studies exhibited concerns in this area, indicating issues like the concealment of allocation sequences or baseline differences between IG. Randomization aims to mitigate the influence of prognostic factors (Higgins et al., 2023), but when these factors affect both group assignment and outcomes, it can introduce bias, known as confounding. GBI are influenced by individual and contextual factors like culture, gender, and age (Ćwil & Howe, 2020; Marston & del Carmen Miranda Duro, 2020; Tondello & Nacke, 2019), which can affect participant interaction. Thus, the bias observed could lead to imbalances between IG and CG, challenging the assessment of GBI's true impact on adult cognition.

The analysis using ROBINS-I revealed significant issues in non-randomized controlled trials, where some studies exhibited a serious risk of bias. The primary bias was associated with "bias due to confounding," indicating instances where confounding factors couldn't be adequately controlled by the study's methodology or measurement instruments. Additionally, "bias in the classification of the intervention" posed a moderate to serious risk, suggesting problems in how IG and CG were defined, potentially impacting trial outcomes. These biases diverge the link between intervention and outcome from its true causal effect, potentially compromising the results (Higgins et al., 2023).

Table 6. Main literature.

	Games	Psychology	Cognition	Learning	Learning and technology	Specific field	Engagement	Behavior	Neurosciences
Boeker et al. (2013)	•								
Baniqued et al. (2015)	•		•						
Wang et al. (2015)	•			•					
Schättin et al. (2016)	•		•						•
Smith (2017)	•					•		•	
Chang et al. (2017)	•	•	•		•				
Kühn et al. (2017)	•	•							•
Dankbaar et al. (2017)	•								
Dankbaar et al. (2017)	•			•		•			
Dunbar et al. (2017) (1)	•	•	•						
Dunbar et al. (2017) (2)	•	•	•						
Wardaszko and Podgórski (2017)	•	•			•				
Rhodes et al. (2017) (1)	•		•	•					
Rhodes et al. (2017) (2)	•		•	•					
Lumsden et al. (2017)	•		•				•		
Thomas (2017)	•	•							
Brom et al. (2018)	•	•	•		•				
Kelders et al. (2018)	•	•	•				•		
Wu (2018)	•	•	•		•				
Chang et al. (2018)	•	•	•		•				
Lee et al. (2018a)				•	•				
Huang and Ho (2018)	•	•	•						
Shaw et al. (2018)	•	•	•		•				
Lee et al. (2018b)			•	•	•				
Friehs et al. (2020)	•	•	•						
Legaki et al. (2021)	•		•		•				
Ma et al. (2021)	•	•			•	•			
Bernecker and Ninaus (2021) (1)	•	•					•		
Bernecker and Ninaus (2021) (2)	•	•					•	•	
Groening and Binnewies (2021) (1)	•	•							
Groening and Binnewies (2021) (2)	•	•							
Groening and Binnewies (2021) (3)	•	•							
Yang et al. (2021)	•					•			
Chan et al. (2021)	•		•	•					
Adams and Toh (2021)	•	•			•				
Luengvilai et al. (2021)			•	•					
Cechella et al. (2021)	•			•					
Bakri et al. (2021)	•		•	•					
Moradi and Noor (2022)	•	•		•	•				
Kyung-Mi (2022)	•						•		
Ye et al. (2022)	•	•	•	•					
Redlinger et al. (2022)	•		•						
Total	39	22	22	12	12	4	5	3	2

Both randomized and non-randomized controlled trials struggled with challenges in forming groups, reflecting difficulties in employing rigorous methods and measurement instruments, underscoring concerns about the credibility of the results' effectiveness (what was considered in the analysis conducted in Section 4.4 Outcomes). The influence of individual and contextual factors further complicates group formation, highlighting the need to address confounding factors and establish more homogeneous groups based on controlled variables like culture, gender, and age.

4.2. General characteristics

Studies were predominantly conducted in the USA, followed closely by Germany and Taiwan, accounting for over half of the total, spanning across America, Europe, and Asia. However, there was a notable absence of studies from Africa and Oceania. Considering the influence of culture on gaming patterns and game production, it's crucial to acknowledge cultural diversity. Gamer identity, player interactions, and game design are significantly impacted by culture (Ćwil & Howe, 2020; Shaw, 2010; Shliakhovchuk & Muñoz García, 2020). As games form the basis of GBI development (Ferreira-Brito et al., 2019), cultural influences within countries may shape the design and implementation of these interventions, offering an intriguing avenue for future exploration.

Gender distribution in our study leaned towards women (57.50%), prompting a discussion on gender's potential impact on the effectiveness of GBI. While our focus was on

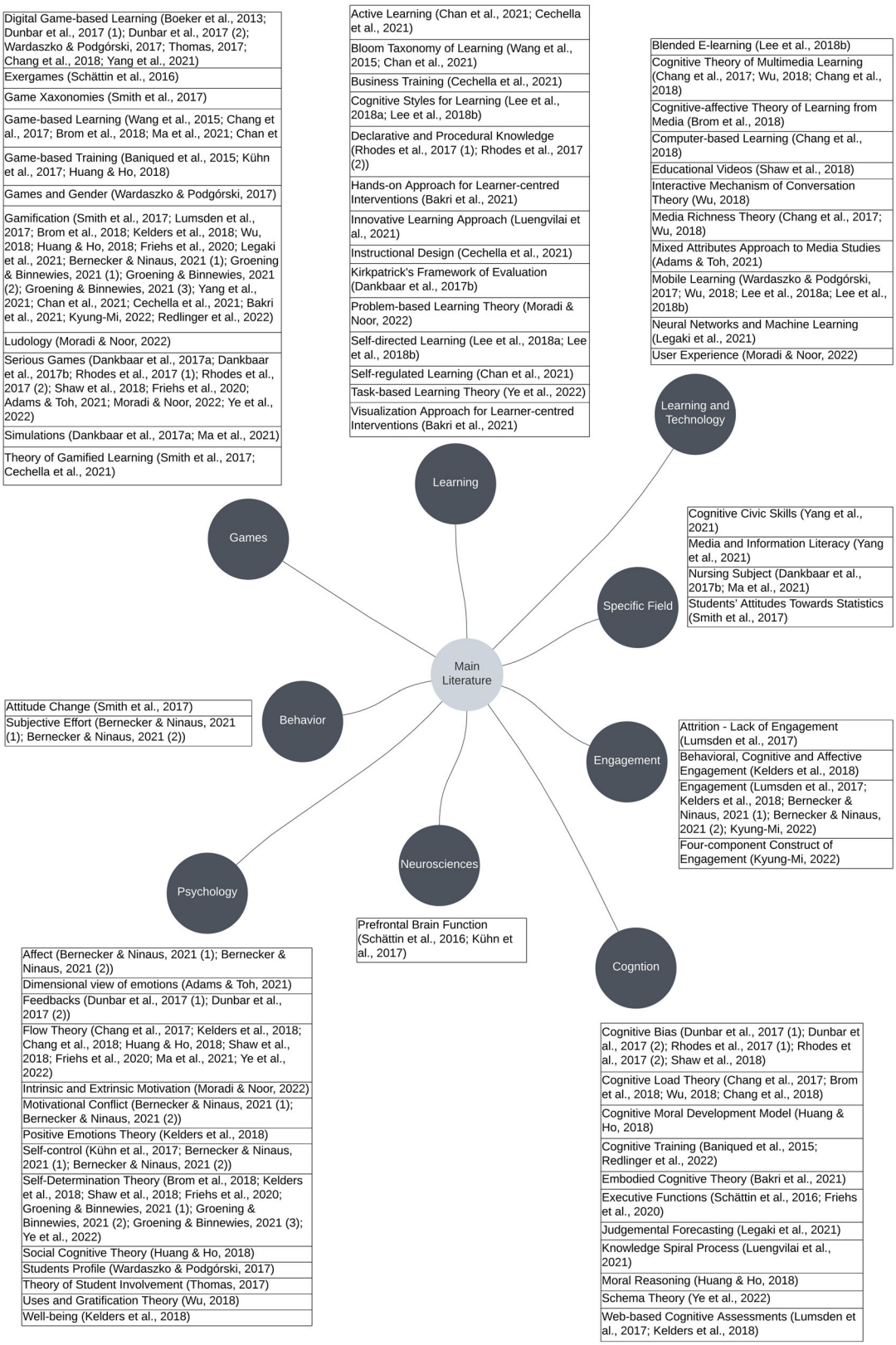


Figure 10. Main literature details.

healthy adults, it is noteworthy that game impact may vary between genders (Lopez-Fernandez et al., 2019; Tondello & Nacke, 2019). Existing literature presents heterogeneous findings, suggesting greater benefits for women (Khan et al., 2017), men (Chen et al., 2021), or both (Dorji et al., 2015). Nearly half of US players are women (Entertainment Software Association, 2022), indicating that both genders are equally significant for the gaming industry and research. However, women's gaming preferences may differ from men's (Tondello & Nacke, 2019), thus future research on

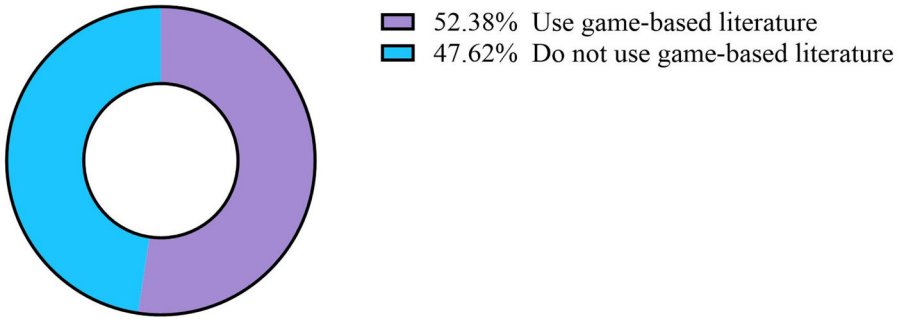


Figure 11. Studies that use game-based literature.

Table 7. Game-based literature.

	Games	Psychology	Learning	Cognition	Instructional Design	User Experience
Boeker et al. (2013)						
Baniqued et al. (2015)						
Wang et al. (2015)				•		
Schättin et al. (2016)				•		
Smith (2017)	•					
Chang et al. (2017)	•					
Kühn et al. (2017)						
Dankbaar et al. (2017)						
Dankbaar et al. (2017)						
Dunbar et al. (2017) (1)	•	•				
Dunbar et al. (2017) (2)	•	•				
Wardaszko and Podgórski (2017)					•	•
Rhodes et al. (2017) (1)						
Rhodes et al. (2017) (2)						
Lumsden et al. (2017)						
Thomas (2017)						
Brom et al. (2018)		•		•		
Kelders et al. (2018)						
Wu (2018)	•					
Chang et al. (2018)						
Lee et al. (2018a)					•	
Huang and Ho (2018)						
Shaw et al. (2018)			•			
Lee et al. (2018b)					•	
Friehs et al. (2020)		•				
Legaki et al. (2021)	•	•				•
Ma et al. (2021)		•				
Bernecker and Ninaus (2021) (1)		•	•			
Bernecker and Ninaus (2021) (2)		•	•			
Groening and Binnewies (2021) (1)						
Groening and Binnewies (2021) (2)						
Groening and Binnewies (2021) (3)						
Yang et al. (2021)			•			
Chan et al. (2021)						
Adams and Toh (2021)						
Luengvilai et al. (2021)			•			
Cechella et al. (2021)						
Bakri et al. (2021)	•					
Moradi and Noor (2022)			•			
Kyung-Mi (2022)						
Ye et al. (2022)	•			•		
Redlinger et al. (2022)						
Total	8	8	6	4	3	2

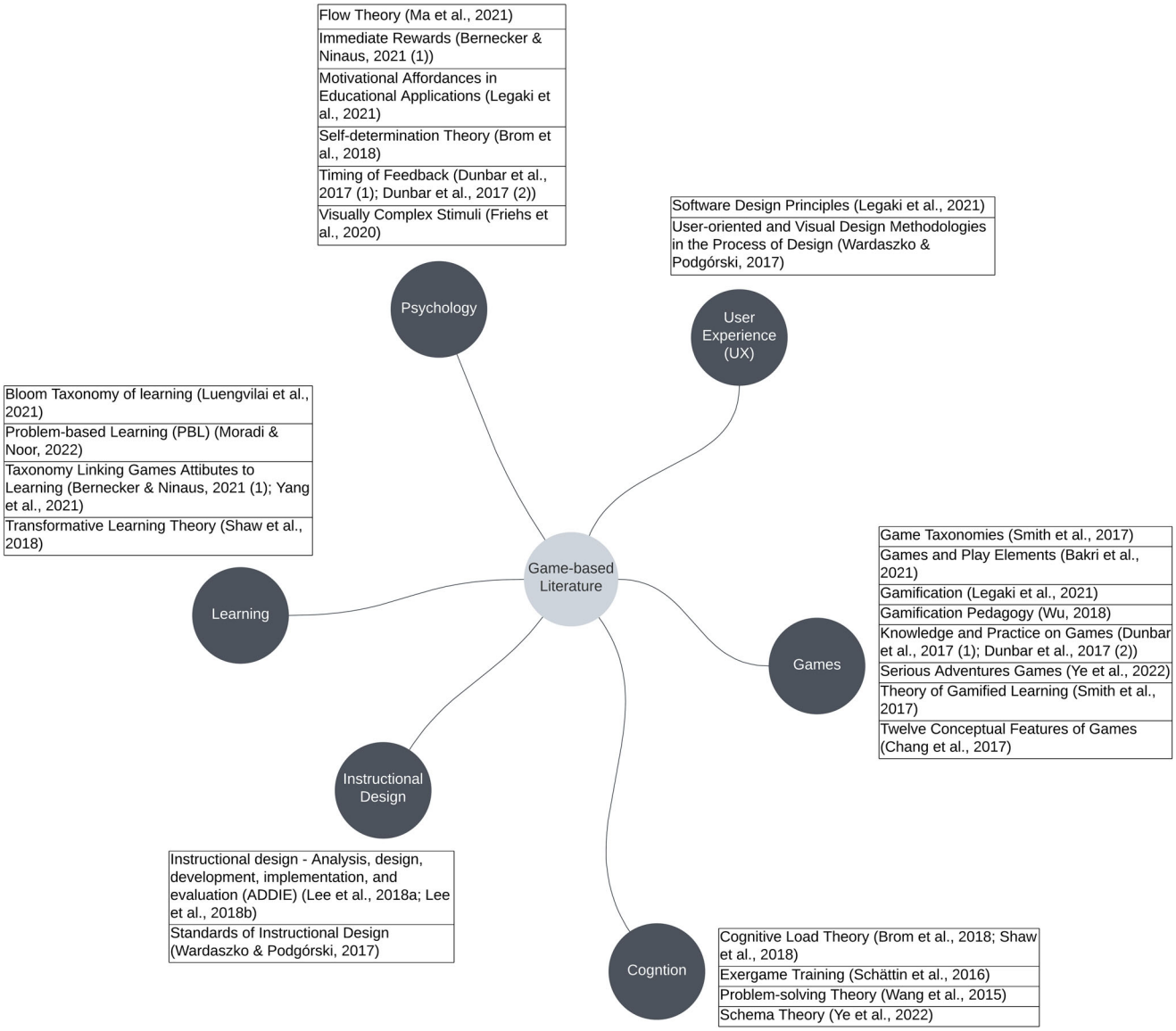


Figure 12. Game-based literature details.

GBI should consider gender differences in gaming preferences, contexts, and behaviors. Games are enjoyable for everyone, and factors such as gender may influence personal preferences. These considerations are important when developing and applying GBI.

Age and generational differences influence gaming behaviors and preferences (Marston & del Carmen Miranda Duro, 2020; Tondello & Nacke, 2019). Technology like games may influence the socialization processes during childhood, influencing personal development and differencing one generation from the other (Ibáñez-Cubillas et al., 2017). The average age of participants in our study was 28.85 years old, with a minimum of 18 and a maximum of 83 years old. According to research conducted in the USA (Entertainment Software Association, 2022), gaming preferences differ among age groups: adults aged 18–34 (36% of players) prefer console and smartphone gaming, engaging in multiplayer gameplay and favoring arcade, puzzle, action, and shooter games. Those aged 35–54 (25% of players) prioritize smartphone gaming and prefer puzzles, arcades, and skill & chance games. Adults over 55 (15% of players) predominantly play on smartphones and computers, favoring puzzle, skill & chance, and arcade games while avoiding consoles and multiplayer gaming. Additionally, cognitive abilities like working memory and inhibitory control show enhancement throughout adolescence and early adulthood, followed by decline from around 30–40 years old onwards (Ferguson et al., 2021). While individual differences in longitudinal changes exist, a general factor of cognitive aging becomes more pronounced with advancing adulthood (Tucker-Drob et al., 2019). These age-related factors, including game preferences and cognitive development, are crucial variables that could influence research outcomes in the context of GBI.

Most interventions utilized digital applications and gamification methods, indicating a prevalent shift towards digitalization in society. This aligns with the literature, which

Table 8. Outcomes categories.

Category type	Category	Details	Articles	# of outcomes
Cognitive outcomes	Attention	Cognitive processes relative to selective, divided, and sustained attention. It also encompasses aspects of multi-tasking, set-shifting, focus and concentration	Baniqued et al. (2015); Wang et al. (2015); Schättin et al. (2016); Groening and Binnewies (2021)	13
	Brain activity and plasticity	Variations of brainwaves, cortical thickness, and blood oxygen level	Schättin et al. (2016); Kühn et al. (2017); Redlinger et al. (2022)	62
	Cognitive bias mitigation	Items related to reduction of bias. They encompass recognition, discrimination, and the elicitation of bias, involving both declarative and procedural knowledge. They also encompass specific cognitive biases, such as the fundamental attribution error, confirmation bias, bias blind spot, and bias mitigation	Rhodes et al. (2017) (1); Rhodes et al. (2017) (2); Shaw et al. (2018)	38
	Cognitive load	Variables that include intrinsic, extraneous, and germane aspects of cognitive load	Chang et al. (2017); Wu (2018); Chang et al. (2018); Ye et al. (2022)	9
	Effort	Measurements of cognitive demand, mental effort, and perceived difficulty of tasks	Baniqued et al. (2015); Thomas (2017); Brom et al. (2018); Bernecker and Ninaus (2021)	7
	Emotions	Components associated with emotional regulation, affective states, and general emotions	Baniqued et al. (2015); Brom et al. (2018); Kelders et al. (2018); Ma et al. (2021); Bernecker and Ninaus (2021); Adams and Toh (2021)	39
	Eye fixation and movement	Projected gaze fixation across various Areas of Interest, representing the average fixation of both eyes of the user	Friehs et al. (2020)	1
	Inhibition control	Measurements of tasks about cognitive processes involving inhibition control	Schättin et al. (2016); Kühn et al. (2017); Lumsden et al. (2017); Friehs et al. (2020)	11
	Intelligence	Subjective assessment of overall intelligence	Baniqued et al. (2015)	1
	Learning	Characteristics related to diverse methods of gauging learning processes. This incorporates academic achievement through both summative and formative assessments immediately following the experiment, as well as at later intervals to assess learning retention. Additionally, this category encompasses the perceived advantages in academic performance, perceived learning, and self-assessments	Boeker et al. (2013); Baniqued et al. (2015); Wang et al. (2015); Smith (2017); Dankbaar et al. (2017); Dankbaar et al. (2017); Wardaszko and Podgórski (2017); Brom et al. (2018); Wu (2018); Chang et al. (2018); Lee et al. (2018a); Lee et al. (2018b); Legaki et al. (2021); Ma et al. (2021); Yang et al. (2021); Chan et al. (2021); Luengvilai et al. (2021); Cechella et al. (2021); Bakri et al. (2021); Bakri et al. (2021)	101
	Long-term memory	Cognitive processes relative to episodic and long-term memory	Baniqued et al. (2015)	2
	Mental health	Reported stress and environment awareness	Dankbaar et al. (2017)	1
	Motivation	Characteristics encompassing elements of extrinsic and intrinsic motivation, along with other correlated factors such as attitude, interest, involvement, and gratification	Boeker et al. (2013); Baniqued et al. (2015); Wang et al. (2015); Smith (2017); Brom et al. (2018); Kelders et al. (2018); Wu (2018); Friehs et al. (2020); Bernecker and Ninaus (2021); Groening and Binnewies (2021); Moradi and Noor (2022); Ye et al. (2022)	50
	Perception	Assessments of activities encompassing the cognitive process and perceived benefit of perception, along with perceptual speed	Baniqued et al. (2015); Groening and Binnewies (2021)	6
	Reasoning	Elements related to problem-solving and cognitive moral development, including accuracy, reaction time, and perceived benefit of reasoning	Baniqued et al. (2015); Huang and Ho (2018)	9
	Spatial visualization	Perceived improvement in spatial visualization	Baniqued et al. (2015)	1
	Spatio-temporal gait	Temporal and spatial gait parameters focused on speed, cadence, and stride length	Schättin et al. (2016)	3
	Visuomotor coordination	Perceived improvement in visuomotor coordination	Baniqued et al. (2015)	1
	Working memory	Metrics related to cognitive tasks and the perceived benefit of working memory	Baniqued et al. (2015); Schättin et al. (2016); Bernecker and Ninaus (2021); Redlinger et al. (2022)	20

(*continued*)

Table 8. Continued.

Category type	Category	Details	Articles	# of outcomes
Cognitive-related outcomes	Engagement	Variables encompassing cognitive, behavioral, and emotional engagement	Baniqued et al. (2015); Dankbaar et al. (2017); Lumsden et al. (2017); Thomas (2017); Kelders et al. (2018); Bernecker and Ninaus (2021); Kyung-Mi (2022)	37
	Flow	Features corresponding to the state of flow, involving immersion and enjoyment	Chang et al. (2017); Kelders et al. (2018); Wu (2018); Chang et al. (2018); Friehs et al. (2020)	19
	Satisfaction	Levels of overall satisfaction with the received intervention	Kelders et al. (2018); Lee et al. (2018a); Lee et al. (2018b)	6
	User experience/Usability	Assessment of system usability and user experience, encompassing quality, engagement, identification, attractiveness, and ease of use	Dankbaar et al. (2017); Kelders et al. (2018); Lee et al. (2018b)	6

states that gamification is an emerging research area in computer science, particularly HCI, and has been used to address user engagement issues in various software categories (Darejeh & Salim, 2016). In HCI models, interaction extends beyond the user and the computer, incorporating socio-cultural, situational, and contextual factors throughout the user research process to optimize the user experience at every stage of system development (Van Hove et al., 2018). Therefore, the data on nationality, culture, gender, age, and individual traits are crucial for understanding the context of GBI user experience from a HCI perspective. Only one intervention employed analog game elements, highlighting a digital transformation trend characterized by increased connectivity, automation, information generation, and artificial intelligence (Hilbert, 2020). Digital GBI in corporate settings offer instant feedback and interactivity, facilitating data analysis and control; while analog interventions provide opportunities for in-person socialization and are more accessible in economically disadvantaged areas (Coelho & Abreu, 2023). Despite the dominance of digital interventions, research on analog interventions is lacking, suggesting a potential avenue for exploration, especially in areas with limited digital access areas (Zainuddin & Keumala, 2021), given that as of the end of 2019, 46.4% of the world's population lacked regular access to the Internet (del Portillo et al., 2021).

4.3. Literature and theories

The overall structure of the main literature categories was strongly linked to diverse fields such as games, psychology, cognition, learning, technology, engagement, behavior, and neurosciences, highlighting the interdisciplinary nature of game science (de Freitas, 2018; Landers, 2014; Landers et al., 2018). Recent systematic reviews and studies have provided comprehensive insights into the theoretical foundations of GBI, with one review identifying 118 interconnected theories related to GBI, motivation, affect, behavior, and learning (Krath et al., 2021). Another study revealed that 252 papers sought to discuss general gamification theory, offering valuable frameworks for researchers (Kasurinen & Knutas, 2018), while a bibliometric analysis demonstrated a significant increase in GBI publications over the years, indicating a growing interest in this field (Schöbel et al., 2021).

Approximately 52% of the studies analyzed in the review used a particular theory or framework to create and directly substantiate the application of the GBI, drawing from fields like games, psychology, learning, and cognition. However, almost half of the studies (48%) did not incorporate such literature, indicating a gap in grounding GBI interventions in established theories. This highlights a need for higher-quality standards in GBI research, as inconsistencies in results often stem from poor experimental designs and a lack of theoretical foundation (Johnson et al., 2016; Krath et al., 2021; Sailer & Homner, 2020; Vermeir et al., 2020). To address this, it is essential to establish rigorous standards and draw upon existing theories to ensure the effectiveness and reliability of GBI interventions. With the growing production of theories derived from games, there is an urgent need to strengthen the theoretical foundation of GBI design to enhance the overall quality of research in this field.

4.4. Outcomes

Given the varied bias levels in the reviewed studies, impacting the credibility of GBI effects, this section is organized into three tiers mirroring Section 3.4.4 (Summary and Credibility of Outcomes). First, outcomes with strong credibility were solely from low-bias studies. Second, medium credibility outcomes were from studies with bias risks ranging from low to serious. Third, weak credibility outcomes were exclusively from studies with medium to serious bias.

Our systematic review aimed to broadly explore general cognition-related outcomes of GBI discussed in the literature. Given the broad range of categories and space constraints, we highlighted only specific topics concerning recent category-related issues. Each category warrants deeper exploration and investigation, which should be addressed in future research.

4.4.1. Strong credibility results

4.4.1.1 Cognitive load. Cognitive load theory focuses on the interaction between information structures and human cognition to guide instructional design, emphasizing the

Table 9. Outcomes results.

		All studies			Low risk of bias studies			Moderate to serious risk of bias studies		
Category type	Outcome category	IG > CG, $p < 0.05$ (%)	IG = CG, $p > 0.05$ (%)	CG > IG, $p < 0.05$ (%)	IG > CG, $p < 0.05$ (%)	IG = CG, $p > 0.05$ (%)	CG > IG, $p < 0,05$ (%)	IG > CG, $p < 0.05$ (%)	IG = CG, $p > 0.05$ (%)	CG > IG, $p < 0.05$ (%)
Cognitive outcomes	Attention	15	77	8	50	50	0	9	82	9
	Brain activity and plasticity	24	74	2	29	71	0	7	86	7
	Cognitive bias mitigation	26	58	16	–	–	–	26	58	16
	Cognitive load	22	44	33	22	44	33	–	–	–
	Effort	29	29	43	33	33	33	25	25	50
	Emotions	26	72	3	38	63	0	23	74	3
	Eye fixation and movement	0	100	0	–	–	–	0	100	0
	Inhibition control	0	100	0	–	–	–	0	100	0
	Intelligence	0	100	0	–	–	–	0	100	0
	Learning	44	55	1	53	46	2	31	69	0
	Long-term memory	0	100	0	–	–	–	0	100	0
	Mental health	0	100	0	–	–	–	0	100	0
	Motivation	32	66	2	50	50	0	18	79	4
	Perception	67	17	17	–	–	–	67	17	17
	Reasoning	33	56	11	–	–	–	33	56	11
	Spatial visualization	0	100	0	–	–	–	0	100	0
	Spatio-temporal gait	0	100	0	–	–	–	0	100	0
	Visuomotor coordination	0	100	0	–	–	–	0	100	0
	Working memory	5	95	0	0	100	0	7	93	0
Cognitive-related outcomes	Engagement	14	86	0	40	60	0	9	91	0
	Flow	47	53	0	100	0	0	0	100	0
	Satisfaction	67	33	0	67	33	0	–	–	–
	User Experience/Usability	33	50	17	40	60	0	0	0	100

management of working memory load to enhance learning and performance (Timothy et al., 2023; van Merriënboer & Sweller, 2005). It identifies three types of cognitive load: intrinsic, arising from the inherent difficulty of the material; extraneous, caused by irrelevant information or distractions; and germane, which is related to developing memory through activities that support learning strategies (Leppink et al., 2013; Sweller et al., 1998; van Merriënboer & Sweller, 2005). However, recent theoretical models have reconceptualized germane cognitive load not as a cognitive load component, but as part of working memory resources allocated to intrinsic cognitive load, thereby simplifying cognitive load into two basic components: intrinsic and extraneous (Sweller et al., 2019). According to the literature, cognitive load is elevated when there are unnecessary demands that hinder effective learning (Sweller et al., 2019). These demands are caused by the inherent complexity of learning tasks (intrinsic cognitive load), and the presentation and organization of learning materials (extraneous cognitive load) (Klepsch et al., 2017; Krieglstein et al., 2022; Sweller et al., 2019). It is worth noting that the concept of germane cognitive load is still referenced in some studies analyzed in this systematic review as a third component of cognitive load (Chang et al., 2017; Ye et al., 2022). Cognitive load aspects have gained significance in contemporary times because virtual environments may immerse users in intricate and stimulating digital spaces, potentially influencing the cognitive load and the learning experience (Andersen & Makransky, 2021). Hence, our data reveal an intriguing pattern. Surprisingly, since the proportion of CG > IG was higher than IG > CG, the absence of additional game elements in the CG seems to increase cognitive load more than when game elements are present (IG). This suggests that enriching environments with game elements may add stimulation without necessarily escalating cognitive load. However, given the strong credibility of this category and the mixed results presented, where most indicate no effect (IG = CG), GBI may not serve as a viable tool to assess the factors and contexts that contribute to an increase in cognitive load. In the era of technological growth and e-learning, examining the integration of HCI and cognitive load theory is vital for guiding system developers to improve learning and user interaction (Banu et al., 2021). By incorporating neurophysiological measurements, such as electroencephalogram (EEG), it is possible to detect spectral power changes across frontal and temporal channels within the alpha frequency band, which are directly linked to cognitive load (Kumar & Kumar, 2016). Additionally, eye-tracking provides insights into cognitive load by assessing metrics like the number and duration of fixations, the length, angle, and velocity of saccades, as well as pupil dilation and blink rate and velocity (Zagermann et al., 2016). Therefore, cognitive load can be measured more objectively, providing valuable data to better understand the factors and contexts influencing cognitive load in GBI and HCI research.

4.4.1.2 Satisfaction. The prevalence of IG > CG in this category is sustained by the literature, mainly relating gamification to learning contexts, where the GBI positively impacts

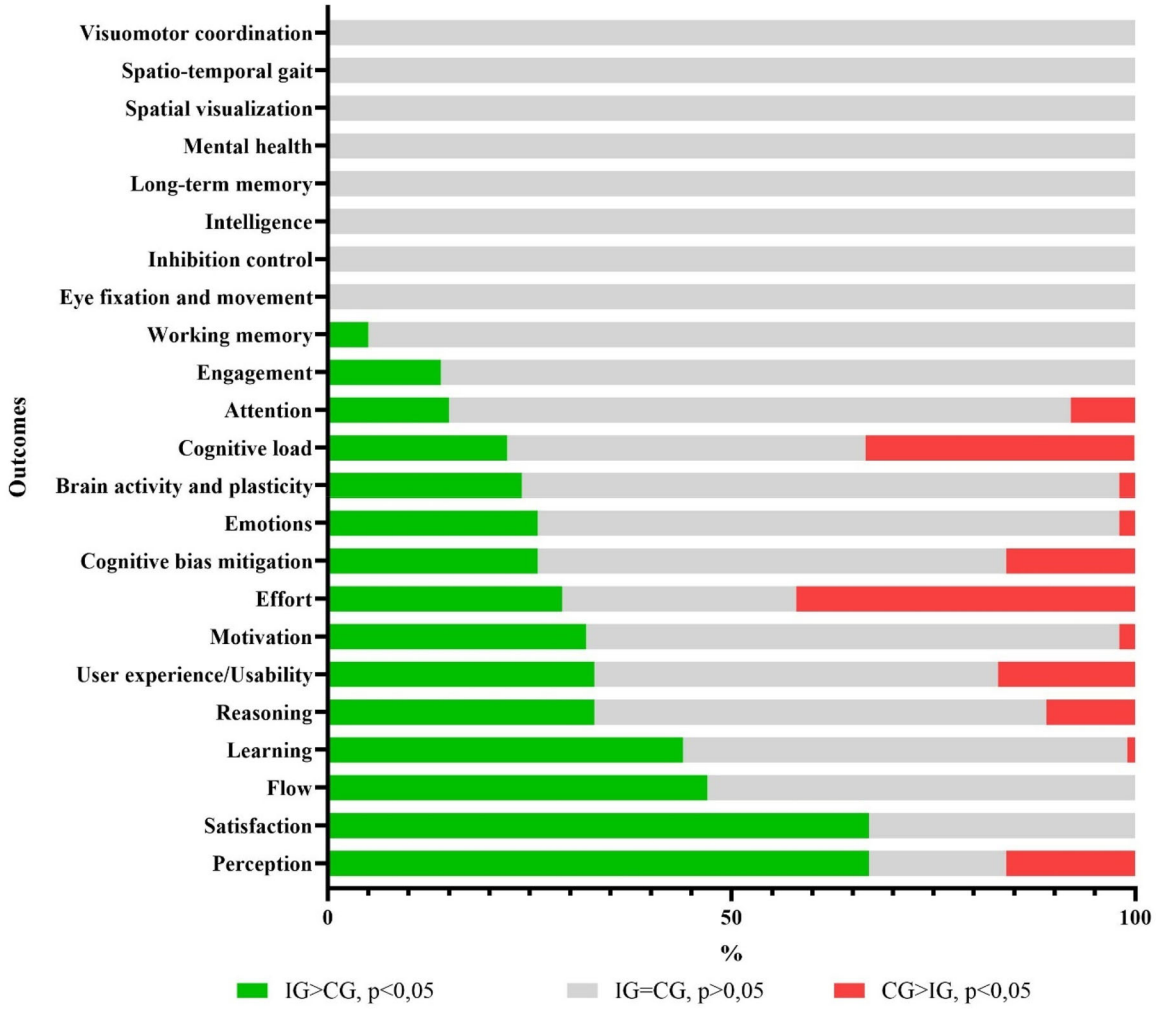


Figure 13. Significant results for all studies.

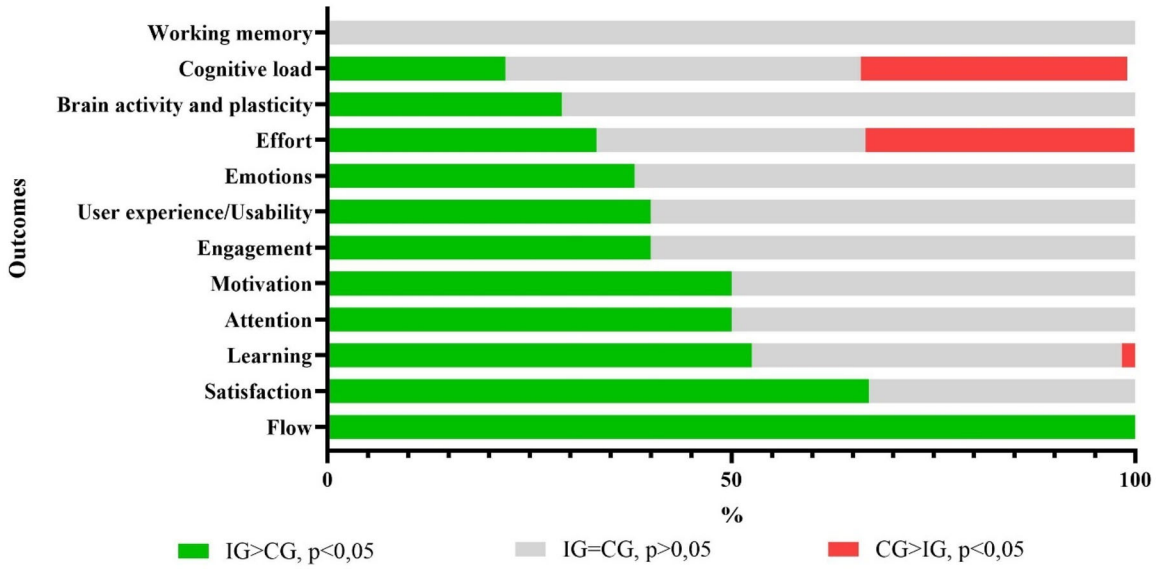


Figure 14. Significant results for low bias studies.

students' satisfaction with the course, although this is not related to knowledge acquisition (Arruzza & Chau, 2021; Zhang & Yu, 2022). In a study centered on cognitive training for the elderly, it was discovered that incorporating games enhanced the satisfaction levels of the training (Lu et al., 2017). According to this study, this heightened

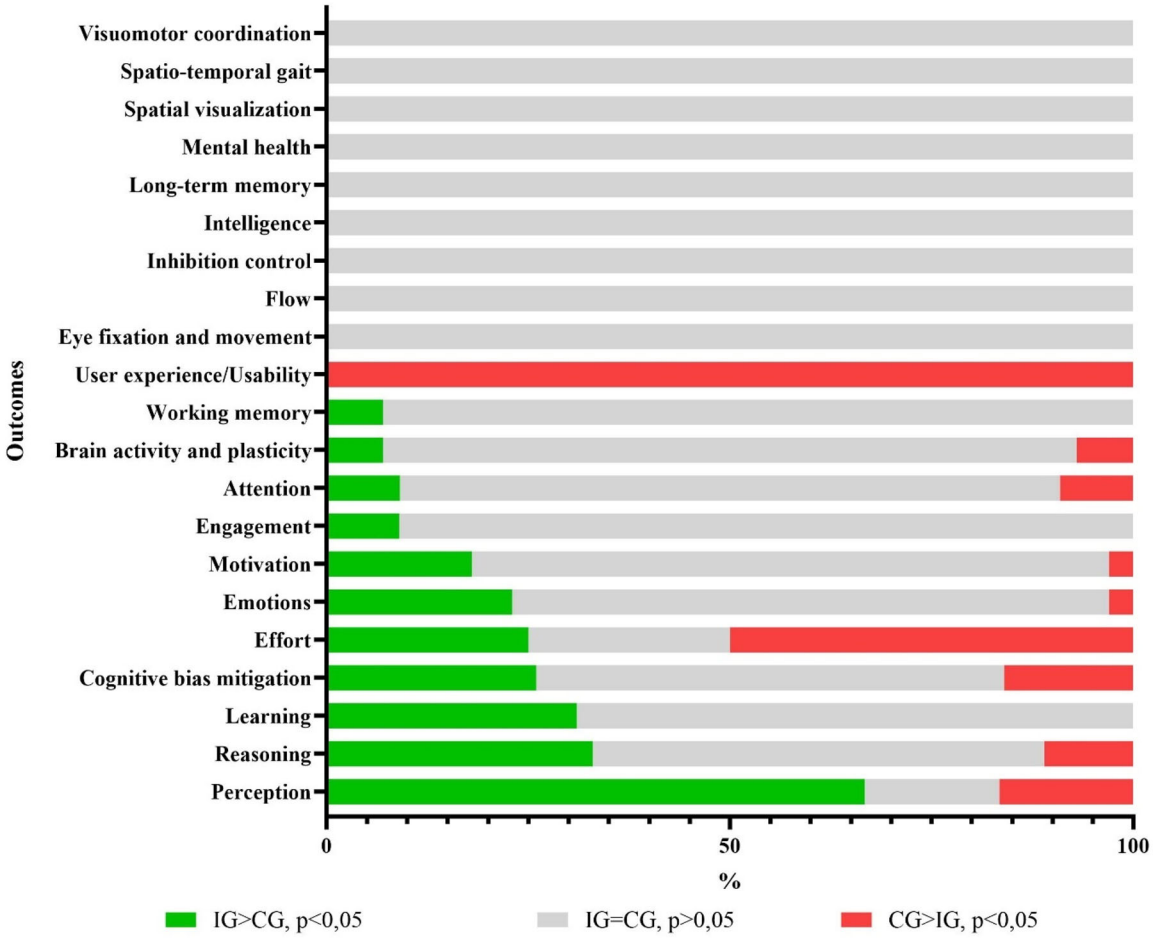


Figure 15. Significant results for moderate to serious bias studies.

satisfaction might also be associated with the ease of use, user-friendliness, and relevance to the participants' everyday lives. Thus, this cognitive-related category represents an important component that may indirectly affect the learning process. Given the strong credibility of this category and the consistent pattern of higher values and significant results favoring the IG, it is reasonable to infer that GBI hold substantial promise in elevating satisfaction levels, thereby enhancing the subjective experiences of individuals.

4.4.2. Medium credibility results

The studies in this section are classified as having medium credibility, highlighting the need for additional high-quality research to strengthen the relationship between GBI and the categories. The existing studies show varying levels of risk of bias, ranging from low to serious, which affects the reliability of the findings.

4.4.2.1. Attention. Attention is a crucial and expansive concept in cognitive processes, encompassing cognitive resources used to perform mental effort and maintain focus (Bruya & Tang, 2018). By using cognitive tasks and questionnaires, the analyzed studies explored outcomes related to selective, divided, and sustained attention, including aspects such as multitasking, set-shifting, focus, and concentration. When it comes to video games, the level of focus exhibited by some players is quite evident. These games command a significant share of their attentional resources, and cognitive development in this cognitive domain has been substantiated under specific circumstances (Dale et al., 2020). However, adapting games to other endeavors, such as GBI, does not always yield the same outcomes. The heterogeneity in our results, with the prevalence of IG = CG, aligns with recent literature on cognitive training, which highlights the challenge of systematically explaining how GBI impact attentional outcomes (Vermeir et al., 2020). In contrast to typical entertainment games, which are primarily crafted for enjoyment, GBI have distinct objectives, such as cognitive training or learning, entailing possible different primary tasks. Gamification, by using game elements, may have the potential to either enhance users' attention, but also divert it from the primary task, causing a division of their cognitive resources in multitasking and compromising the central objective of the activity. Perhaps, in this scenario, full-fledged games designed with a specific outcome in mind rather than purely for entertainment, such as serious games, may offer a superior option for attentional enhancement. If these games integrate properly the primary cognitive tasks and learning with game-like features, they may reduce distractions and enhance attention to the main features (Chi et al., 2017). While the results in this category are mixed, it is reasonable to infer that GBI may not have a significant impact on attention.

Table 10. Game elements.

Game elements	Description	# of games
Emotions	All elements contributing to the creation of playfulness	56
Feedback	Provision of pertinent information to users	54
Single-player	Allows users to engage in solitary gameplay	52
Narrative	Plotlines and thematic content	43
Choice	Decision-making autonomy from users	42
Level	User progression tracking	28
Signposting	Guidance similar to a tutorial	28
Points	Numerical feedback to an action	26
Challenges	Variety of situations to deal with to achieve an objective	18
Meaning	Connection with the system through a common purpose	18
Consequence	User's observation of the cause-and-effect relationship of their behavior	14
Time pressure	Constraint to push the user to complete a particular task at a specific time	14
Competition	Social comparison among users and provides an opportunity for individuals to demonstrate their superiority over others	13
Customization	Self-expression through the creation and edition of a virtual space, avatar, or the system itself	12
Exploration	Opportunity to explore and uncover different areas and features of the system	12
Social pressure	To influence or be influenced by others	12
Collection	Sense of ownership through accumulating things	11
Leaderboard	Organization of users based on specific criteria, facilitating comparisons between them	10
Prize	Reward for the user's action	10
Strategy	Possibility of a strategic plan to capitalize on opportunities or minimize losses	6
Social network	Connection between the users	5
Unlockable	Exclusive content made available based on a user's specific action	5
Badge	Graphical display illustrating the user's achievement	3
Guild	Participating in a team that collaborates jointly	3
Reward schedule	Consistent reinforcements to shape and strengthen the user's behavior in anticipation of forthcoming rewards	3
Social status	Possibility to showcase the achievements and accomplishments within the system	1
Virtual economy	Virtual currency system that enables users to purchase things	1
Anarchy	An environment devoid of restrictions	0
Anonymity	Option to share data without user identification	0
Easter egg	Unexpected system responses to user actions	0
Gifting	Possibility to share resources with other users	0
Honor system	Reputation scoring mechanism	0
Learning	Acquisition and mastery of new in-game skills	0
Lottery	Element of randomness within the system	0
Social discovery	Possibility to find fellow players	0
Voting	Possibility of ratings, votes, or opinions on various aspects	0

4.4.2.2. Brain activity and plasticity. Considering the brain activity outcomes, the analyzed studies confirmed that, during a GBI, the number of beta waves significantly increases (Redlinger et al., 2022), and theta waves either increase or decrease (Redlinger et al., 2022; Schättin et al., 2016), and there is no impact on other brainwaves (neutral effects). The elevation of beta brainwaves is associated with active thinking, concentration, and problem-solving, while theta waves are linked to creative thinking and emotional stress (Rahmad & Zarlis, 2022). Thus, our results show that GBI increases concentration (beta brainwaves) while increasing or decreasing creative thinking and emotional stress (theta waves). Moreover, concerning the brain plasticity outcomes, our results show that GBI also can enhance cortical thickness during the intervention (Kühn et al., 2017), which is related to improved inhibitory control (Aron et al., 2014).

Connecting all this information, although the studies conclude that the brainwave oscillation only occurred at the perceptual level, and not behavioral (Redlinger et al., 2022; Schättin et al., 2016), GBI appears to improve concentration and inhibitory control aspects, while enhancing or decreasing creative thinking and stress. This could be explained by the deactivation of the brain's default mode network with GBI, which causes increased goal orientation, enhanced stress, reduced occurrences of mind wandering, and improved focus (Howard-Jones et al., 2016). Applying this same premise, and considering the observed possible decrease in theta, it is plausible to infer that goal orientation and focus may enhance stress, impacting negatively on creative thinking. Stress alters brain activity, increasing the salience network and sensory cortex involvement while reducing executive control network activity (Vartanian et al., 2020). Still, this shift hampers the interaction between the default mode and executive control networks, essential for creativity. Conversely, it is possible that an increase in theta waves may be related to the creative cognition processes, together with the activation of the default mode, executive control, and salience networks (Eskine, 2023). Thus, as our results showed, gaming and GBI can impact brain activities and behaviors in different ways. This may occur based on how the game is played (Brilliant et al., 2019), together with the individual's profile, history of gaming, and gaming content (Wang et al., 2023).

4.4.2.3. Effort. As in Cognitive Load Section, the higher proportion of CG > IG compared to IG > CG could be attributed to the association between mental effort and cognitive load (Haji et al., 2015). GBI may amplify effort by enhancing participant motivation and engagement, encouraging increased psychological investment in tasks and learning (Khaleghi et al., 2021; Qiao et al., 2023). Conversely, game-based learning might also be perceived as less demanding and easier for participants, reducing effort (Bernecker & Ninaus, 2021; Brom et al., 2018). This diversity can be explained by the potential of games to elevate dopamine levels (Han et al., 2011), influencing cognitive effort by

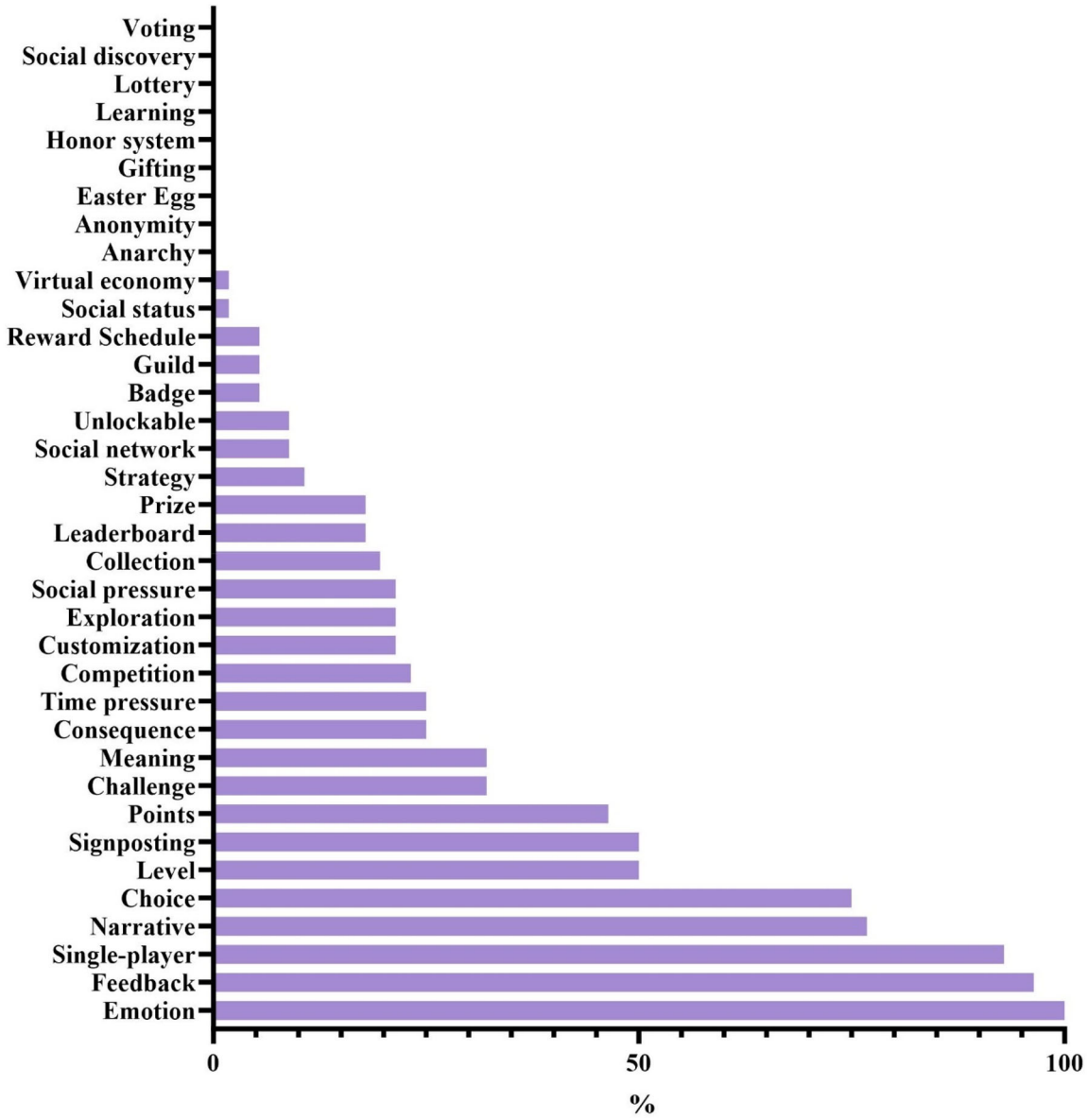


Figure 16. Game elements presented in the games.

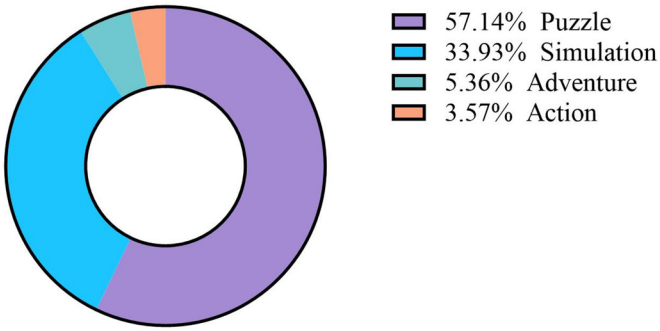


Figure 17. Genres.

balancing the benefits and costs of cognitive work (Westbrook et al., 2020). Moreover, difficulties are desirable when performance meets or exceeds learner expectations (Hodges & Lohse, 2020). Thus, GBI might raise expectations or effectively simplify the experience, reducing the effort. Therefore, it is crucial to consider the design and application of GBI, as different game elements can either facilitate or hinder the experience. For instance, the game element of introducing levels may increase effort (Thomas, 2017), while the effort was reduced when using the game elements of game-like visual design, game narrative, individual score, progress bar, and streaks, i.e., extra points for 5 correct answers in a row (Bernecker & Ninaus, 2021).

4.4.2.4. Emotions. In the examined studies, IG demonstrated higher positive emotions (e.g., inspiration, interest, joviality, self-assurance, attentiveness, surprise, and others) and lower negative emotions (fatigue) compared to the CG. GBI have the potential to engage players by stimulating both emotions and cognition, serving as a powerful tool to activate the brain (Mullins & Sabherwal, 2020). The stimulation of positive emotions is associated with improved learning performance (Park et al., 2015),

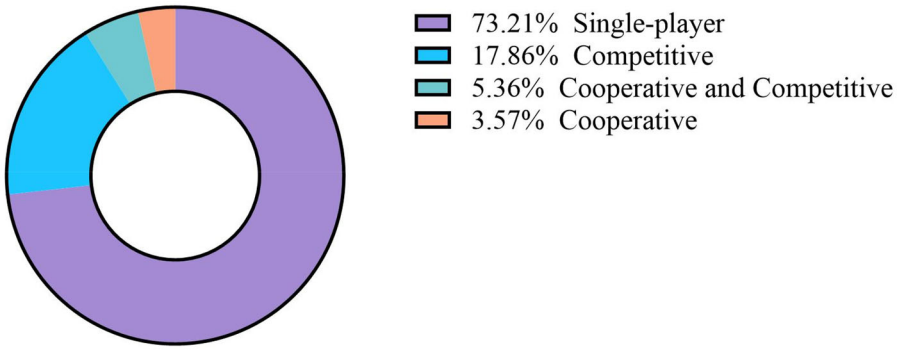


Figure 18. Social mode.

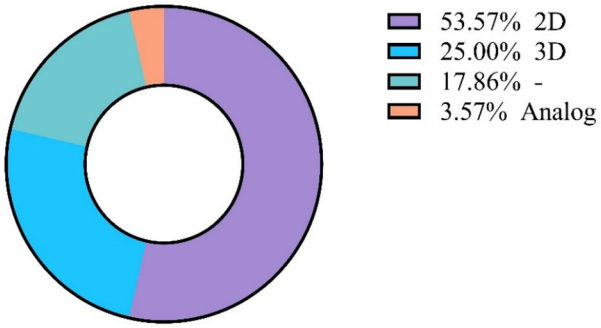


Figure 19. Design.

enhanced mental health (Gloria & Steinhardt, 2016), and an increased sense of well-being (Van Cappellen et al., 2016). Conversely, the negative emotion of fatigue can impede perception and cognition performance (Dong et al., 2024). The results from this category suggest that the IG experienced a more favorable emotional state than the CG (more positive emotions and fewer negative ones). Despite the prevailing neutral effect (IG = CG), the more favorable scenario for IG (IG > CG) underscores GBI as a potential tool for stimulating emotions. The study of emotions in GBI has become a research area with a growing body of literature (Chen et al., 2021). This highlights the clear relation between games and emotional states, underscoring the importance of further investigation in this area. However, the reliance on questionnaires for measurements may not fully capture the participants' real-time affective state throughout the entire intervention, as questionnaires provide only point-in-time information and emotions are complex to analyze through subjective responses. Although questionnaires are commonly used in various outcome categories as well, future studies could explore less subjective instruments for assessing emotions, such as machine learning with facial emotion recognition (Ninaus et al., 2019).

4.4.2.5. Engagement. Engagement is a prevalent concept in GBI, largely due to the desired level of immersion and adherence drawn from gaming, aiming to enhance the overall experience (Mullins & Sabherwal, 2020). Gameplay is an experience that refers to how players interact with a game. It involves both the actions they take within the game to achieve their goals and the engagement that connects them to its features (Abdul Jabbar & Felicia, 2015). By enhancing behavioral, emotional, and cognitive engagement, gameplay can deeply immerse players in the experience and make them more invested in it (Abdul Jabbar & Felicia, 2015; Matsuda et al., 2024). Thus, this cognitive-related category represents an important component that may indirectly affect attention and effort in cognitive activities. However, while our findings did not uncover any result favoring the CG (CG > IG), there was a low incidence of results favoring IG (IG > CG). This finding contradicts some existing literature (Looyestyn et al., 2017; Suh et al., 2018), but might be attributed to the extensive use of self-developed, and unvalidated questionnaires for assessing engagement (Gris & Bengtson, 2021; Vermeir et al., 2020), compromising the validity of the collected data and the reliability of the instruments (i.e., there is a lack of evidence regarding the suitability of some questionnaires for analyzing outcomes and inconsistency in whether the results can be reproduced under the same conditions). To address these issues, the research community could benefit from using established frameworks to guide future studies in the application and measurement of effective engagement interventions (Rivera & Garden, 2021). It is imperative to establish consensus and develop validated tools to enhance the quality of research related to GBI and engagement. Given the strong relation in the literature between engagement and games (Boyle et al., 2012), and the limited evidence of GBI effectiveness discussed earlier, we strongly recommend special attention to evaluating the circumstances under which GBI can genuinely enhance cognitive, emotional, and behavioral engagement.

4.4.2.6. Flow. The Theory of Flow is commonly used in games and GBI literature (Jarnac de Freitas & Mira da Silva, 2023; Schaffer & Fang, 2019) and posits that individuals can immerse themselves in an elevated state of concentration and pleasure when involved in a task that offers a sufficient challenge to stave off boredom but is also within a manageable threshold to avoid frustration (Chapman et al., 2023; Csikszentmihalyi, 2000). Results are evenly distributed through neutral (IG = CG, 53%) and favoring IG (IG > CG, 47%), which is a valuable contribution to the scientific community, as it conflicts with certain findings in the literature. In a meta-analysis focusing on the impact of GBI on cognitive training, it was determined that the influence of

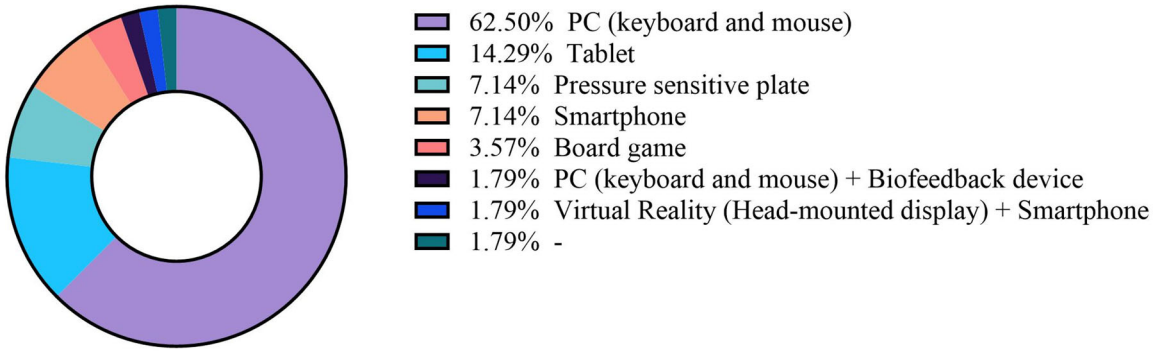


Figure 20. Technological interaction.

gamification on the flow experience was not statistically significant (Vermeir et al., 2020). In another systematic review, examining the flow experience within educational contexts yielded mixed results (Oliveira et al., 2021). Therefore, our findings indicate that GBI have a positive or neutral influence on flow outcomes, presenting a potential means to enhance this mental state, increasing the connection between the person and the experience.

Relating flow state to cognition and the brain, an interesting study proposed that intermittent rewards, rather than consistent or nonexistent ones, decreased hippocampal GABA levels, potentially boosting hippocampal activity (Prena et al., 2020). This suppression, fueled by anticipated rewards, could enhance learning and declarative memory. The authors suggest a connection between GABA neurotransmitter levels and the flow state in gaming, where players who engage with the challenge without feeling bored or anxious enter a state of flow. Another study introduced a new concept, "Fuse," defined as the fusion of activity-related sensory stimuli with awareness, to explore the flow state within the cognitive sciences field (Jalife et al., 2021). This novel concept is intended to characterize experiences where awareness is completely immersed in activity-related senses and seeks to improve conceptual clarity and theoretical robustness in the literature by reexamining the concept of flow from a cognitive perspective. Thus, flow is a cognitive-related category and represents an important component that may indirectly affect attention, learning, and memory in cognitive activities. However, given the subjectivity of the measurements, the absence of consensus on the appropriate questionnaire to employ, and the necessity to use validated questionnaires may pose challenges in accurately assessing flow and increasing the quality of research in this area.

4.4.2.7. Learning. Interdisciplinary fields like game science and gamification science (de Freitas, 2018; Landers, 2014; Landers et al., 2018) integrate education science, game studies, neuroscience, and information science to explore the application of GBI in learning contexts. The establishment of these disciplines, coupled with the increasing number of systematic reviews and meta-analyses focusing on GBI in education (Manzano-León et al., 2021; Sailer & Homner, 2020; Zainuddin et al., 2020; Zhonggen, 2019), highlights the strong connection between GBI and learning among healthy adults. Educational contexts have a strong presence in the field of GBI, where such interventions have been shown to effectively enhance learning, as we presented here with 44% IG > CG and just 1% CG > IG. However, the literature on this topic also presents mixed and varied results, with numerous factors contributing to the success of GBI that remain unresolved (Sailer & Homner, 2020). Many studies in this area have shortcomings, such as undefined CG and a lack of theoretical underpinnings to comprehend the underlying processes (van Gaalen et al., 2021). Moreover, there is a noticeable gap in longitudinal studies and training of teachers and instructors involved in the educational process, particularly in contemporary methods and instructional pedagogies like GBI, which is crucial to the overall success of this kind of intervention (Zainuddin et al., 2020). While educational settings hold promises for GBI, they pose challenges to researchers due to the complexity of their applications and the numerous variables involved in the learning process. The literature and the field of game science have advanced, offering valuable tools and theories (Laine & Lindberg, 2020; Landers et al., 2018) that can guide researchers in conducting new investigations with scientific rigor.

4.4.2.8. Motivation. The Self-determination Theory (Ryan & Deci, 2020) is the predominant motivational framework adopted in gamification literature (Zainuddin et al., 2020). It highlights the importance of intrinsic motivation, which can be enhanced through GBI, positively impacting behavior and cognition (Liu et al., 2021; Xu et al., 2021). Within educational settings, where motivation tends to wane over time, GBI emerge as promising tools for sustaining desired behaviors (Krath et al., 2021). However, it is imperative to approach the incorporation of game elements into these environments with caution, considering the interplay between intrinsic and extrinsic motivation. The use of coercive instructions, excessive rewards, or undue pressure should be avoided, as these can yield detrimental consequences on both cognitive processes and motivation, (Zhang & Yu, 2022). Thus, our findings showed that 32% of the results were higher in IG (IG > CG), but most of them were neutral (IG = CG), and a small part was higher in CG (CG > IG). As noted before, this mixed pattern may be attributed to methodological limitations and insufficient integration of

theoretical frameworks within the field of GBI (Sailer & Homner, 2020). External factors beyond control, such as the intricacies of game design, coupled with internal dynamics like individual frustration or distraction, have the potential to detrimentally affect participants' experiences and hinder their progress (Zhang & Yu, 2022). Considering the mixed results, it is essential to undertake further research with rigorous methodologies to gain a thorough understanding of how GBI may enhance motivational outcomes.

4.4.2.9. User experience/usability. User experience is perceived as a comprehensive concept encompassing various emotional, cognitive, or physical responses related to an experience, that should be characterized by ease of learning, efficiency of use, and effective control, coupled with additional criteria such as aesthetics, joy-of-use, novelty, or attractiveness (Hinderks et al., 2019). User experience describes the experience of using interactive products, and its consequences, with models primarily developed in HCI literature to understand the experiential and hedonic aspects of technology use (Hornbæk & Hertzum, 2017). In digital environments, GBI may enhance the overall user experience by making the system more enjoyable and motivating (Fitz-Walter et al., 2017). Thus, this cognitive-related category represents an important component that may indirectly affect learning and motivation in cognitive activities. However, while GBI show promise in enhancing user experience (as indicated by the 33% IG > CG), this is underscored by a prevalent number of neutral results (IG = CG) and relevant outcomes favoring the CG (CG > IG). Not all systems may be equipped to incorporate this additional layer of fun. Some systems may lack technical refinement, clear purpose, and efficiency, thereby compromising user experience and potentially overshadowing any benefits of GBI, which explains our mixed results. Recent research, exemplified by a systematic review of gamified systems and user experience, indicates a scarcity of studies focusing on the usability and associated aspects of gamified systems (Magylaitė et al., 2022). Therefore, it becomes imperative to disentangle the effects of game elements from other factors to evaluate the overall user experience and ascertain the true impact of GBI. There is an increase in the utilization of serious games in educational settings, and there is a need to develop and apply evaluation tools, built with scientific rigor, to increase the quality of games, and the experience of users and to properly develop better systems (Moizer et al., 2019). For instance, neurological and physiological measure-based user experience evaluations, like electroencephalogram and galvanic skin response, are vital in information systems and are increasingly used in GBI and video games, fueling further HCI research (Zaki & Islam, 2021). By using these more objective tools and building on GBI research, HCI can gain valuable insights to enhance the user experience of digital products.

4.4.2.10. Working memory. Working memory refers to the capacity to hold and manipulate information over short periods of time, often to assist in performing a current task (Nozari & Martin, 2024). Entertainment games have the potential to enhance working memory and other cognitive processes, as they often require focus, skills, and abilities for successful play (Yao et al., 2020). However, when it comes to GBI, the effect is not the same. While earlier research has demonstrated that GBI can boost motivation, subjective experience, affect, and even perception during a cognitive task, these kinds of intervention may fall short in enhancing participants' working memory performance (Mystakidou & van den Berg, 2020; Redlinger et al., 2022; Scharinger et al., 2023). This might be explained as gamified cognitive tasks can be more demanding, with the level of demand potentially linked to the specific game elements used and how they are incorporated (Chaldogeridis & Tsiatsos, 2022). Similarly, as we previously discussed in the Attention Section, the inclusion of game elements could potentially lead to a division of participants' cognitive resources, introducing multitasking and compromising the primary objective of the activity. Different stimuli may impose varying levels of demand on working memory capacity. While most results were neutral (IG = CG), there were outcomes favoring CG (CG > IG), and some favoring IG (IG > CG), obscuring the conditions under which GBI may be effective regarding its impact on working memory.

4.4.3. Weak credibility results

Since the categories in this section represent weak credibility, it is important to note that high-quality research is needed to establish a connection between GBI and the corresponding category, as the studies exhibit bias risks ranging from medium to serious, which compromises their validity.

4.4.3.1. Reasoning. Reasoning is the ability to generate conclusions from incomplete or inconsistent knowledge and involves processing, updating, and deriving insights from information in a way that is both actionable and executable (Furbach et al., 2019). Games can potentially enhance problem-solving skills by providing practice and tracking user achievements, although the fit of gaming elements for scientific reasoning, involving deliberative and metacognitive processes, may be limited (Morris et al., 2013). Similar to our mixed results, the literature seems to exhibit heterogeneity on this subject, as a study examining a learning scenario discovered that GBI could enhance critical thinking but had no impact on the perception of problem-solving skills (Asigigan & Samur, 2021). Another study revealed that while GBI may boost satisfaction and motivation in situations requiring reasoning skills, their performance on these skills remains unaffected (Blanié et al., 2020). In a recent systematic review of game-based learning and argumentation skills, games cultivated a favorable disposition toward honing argumentation skills and aiding in developing reasoning competencies in learners (Noroozi et al., 2020). Conversely, a meta-analysis investigating cognitive training through video games in older adults yielded no discernible impact on reasoning skills (Mansor et al., 2020). There is uncertainty surrounding the impact of GBI on reasoning, due to the diverse study designs and methodologies, along with inconclusive and mixed results within this category.

4.4.3.2. Perception. Perception can be defined as the cognitive ability to form an internal representation of incoming information, which then may direct processing and actions based on that information (Boem et al., 2024; Zipoli Caiani, 2011). Action video game players often exhibit enhanced speed of processing and reaction times when compared to non-video game players (Dale et al., 2020). Improvements in perceptual skills, especially in the dorsal stream (what sustains localization of objects and guides motor action) and peripheral vision (perception rather than target localization), are also experienced by frequent action video game players (Chopin et al., 2019). This phenomenon may be attributed to the rapid responses required in various video games, such as hitting something to avoid in-game death or accurately timing actions. Similar to those games, a comparable phenomenon seems to occur in GBI, where perceptual speed tends to elevate with the incorporation of game elements into cognitive tasks (Attali & Arieli-Attali, 2015; Baniqued et al., 2015; Wang et al., 2021). This aligns with our results, where most of the outcomes considerably favored the IG (IG > CG). We advocate for additional research with rigorous methodologies to verify the consistency of this result favoring GBI.

4.4.3.3. Cognitive bias mitigation. Cognitive bias mitigation is the ability to reduce systematic distortions in thinking that influence judgment and decision-making, often resulting in illogical or improbable outcomes, particularly when the consequences are uncertain (Korteling et al., 2021). According to the literature, GBI have the potential to improve cognitive bias mitigation, as they enable users to explore various situations, engage with ideas, witness the practical application of lessons, and receive feedback, all while being motivated by the game elements (Clegg et al., 2015; Legaki et al., 2021; Strzalkowski & Symborski, 2017). GBI actively engage individuals in confronting biases and immerse them in learning settings where the consequences of biases are directly encountered (Korteling et al., 2021). However, our findings indicate mixed results, with slightly more favorable outcomes for the IG (IG > CG) compared to the CG (CG > IG). The differences are not substantial, and neutral results are predominant. This variability could be attributed to diverse methods of measuring cognitive bias, leading to varying impacts of GBI. Based on the literature, practicing judgment with feedback in GBI is effective for acquiring procedural knowledge to mitigate cognitive biases, while noninteractive media may be more suitable for learning factual information and recognizing biases (Rhodes et al., 2017). In addition, the value of bias mitigation interventions lies in their ability to enhance decision-making in practical situations over the long term, but there is insufficient evidence for the transfer and retention of these interventions (Korteling et al., 2021). The absence of high-quality research in this area necessitates further investigation using rigorous methodologies, considering various types of cognitive bias, and incorporating knowledge retention assessments to properly evaluate how GBI may affect this category.

4.4.4. Categories without significant results

Finally, across all studies, 100% of the following domain outcomes did not present any significant differences between IG and CG: Eye fixation and movement, Inhibition control, Intelligence, Long-term memory, Mental health, Spatial Visualization, Spatio-temporal gait, and Visuomotor Coordination. While these outcomes present intriguing opportunities for studying the relationship between GBI and cognition, our analysis did not reveal any discernible impacts. Nonetheless, these domains are addressed in the literature related to GBI, and thus, we highly recommend additional research into these domains to gain further insights into the topic.

4.5. GBI characteristics

4.5.1. Game elements

The analysis of games across the studies revealed a range of 5 to 16 game elements used, with an average of 9 elements per game. According to the gamified learning theory and the gamification science framework (Landers, 2014; Landers et al., 2018), individual game elements can influence psychological states and behaviors, impacting outcomes. It is essential to evaluate the impact of individual game elements and their combined effects to understand the diverse impacts they may have in similar circumstances (Coelho et al., 2023). Conversely, non-gamification interventions often do not detail the specific game elements used, as GBI can be frequently designed with the entire game in mind, omitting the individual component descriptions. Consequently, we examined the game elements of these other GBI using descriptions and visual representations within the studies. This effort aimed to establish a common method for comparing various types of GBI within an unified game elements framework. However, with an average of 9 elements per game, it becomes challenging to isolate the specific elements or their combined effects on outcomes. This complexity hinders the ability to reproduce gaming settings reliably for research and make meaningful comparisons between different GBI.

In Section 4.3 (Literature and Theories), we highlighted that nearly half of the studies examined in this review lacked support from existing game-based literature for their interventions. Considering the potential influence of different game element arrangements on user experience and the lack of theoretical frameworks in half of the reviewed studies, the game design could be a confounding factor in the interventions. This raises concerns about the scientific rigor of the GBI development process.

In our analysis, we found that seven game elements were frequently utilized in over half of the studies: Emotions, Feedback, Single-player, Narrative, Choice, Level, and Signposting. These elements shed light on the typical design approach for most GBI, which often offer solitary experiences with clear guidance, decision-making autonomy, progress tracking, feedback, storytelling, and emotional engagement. On the other hand, certain game elements like Voting, Social Discovery, Lottery, Learning, Honor System, Gifting, Easter Egg, Anonymity, and Anarchy were absent in

all analyzed interventions. Considering an alternative perspective, these absent elements could contribute to a GBI where players engage in learning activities, explore social connections, rate friends, monitor reputation scores, exchange virtual gifts anonymously, discover surprises, and experience freedom from penalties or negative feedback. The two described game designs illustrate distinct motivational characteristics. According to the self-determination theory (Ryan & Deci, 2020), a predominant motivational framework often embraced in gamification literature (Zainuddin et al., 2020), the first design could emphasize autonomy and competence through feedback and clear rules, while the second design could emphasize autonomy and social relatedness, fostering a social environment with surprises.

These two configurations of game elements create unique experiences that tap into various motivating factors. Just as there is a wide array of entertainment games available, numerous game elements are continuously emerging, providing opportunities for exploration. Designing diverse and innovative game-based experiences is crucial, as relying solely on established formulas may limit effectiveness. Many untapped game elements offer the potential for richer and more varied experiences.

It is also important to note that the term "game element" can have varied categorizations and definitions, impacting the design and research of GBI. This study employs a framework focusing on general game elements identified in several studies across a review of the literature (Klock et al., 2020). However, there are other widely recognized typologies for game elements, such as Dynamics, Mechanics, and Components (Werbach et al., 2012; Werbach & Hunter, 2015), which respectively encompass overarching aspects, basic processes driving engagement, and specific forms within gamified systems. Another notable framework is MDA (Mechanics, Dynamics, and Aesthetics) each contributing to different facets of gameplay (Hunicke et al., 2004; Pedroso et al., 2019). Additional recent literature proposes various models for classifying and designing game elements (Ferro, 2021; Swacha, 2023; Walk et al., 2017). Hence, the coexistence of basic and intricate game elements within theories, along with their interplay, may yield different outcomes and highlight the necessity for empirical research and meticulous GBI design grounded in scientific literature to uphold data integrity.

Finally, it is crucial to consider the interplay between game design, contextual factors, and individual characteristics when aiming to enhance the quality of future investigations. Beyond the previously discussed gamified learning theory, self-determination theory, and definitions of "game elements," there is a wealth of GBI frameworks and relevant literature, including discussions on individual traits (Mora et al., 2017; Santos et al., 2021; Tondello & Nacke, 2019), which can provide valuable insights to enhance the quality of research in the field of GBI.

4.5.2. Features

By analyzing the genre features of the games used in GBI, we found that most were based on the Puzzle and Simulation genres. These results reveal an interesting pattern: by incorporating game elements, the studies' cognitive tasks, which typically involved sequential problem-solving and answering questions based on stimuli and rule sets, were transformed into engaging puzzles. Likewise, the studies' learning interventions, where students had to absorb content and practice knowledge through various exercises, became simulations. While cognitive tasks can often be perceived as boring and not interesting (Boendermaker et al., 2017; Mohammed et al., 2017), puzzles can provide stimulating challenges, boost participant interest, and enhance engagement, ultimately leading to improved performance over time (Horváth & Pietriková, 2023; Urwyler et al., 2023). Similarly, traditional classroom settings often face challenges with student participation, engagement, and motivation (Mariappan, 2024; Yue, 2024). Nonetheless, simulations boost motivation and immersion by replicating real-life situations, making them an effective method for developing complex skills and achieving learning objectives in a risk-free environment, allowing experimentation in high-risk scenarios, such as a simulated surgical emergency, without real-life consequences (King, 2022; Kumar et al., 2023; Singh et al., 2024). These findings demonstrate how GBI can transform cognitive and learning interventions. By shifting from function-based experiences to a more human-centered approach, GBI's can enhance the overall user experience, making tasks more engaging and interactive (Kessing et al., 2024; Savazzi et al., 2018).

Regarding the social mode and design features, we found that most GBI were single-player, and 2D. In controlled trials, the focus of this systematic review, laboratory environments aim to preserve internal validity by reducing bias and confounding variables, with participants being closely monitored (Kirtschig et al., 2019). This may justify the use of single-player mode, as monitoring one person can be more convenient than one group. 3D modeling and animation are time-consuming tasks that increase complexity and processing demands, which may justify the use of a 2D format. Additionally, since gamification incorporates game elements into other contexts (Deterding et al., 2011), the prevalence of 2D applications, such as websites or Learning Management Systems like Moodle (Poondej & Lerdpornkulrat, 2019), makes implementing 2D game elements more synergic. Although these features are convenient and cost-effective, we recommend further investigation into components like 3D design and multiplayer social modes. These are underrepresented in studies but could offer valuable insights into HCI, as 3D environments enhance immersion (Kulshreshth et al., 2017), while multiplayer gameplay fosters social and emotional skills, such as predicting behaviors, offering support, and building relationships (Akin, 2023).

Concerning the technological interaction features, most GBI were played on PC (keyboard and mouse). In line with the simpler and more convenient features used in GBI, PC (keyboard and mouse) interaction might be preferred for its simplicity and widespread availability in universities and laboratories, reducing the need for extra technological

investments. However, three studies from this systematic review analysis introduced innovative ways of interacting with GBI. One used biofeedback devices, such as finger sensors measuring skin conductance and heart rate, to adapt gameplay based on the player's neurophysiological state, complementing the need for manual input (Dankbaar et al., 2017). Another study used pressure-sensitive plates to monitor movements during gameplay and the intervention (Schättin et al., 2016). The third employed virtual reality to present stimuli, with smartphones collecting touch screen data (Redlinger et al., 2022), aiming to minimize distractions and enhance immersion. While these studies are few, they highlight promising approaches that should be explored further, particularly for their use of real-time data to enable dynamic adaptations in HCI, making the technology integral to gameplay rather than just post-analysis. For instance, electrical biosignals, including electromyography, electroencephalogram, electrodermal activity, eye tracking, and electrooculography are used in game research to gather valuable neurophysiological data and adjust game difficulty or experience in real-time, based on monitoring stress for example (Hughes & Jorda, 2021).

5. Conclusions

This systematic review has shed light on the current landscape of GBI in a cognitive context. Concluding the preceding discussions, Section 4.1 (Discussion – Selection data and bias assessment) of this systematic review sought to present the selected studies and classify them according to their risk of bias. Our analysis indicated a prevalent deficiency in high methodological and scientific standards within the literature on this subject, with only a few studies exhibiting a low risk of bias in all analyzed domains, and some even display serious risk.

Section 4.2 (Discussion – General characteristics) explored the overall characteristics of the studies, encompassing factors like nationality, gender, age, and types of GBI under scrutiny. These findings underscored the importance of considering contextual factors, including nationality, culture, gender, age, and individual traits, in the design and research of GBI, as they can influence outcomes. Additionally, our analysis revealed a prevalence of research on digital applications compared to analog ones, demonstrating a widespread move towards digitalization of society and emphasizing the link between GBI and HCI. Given the importance of contextual and user information in optimizing user experience throughout system development, all these study characteristics (i.e., nationality, culture, gender, age, and individual traits) are essential for understanding the GBI user experience from a HCI perspective.

In Section 4.3 (Discussion – Literature and theories), we delved into the recent application of theoretical frameworks, their origins in scientific fields, and the potential impact on the implementation of GBI. This exploration revealed a robust interconnection between GBI and diverse scientific fields, encompassing psychology, cognition, learning, technology, engagement, behavior, and neurosciences. Despite the growing prominence of GBI as a scientific field, it appears to be in its early stages, marked by widespread applications that require the establishment of high-quality standards supported by literature and theoretical frameworks.

Section 4.4 (Discussion – Outcomes) centered on the results derived from the examined studies, encompassing diverse variables, instruments, and measurements used to compare 23 different outcome categories between the IG and CG. Notably, within the outcomes with strong credibility, only Satisfaction indicated a positive impact of GBI, with most results favoring the IG. Within medium credibility outcomes, Flow, Learning, and Motivation exhibited positive associations with GBI, predominantly showing higher values for the IG. Within weak credibility outcomes, only Perception suggested an enhancement due to GBI, with a prevalence of higher values for the IG. Eight other outcome categories presented mixed effects (Cognitive load, Attention, Brain activity and plasticity, Effort, Emotions, User experience/Usability, Reasoning, and Cognitive bias mitigation), and two categories presented a high prevalence of neutral effects (Engagement, and Working memory), concealing the impact of GBI. Additionally, eight outcome categories mentioned in the studies showed no significant influence from GBI (Eye fixation and movement, Inhibition control, Intelligence, Long-term memory, Mental health, Spatial Visualization, Spatio-temporal gait, and Visuomotor Coordination).

Lastly, Section 4.5 (Discussion – GBI Characteristics) centers on the game elements and features utilized in the design and implementation of GBI. Considering that GBI incorporated an average of 9 game elements, it is challenging to pinpoint the specific elements influencing outcomes. This complexity hinders the elucidation of the impact of individual game elements, making it difficult to replicate the gaming setting for research reliability and draw meaningful comparisons between different interventions. The abundance of continually emerging game elements and diverse typologies for categorizing and interacting with them presents opportunities for broader exploration, given that studies tend to utilize a consistent set of elements. Concerning the features, most GBI were based on Puzzle and Simulation genres. Cognitive tasks can be boring, but puzzles boost engagement and performance. Traditional classrooms can struggle with motivation, while simulations enhance immersion by replicating real-life situations. Shifting to a human-centered approach, GBI improves user experience, making tasks more engaging and interactive. Furthermore, Most GBI were single-player and 2D, which can be explained as simplicity and cost-effectiveness. Finally, while most GBIs were played on PC, studies using neurophysiological tools, movement monitoring, and virtual reality have shown promising approaches for real-time interaction and dynamic adaptation in HCI research and practice.

6. Limitations

We have detected certain limitations. First, the studies extracted were confined by the search terms employed, the scientific databases consulted, and the temporal scope

applied to the selection of papers. Nonetheless, the assortment of papers explored within this literature review offers valuable insights into the field of research about the impact of GBI on the cognition of healthy adults, providing a glimpse into the state of knowledge within this domain at the time.

Regarding the inclusion and exclusion criteria, we opted to conduct this systematic review by applying principles of rigor derived from health research, including the PICO framework, PRISMA guidelines, and the Cochrane Collaboration's guidelines (Higgins et al., 2023; Page et al., 2021; Pati & Lorusso, 2018). Therefore, our focus was on randomized and non-randomized controlled trials, excluding studies that did not adhere to these methodologies. Given that GBI may involve playful experiences, some studies may adopt other methodologies to preserve external validity, which is crucial for the generalizability of results (Coelho et al., 2024a; Khorsan & Crawford, 2014). Other studies emphasize qualitative data, exploring perceptions of GBI to generate insights into why individuals may enjoy or dislike GBI (Bai et al., 2020) and to propose new ideas and models for more effective interventions (Khaleghi et al., 2021). Prioritizing controlled trials allowed for causal comparisons between GBI and non-GBI across multiple outcomes but may have restricted the reported findings related to GBI, such as those putatively obtained by qualitative studies. Furthermore, adhering to these frameworks and guidelines, the assessment of bias primarily focused on internal validity and methodology. Consequently, biases stemming from the absence of theoretical frameworks for GBI development, for instance, were acknowledged in this systematic review but not included as exclusion criteria, potentially considering different biases in the analysis of the results. Additionally, we focused on broad cognitive outcomes. This approach aimed to explore a wider range of outcomes, including some that are not intrinsically related to cognition, as discussed in Section 4.4 (Discussion – Outcomes). However, this may have limited a deeper analysis of specific cognitive domains.

Concerning the studies' general characteristics, some did not provide information on participants' age or gender, limiting the illustration of the overall participant profile. In analyzing outcome categories, we encountered challenges due to numerous measurements in different studies, requiring us to group them to identify similarities. Therefore, we explored the overarching aspects of each outcome category, incorporating subtle differences in instruments measuring the same category into the same analysis, and comparing the IG to the CG. Additionally, we expanded our analysis by assessing the significance of outcomes to identify categories showing GBI effectiveness. This step offers valuable insights for future research and a deeper understanding of GBI's impact beyond simple outcome categorization. However, we acknowledge potential biases, such as the lack of sample variance and effect size evaluation.

Addressing the analysis of game elements, it is important to note that our approach was based on a proposed framework of game elements classification (Klock et al., 2020), though other frameworks exist. Studies not related to gamification often lack detailed descriptions of the game elements used, as GBI are sometimes designed with the whole game in mind, without specifying all the individual elements. Therefore, analyzing game elements of these other GBI, based on descriptions and visual representations in the manuscripts, gives rise to a subjective bias in listing the elements and fitting them into the framework. Although this process aimed to create a common method for comparing different types of GBI, it has limitations due to attempting to fit diverse interventions into the same framework.

Finally, it is important to highlight that this systematic review underwent several changes compared to the protocol registered in PROSPERO. These changes were implemented during the initial phases of the research to improve the study's quality. Firstly, after data extraction, we recognized that there was valuable material on various GBI, not limited to gamification as initially indicated in the protocol's title. Consequently, we modified the title and the outcome analyses to encompass all types of GBI. We adjusted the search criteria to specifically target randomized and non-randomized studies, aiming to examine the effects of GBI within more controlled research design studies. The initial query outlined in the protocol yielded a wide range of diverse studies, prompting us to narrow our focus to randomized and non-randomized studies.

7. Recommendations for future research

In terms of study quality, future investigations, whether randomized or non-randomized control trials, must prioritize methodological and scientific rigor throughout their design processes. Factors such as individual traits, cultural backgrounds, gender, generational differences, and other societal aspects need to be considered in research designs, as they may correlate with the outcomes. The participants' cultural context can shape their expectations and behaviors, while gender and generational disparities can affect preferences and choices in using GBI. Additionally, the contrast between digital and analog interventions, with the relative scarcity of analog studies, represents a gap in the existing literature on this topic. To improve the clarity of results, the use of theoretical frameworks to support the application of GBI is imperative, as this helps control and account for various game elements. For example, the theory of gamified learning and the gamification science framework (Landers, 2014; Landers et al., 2018) are well-established theoretical models for application in experimental research. Given the significance of qualitative research in GBI literature, we recommend future studies incorporate qualitative data via systematic or scoping reviews to explore perceptions of GBI across diverse contexts, complementing the quantitative findings of this review. For instance, examining participant perspectives on various GBI theoretical frameworks could offer valuable insights for theory refinement.

Through this systematic review, we aimed to investigate cognitive outcomes in the literature, leading us to discover a wide array of different types of cognitive categories. It is essential to comprehensively investigate the various factors

that affect the impact of GBI on each cognitive outcomes category. This involves scrutinizing multiple instruments and exploring different aspects within the same category, requiring a more thorough exploration. Furthermore, the cognitive-related outcomes of engagement, flow, satisfaction, and user experience/usability, may extend beyond the traditional cognitive domains from psychology and neurosciences, thus warranting expansion and further exploration within the scientific field of cognitive sciences.

We opted to explore the outcomes based on their significance, analyzing the cognitive variables in which GBI can exert an impact. However, given the multitude of significant findings uncovered in our investigation, we strongly advocate further analyses through meta-analyses. Excessive heterogeneity and poor methodological quality in studies can lead to misleading conclusions in meta-analysis by obscuring true effects and producing unreliable results (Akhter et al., 2019; Lee, 2018). We recommend analyzing each outcome category individually, or at least focusing on fewer categories, ensuring a more consistent approach and only including studies with a low risk of bias. This approach would consider sample variances and assess the effect sizes of each outcome category in a robust comparative manner, offering greater detail on each specific outcome category and enhancing the understanding of GBI impact.

Most GBI were digital, so analyzing their design and implementation could offer valuable insights for improvements and research opportunities in HCI. There is a need for diversification in the exploration of game elements. While research often gravitates toward familiar elements, the field could greatly benefit from innovative applications grounded in theory and conducted with scientific thoroughness. Based on the same literature used for classifying game elements in this systematic review (Klock et al., 2020), the game elements of Voting, Social Discovery, Lottery, Learning, Honor System, Gifting, Easter Egg, Anonymity, and Anarchy were absent in all analyzed interventions (see Table 10 for the game elements descriptions). We suggest that less familiar game elements from the literature might be avoided due to their lack of well-established exploration. This might also be related to the potentially complex implementation of these game elements, as they are not commonly referenced in GBI. Additionally, these elements may be overlooked because their existence is simply unknown, as this systematic review revealed a lack of theoretical frameworks supporting GBI applications. Thus, such game elements present putative innovative approaches for future GBI. Additionally, analyzing GBI features, while most studies focused on Puzzle and Simulation genres, other genres like Action or Adventure should be further explored. Combining these genres with the previously discussed game elements could yield different outcomes and provide new insights for GBI research. As most GBI were single-player and 2D for simplicity and cost-effectiveness, further research into 3D design and multiplayer modes could offer valuable insights, as 3D enhances immersion (Kulshreshth et al., 2017) and multiplayer promotes social skills (Akin, 2023). Finally, while most GBI were played on PC, the use of neurophysiological tools to collect data, adjust gameplay, and assess or improve user experience, should be further explored, offering innovation for HCI research and practice.

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