A Taxonomy of Social Augmentation Mechanisms in VR Exergames: Interaction, Structure, and Agent Representation

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Abstract

Social features are widely used to improve motivation and engagement in VR exergames, yet prior work is difficult to compare because designs are scattered across competition, cooperation, co-presence cues, ghost-based comparison, and AI-mediated coaching. We introduce a taxonomy for social augmentation in VR exergames (3DoF/6DoF systems) that captures how social signals, real people, and socially legible agents shape training experience. Using a framework synthesis approach, we define three composable axes with explicit decision rules: **social mechanism** (competition, cooperation, co-presence), **interaction structure** (synchrony × symmetry), and **agent representation** (real, ghost/recorded, NPC/AI). We validate the taxonomy by mapping 37 peer-reviewed studies (2011–2024) into the design space. The literature concentrates on synchronous–symmetric competitive designs with real partners and asynchronous–symmetric competitive designs enabled by ghost traces, while asynchronous–asymmetric role-differentiated support remains rare. We discuss design implications and outline an agenda for scalable, agent-enabled support with attention to evaluation, transparency, social pressure, and accessibility.

Keywords

Taxonomy, Social Augmentation, Virtual reality, Exergames, Games for health

1. Introduction

Exergames have long been promoted as a way to make physical training more engaging and sustainable, yet adherence and sustained motivation remain persistent challenges in digital health games and movement-based play [1, 2]. A recurrent response across HCI and health-game design is to add social ingredients. This extends beyond connecting players through multiplayer modes to include social cues such as spectator mechanisms, audience interaction, leaderboards, or anthropomorphized virtual companions [3, 4, 5]. In immersive XR exergames, these social ingredients become especially potent because the medium amplifies presence, embodiment, and the felt immediacy of “being with” others [6, 7].

In this paper, we use the term social augmentation to denote the deliberate use of social signals, other (real) people, and/or socially legible agents to enhance motivation, engagement, and training experience within an exergame. Conceptually, social augmentation is grounded in established motivational accounts: (i) Self-Determination Theory (SDT) explains why competitive feedback may heighten competence while cooperative designs can support relatedness [8]; (ii) Social comparison processes explain why others' performance, even when mediated by rankings or ghost replays, can shift effort and self-evaluation [9]; and (iii) Social facilitation highlights that merely being observed can change performance and exertion patterns [7].

Despite the rapid growth of “social XR fitness,” the research landscape remains fragmented. Studies are scattered across competitive and cooperative multiplayer designs, co-presence or audience effects,

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asynchronous comparison via leaderboards or ghost avatars, and AI-mediated coaching or companionship [3, 4, 5]. This fragmentation makes it difficult to compare findings, accumulate evidence about which social ingredients align with particular training goals and populations, and translate results into actionable design guidance. What is missing is a unified, comparable taxonomy that can describe heterogeneous systems with consistent terms and decision rules, so that evidence can be mapped, contrasted, and extended. Design research has repeatedly shown the value of explicit design-space representations for structuring comparison and revealing underexplored regions [10], but the current social-XR exergame literature lacks a shared taxonomy that connects *mechanisms* (competition, cooperation, co-presence), *structures* (time-coupling and role organization), and *agent forms* (real people, recorded ghosts, AI/NPCs) into one coherent description language.

To address this gap, we present a taxonomy-oriented synthesis of 37 immersive VR exergame studies that incorporate social interaction features. Rather than treating "social" as a single binary attribute, our approach operationalizes social augmentation along three composable axes: *social mechanism* (competition, cooperation, co-presence), *interaction structure* (synchrony × symmetry), and *agent representation* (real, ghost/recorded, NPC/AI). This taxonomy enables us to map the literature into a single design space, quantify dominant configurations, and identify systematic gaps (e.g., the rarity of asynchronous–asymmetric cooperative support).

Contributions. We make three contributions:

1. **A taxonomy and decision rules** for social augmentation in immersive VR exergames, organizing designs by (i) social mechanism, (ii) synchrony × symmetry, and (iii) agent representation.
2. **A structured mapping of 37 papers** into this taxonomy, revealing dominant patterns (e.g., synchronous–symmetric competition with real partners) and consistent gaps (e.g., asynchronous vs. asymmetric cooperative support).
3. **A forward-looking research agenda** for social augmentation in XR, highlighting implications for agent-mediated partners, transparency, accessibility, and evaluation practices for sustained training outcomes.

2. Taxonomy Development

We developed our taxonomy through a **framework synthesis** process [11, 12] that combined (i) a systematic survey of prior work with (ii) iterative, rule-driven coding to ensure consistent and comparable categorization of social augmentation designs in VR exergames.

2.1. Literature Survey

We surveyed five major databases (ACM Digital Library, IEEE Xplore, Scopus, Web of Science, and PubMed), complemented by backward and forward snowballing. Searches were conducted in March 2025 and covered publications from January 2010 to March 2025. The core query combined terms for VR, exergames, and social features, and explicitly included both human–human and human–agent interaction descriptors (e.g., multiplayer, cooperative, competitive; avatar, ghost, virtual agent, virtual opponent). Minor syntactic adjustments (e.g., field restrictions) were applied per database.

Core search string. The following core string was used across databases (with minor syntax adaptations such as title/abstract field restrictions where required):

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 ("virtual reality" OR VR OR "head-mounted" OR HMD OR 3DoF OR 6DoF) AND
(exergame OR "active video game" OR "motion-based game" OR "serious game")
AND (multiplayer OR "multi-user" OR social OR collaborative OR cooperative
OR competitive OR "co-presence" OR spectator OR audience OR leaderboard OR
ghost) AND ("virtual agent" OR "virtual opponent" OR "virtual partner" OR
"virtual character" OR avatar OR "self-avatar" OR "self-representation" OR
"virtual self")
```

2.2. Eligibility Criteria

We included peer-reviewed studies that met all of the following criteria: (i) **VR with 3DoF or 6DoF**: the system used a head-mounted VR display or equivalent VR setup that supported at least orientation tracking (3DoF) and, where available, position tracking (6DoF); (ii) **Exergame context**: bodily movement was a core gameplay input used to control or progress within the game; (iii) **Social augmentation feature**: the system incorporated interaction with real people or socially legible agents (e.g., ghost replays, NPCs, virtual coaches) intended to evoke social presence, peer modeling, or social comparison; (iv) **Game or motivational design focus**: the paper reported game mechanics, interaction design, or motivational elements (not only sensing, tracking, or hardware validation).

We excluded: (a) non-VR platforms (e.g., conventional screen-based games without head or device coupled viewpoint updating), (b) single-player designs without any social augmentation component, (c) applications without an exercise component, and (d) grey literature (e.g., posters, extended abstracts, non-peer-reviewed reports).

2.3. Screening Process

We followed a PRISMA-style screening procedure [13] to ensure transparent corpus construction for taxonomy mapping. Appendix 3 summarizes identification, screening, and inclusion.

We identified **N = 427** records via database search and **n = 11** additional records via backward and forward citation searching. After removing **111** duplicates and excluding **78** records via automated filters (e.g., non-peer-reviewed items or irrelevant publication types), **N = 227** records proceeded to title and abstract screening. We excluded **141** records at this stage, resulting in **N = 86** full-text articles assessed for eligibility.

Full-text screening excluded **57** records for the following reasons: not VR with 3DoF/6DoF or not head-mounted VR (**n = 20**), not an exergame (**n = 9**), no social augmentation feature (**n = 16**), or review papers (**n = 12**). From citation searching, **n = 12** records were assessed in full text and **n = 4** were excluded for not meeting the VR criterion. This yielded a final corpus of **N = 37** studies for taxonomy mapping.

2.4. Framework Synthesis and Coding Scheme

Our taxonomy operationalizes social augmentation designs along three composable axes [11, 12]: **(1) Social mechanism** (competition, cooperation, and co-presence), **(2) Interaction structure** (synchrony by symmetry), and **(3) Agent representation** (real partners, ghost or recorded partners, and NPC or AI agents).

We created a structured extraction form to capture study metadata (population, methods, duration), technical setup (including 3DoF or 6DoF capability where reported), and outcome measures, but taxonomy placement was driven primarily by interaction design descriptions and the implemented social features.

To improve coding reliability across heterogeneous systems, we used explicit decision rules. **Competition** required performance comparison with rank, score, or win–lose framing. **Cooperation** required shared goals or interdependence. **Co-presence** required a design that leveraged being observed, audiences, or social cues without necessarily sharing goals or competing. **Synchronous** required real-time coupling of participants or agents; **asynchronous** allowed time-decoupled comparison or interaction (e.g., ghost replays, leaderboards). **Symmetric** required equivalent roles and tasks, whereas **asymmetric** required differentiated roles or complementary responsibilities (e.g., coach–trainee). **Real**, **ghost**, and **NPC or AI** were assigned based on whether the “other” was a live human, a recorded trace of behavior, or a software-driven agent.

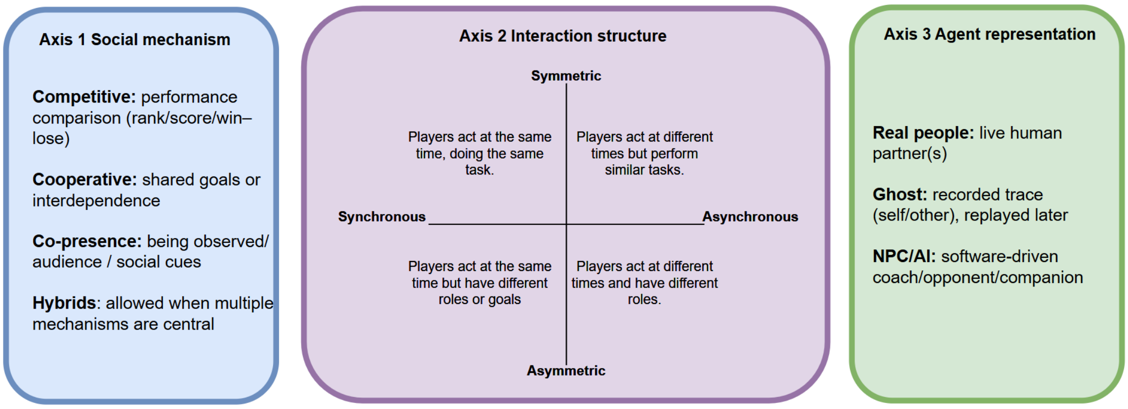


Figure 1: Taxonomy overview for social augmentation in VR exergames (3DoF/6DoF). The taxonomy comprises three axes: social mechanism (competitive, cooperative, co-presence, hybrids), interaction structure (synchrony by symmetry), and agent representation (real people, ghost traces, NPC/AI).

2.5. Quality Appraisal and Synthesis Strategy

Because our primary contribution is a taxonomy rather than a causal estimate of effects, we used quality appraisal mainly to contextualize evidence strength. Empirical user studies were appraised with the Standard Quality Assessment Criteria [14], while conceptual or technical design papers without user evaluation were retained for design-space coverage but not scored. We then aggregated findings descriptively across the three axes: we summarized distributions by population and period, mapped each study in the synchrony by symmetry space, and analyzed how agent representation clustered with mechanisms and structures. Meta-analysis was not attempted due to heterogeneity in study designs and outcome measures.

3. Taxonomy of Social Augmentation in VR Exergames

Figure 1 summarizes our taxonomy as a three-axis design space for social augmentation in VR exergames. The taxonomy is intended for systems implemented in **VR with 3DoF or 6DoF tracking**, where bodily movement is a core gameplay input and social features are designed to shape motivation, engagement, or training experience. We characterize each system along: (1) **social mechanism** (why the social feature motivates), (2) **interaction structure** (how time and roles are organized), and (3) **agent representation** (who or what the "other" is). These axes are designed to be composable: a single system can combine multiple mechanisms (hybrids), while structural and agent choices systematically constrain what mechanisms are feasible and what social experiences are likely to emerge.

3.1. Axis 1: Social mechanism

We define **social mechanism** as the *primary motivational logic* a design uses to leverage the presence (real or mediated) of others. We distinguish three recurring mechanisms, while allowing hybrids.

Competitive. Competitive designs use **performance comparison** to create motivational pressure or challenge, typically through scores, ranking, racing, win–lose framing, or explicit opponent framing. Competition can be synchronous (head-to-head) or asynchronous (leaderboards, ghost traces), and it often emphasizes competence signals and social comparison.

Cooperative. Cooperative designs create **interdependence** between players or between a player and an assisting agent. The motivational logic relies on shared goals (e.g., jointly achieving a target), complementary contributions, or mutual support and coordination. Cooperation appears in both symmetric settings (same task, shared goal) and asymmetric settings (coach–trainee, helper–performer), and it is especially common in scenarios that benefit from guidance, scaffolding, or reduced social risk.

Co-presence. Co-presence designs leverage the **felt presence of others** without requiring explicit competition or cooperation. The mechanism relies on being observed, audiences, spectatorship, social cues (e.g., "someone is here"), or accountability effects. Co-presence can be a standalone mechanism (observation as the main driver), but it frequently functions as an overlay layered onto competition or cooperation, which is why it appears as a distinct set in Figure 1 and also within hybrid clusters.

Hybrids. Many systems blend mechanisms. For example, a competitive game may add audience cues that increase accountability (competitive plus co-presence), or a cooperative setting may include mild performance comparison to sustain engagement. In our coding, hybrids are assigned when two mechanisms are both explicit in the design and both plausibly central to the intended user experience (see decision rules below).

3.2. Axis 2: Interaction structure (Synchrony by symmetry)

The second axis captures how interaction is organized in time and roles, independent of the motivating mechanism. We define two orthogonal dimensions:

Synchrony indicates whether interaction is time-coupled (*synchronous*) or time-decoupled (*asynchronous*). **Symmetry** indicates whether participants have equivalent roles and tasks (*symmetric*) or differentiated roles and responsibilities (*asymmetric*).

Their intersection yields four structural configurations (Figure 1):

Synchronous and symmetric. Players act at the same time and perform the same task. This configuration supports fast feedback loops and strong moment-to-moment social salience, but it increases coordination cost (matching schedules) and often amplifies social pressure because performance is directly comparable.

Asynchronous and symmetric. Players act at different times but perform similar tasks. This configuration is commonly enabled by ghost traces, leaderboards, or recorded traces, offering scalability and low coordination burden. Its design implication is that it can sustain routine engagement and self-improvement with reduced social risk, while typically providing weaker social-emotional support than live interaction.

Synchronous and asymmetric. Players act at the same time but have different roles or goals (e.g., coach–trainee, helper–performer). This configuration enables role specialization (guidance, monitoring, encouragement), often fitting rehabilitation or training contexts. Its key implication is that it can deliver support and accountability while avoiding direct peer comparison, at the cost of additional role design complexity.

Asynchronous and asymmetric. Players act at different times and have different roles. This configuration is rare in the literature (as reflected by sparsity in the lower-right quadrant), yet it represents a promising opportunity for scalable support. For example, a trainee may complete a session, and a coach (human or AI) reviews and responds later, or a system assigns complementary tasks that accumulate toward a shared goal. Its main implication is strong scalability and personalization, with careful design needed to preserve social meaning despite time separation.

3.3. Axis 3: Agent representation

The third axis specifies **who or what constitutes the "other"** in the social augmentation design (Figure 1). We distinguish three recurring representations:

Real people. A real person participates directly (co-located or remote). Real partners naturally enable synchronous interaction and rich social signaling. They also make both competitive and cooperative mechanisms straightforward to implement, especially in symmetric structures where comparability is high. However, reliance on real partners increases coordination burden and may raise social anxiety or exclusion risk for some users.

Ghost or recorded partner. A ghost partner is a recorded trace (of the user or another person), replayed to enable comparison or accompaniment without requiring co-attendance. Ghosts systematically enable asynchronous and symmetric structures, because the most robust use case is replaying the same task for comparable metrics. Ghosts are therefore strongly associated with competitive mechanisms (leaderboards, time trials), and are less often used for rich cooperative or role-differentiated interaction.

NPC or AI agent. An NPC or AI agent is software-driven and can act as coach, opponent, companion, or audience. Agents systematically reduce coordination requirements and can enable both synchronous and asynchronous interaction. They also make asymmetric structures more feasible (coach–trainee), because the agent can be designed to provide guidance, monitoring, or adaptive feedback. This representation is therefore a key enabler for underexplored regions such as asynchronous and asymmetric supportive designs.

3.4. Coding decision rules

To ensure consistent placement of studies into Figure 1, we used the following decision rules during coding.

> **Decision rule set (applied in order).**
>
> **Mechanism.** Assign **competitive** if the system contains explicit performance comparison framed as winning, losing, ranking, racing, or direct opponent framing, and the comparison is intended to motivate effort. Assign **cooperative** if the system requires shared goals, mutual dependence, or complementary contributions to succeed (not merely playing "together"). Assign **co-presence** if the system explicitly leverages being observed, audiences, spectatorship, or social cues for accountability or experience, without requiring shared goals or opponent framing. Assign a **hybrid** only if two mechanisms are both clearly implemented and both central to the intended experience (e.g., explicit competition plus explicit audience manipulation).
>
> **Synchrony.** Assign **synchronous** if the "other" responds in real time or the interaction depends on simultaneous participation. Assign **asynchronous** if the social influence is mediated by recorded traces, delayed feedback, or non-simultaneous participation (e.g., ghost replay, leaderboard, post-session coach review). Assign **both** if the paper reports two distinct modes or a switchable design where both forms are core.
>
> **Symmetry.** Assign **symmetric** if roles and tasks are equivalent and directly comparable for all participants (including ghost comparison of the same task). Assign **asymmetric** if roles, permissions, responsibilities, or goals differ materially (e.g., coach gives feedback while trainee performs; one observes while another exercises).
>
> **Agent.** Assign **real people** if another live human participates. Assign **ghost** if the "other" is a replayed or recorded trace (self or other), and the design relies on that trace for social influence. Assign **NPC or AI** if the "other" is software-driven (rule-based or learned), regardless of whether it is labeled as avatar, virtual coach, or opponent.

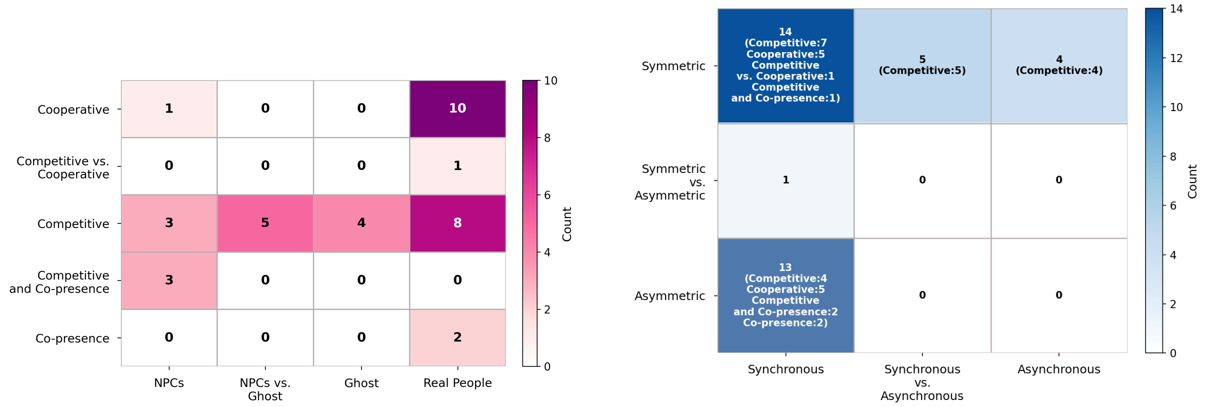
How the axes work together. The three axes jointly explain why certain regions dominate the literature. Real people naturally support synchronous interaction and make symmetric competition easy to implement, producing the large cluster in the synchronous and symmetric region. Ghost representations strongly enable asynchronous and symmetric designs, which explains their concentration in that quadrant. NPC or AI representations reduce coordination requirements and make role differentiation feasible, which is why they appear frequently in asymmetric structures and can serve as the primary enabler for the sparsely explored asynchronous and asymmetric region.

4. Validation via Mapping

To validate the usefulness of the proposed taxonomy, we mapped all included studies into the design space defined by our three axes: social mechanism, interaction structure, and agent representation. Rather than estimating effect sizes, the goal is to reveal which regions of the design space are heavily explored and which remain sparse.

4.1. Corpus snapshot

The mapped corpus comprises **37 studies** published between 2011 and 2024. Most work targets **general adults (28)**, followed by **rehabilitation contexts (6)** and **older adults (3)**, with one study involving astronauts. Methods are predominantly quantitative (18) or mixed-methods (16), with relatively few qualitative-only studies (3). Three papers present design concepts without empirical evaluation (Appendix 1).



(a) Mechanism × Agent (studies counts). Darker red indicates higher frequency.

(b) Synchrony × Symmetry (studies counts). Darker blue indicates higher frequency.

Figure 2: Distribution of studies across the taxonomy axes.

4.2. Structure mapping: synchrony by symmetry

Figure 2b shows the distribution of studies across *synchrony* (synchronous vs. asynchronous) and *symmetry* (symmetric vs. asymmetric). Appendix 4 visualizes the study-level placement of all 37 papers, enabling direct inspection of how individual IDs contribute to the aggregate patterns shown in Figures 2a and 2b.

Dominant region: synchronous and symmetric (n = 14). The most common configuration is **synchronous–symmetric**. This region includes competitive designs (7), cooperative designs (5), one competitive–cooperative hybrid, and one competitive–co-presence hybrid. The literature therefore strongly favors real-time interaction with directly comparable roles and tasks.

Second region: synchronous and asymmetric (n = 13). A similarly substantial number of studies adopt **synchronous–asymmetric** structures. This region includes competitive (4), cooperative (5), competitive–co-presence (2), and co-presence (2) mechanisms. These designs typically involve role differentiation (e.g., coach–trainee, observer–performer) and are common in guidance-oriented contexts.

Asynchronous and symmetric (n = 5). The **asynchronous–symmetric** configuration appears less frequently and consists entirely of competitive designs. This suggests that when interaction is time-decoupled, studies overwhelmingly preserve task equivalence and performance comparability (e.g., ghost replay or leaderboard-based competition).

Sparse region: asynchronous and asymmetric. The **asynchronous–asymmetric** quadrant is nearly empty. This indicates a largely unexplored design space for scalable, time-decoupled interaction with differentiated roles (e.g., delayed coaching, review-based collaboration).

4.3. Mechanism and agent mapping

Figure 2a shows how *social mechanisms* distribute across *agent representations.*

Real people dominate cooperative designs. Cooperative mechanisms are overwhelmingly associated with **real people** (n = 10), with only one cooperative case implemented via NPCs. This suggests that shared goals and interdependence are most commonly realized through live human partners.

Competitive designs span all agent types. Competitive mechanisms appear across all representations: NPCs (3), NPC vs. Ghost (5), Ghost (4), and Real People (8). Real people and NPC-vs-ghost setups are particularly common, indicating a strong emphasis on structured performance comparison.

Hybrids remain limited. Competitive–cooperative hybrids (n = 1) and competitive–co-presence hybrids (n = 3) are comparatively rare and unevenly distributed across agent types, suggesting that explicit multi-mechanism designs remain underdeveloped.

Co-presence is concentrated in real-people setups. Standalone co-presence designs are sparse (n = 2), both implemented with real people. This suggests that audience or observational mechanisms are still primarily tied to live human contexts rather than AI or ghost-based implementations.

4.4. Summary of mapping evidence

Taken together, Figures 2a and 2b reveal a clear structural bias in the literature. The design space is dominated by **synchronous symmetric interaction** and by **competitive mechanisms**, particularly those involving real people. Cooperative designs are strongly tied to live human partners, while ghost-based implementations primarily support competitive asynchronous comparison.

In contrast, **asynchronous asymmetric** configurations remain largely unexplored, especially those leveraging NPC or AI agents. This region represents a promising opportunity for scalable, time-decoupled supportive designs.

5. Discussion

This paper contributes a shared description language for social augmentation in VR exergames, enabling cumulative comparison across heterogeneous designs. The mapping shows two dominant configurations: **synchronous–symmetric competitive designs with real people** and **asynchronous–symmetric competitive designs with ghost traces**. These clusters are largely explained by cross-axis constraints. Competition benefits from *symmetry* because comparable tasks and metrics make ranking and win–lose framing straightforward. Agent representation further constrains structure: real partners naturally enable synchronous interaction, while ghost traces inherently enable asynchronous comparison with preserved task equivalence. In contrast, NPC or AI agents reduce coordination cost and make role differentiation feasible, which is why they more often appear in asymmetric designs.

The taxonomy also clarifies design implications. For short-session intensity, synchronous–symmetric competition with real partners is a pragmatic default, but it increases coordination burden and social pressure. For routine engagement, asynchronous–symmetric ghost-based comparison scales well, but typically provides weaker social-emotional support. For guidance-oriented or vulnerable populations, synchronous–asymmetric cooperation (e.g., coach–trainee) can deliver support without forcing direct peer comparison. Co-presence often functions as a *dosable overlay* and tends to be instantiated via asymmetric roles (observer, audience, evaluator), suggesting designers should calibrate accountability cues to avoid excessive self-monitoring.

The most actionable research gap is the sparsity of **asynchronous–asymmetric** designs. This quadrant could combine scalability (time decoupling) with supportive differentiation (role-based feedback), and NPC or AI agents are the natural enabler for such "support at a distance" (e.g., delayed coaching, review-based encouragement). Future work should therefore move beyond "comparison at a distance" toward scalable, role-differentiated support, and evaluate these systems with outcomes aligned to their structure (e.g., adherence for asynchronous designs; trust and social comfort for agent-mediated coaching; standardized exertion proxies for real-time competition), while addressing transparency, social pressure, and accessibility.

The mapping yields four practical implications for design and future research. First, the literature concentrates in synchronous–symmetric interaction (often competitive with real partners) and in time-decoupled competitive comparison enabled by ghost traces, indicating a prevailing reliance on directly comparable tasks. Second, agent representation constrains feasible structures: real partners favor synchronous coupling, ghost traces support asynchronous comparison with preserved task equivalence, and NPC/AI agents lower coordination cost and enable role differentiation. Third, co-presence is most often realized through asymmetric roles (e.g., observer/evaluator/coach) rather than equal-task peer interaction, suggesting it functions as a calibrated accountability overlay. Finally, the most actionable opportunity is to expand into asynchronous–asymmetric designs for scalable, role-differentiated support (e.g., delayed coaching and adaptive review), particularly with NPC/AI agents.

6. Limitations

Our corpus is limited to peer-reviewed, English-language work and VR systems with 3DoF or 6DoF, which may under-represent commercial systems and other platforms. The three-axis taxonomy prioritizes usability over completeness; dynamic mode switching, graded co-presence intensity, and other nuances may not be fully captured by a single label per axis (partly mitigated by hybrid and "both" labels). Although we used explicit decision rules, some borderline cases require interpretation, and inter-rater reliability was not formally reported. Finally, the mapping is descriptive rather than causal: dominance or sparsity in the design space indicates research attention, not superiority of any configuration.

7. Conclusion

We introduced a taxonomy for social augmentation in VR exergames and validated its usefulness by mapping 37 studies into a three-axis design space: **social mechanism** (competition, cooperation, co-presence), **interaction structure** (synchrony $\times$ symmetry), and **agent representation** (real, ghost, NPC/AI). The mapping shows a clear concentration in **synchronous–symmetric competitive designs with real partners**, followed by **asynchronous–symmetric competitive designs enabled by ghost traces**, while **asynchronous–asymmetric** configurations remain scarce. These patterns highlight how agent choices systematically constrain feasible structures and mechanisms, shaping what the field has studied and what remains underexplored.

By providing explicit decision rules and a comparable description language, our taxonomy supports cumulative analysis across heterogeneous systems and helps designers select social configurations that match training goals (e.g., intensity, adherence, supportive participation). The most promising opportunity is to expand into scalable, role-differentiated support,particularly **asynchronous–asymmetric** designs enabled by NPC/AI.

Declaration on Generative AI

The authors have not used any Generative AI tools.

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8. Appendix

Table 1

ID	Paper	Year	Symmetric/Asymmetric	Synchronous/ Asynchronous	Competitive/ Cooperative/ Co-presence	Object	Target Populations	Evaluation Method
1	Chang et al.[15]	2024	Asymmetric	Synchronous	Competitive	Real People	General Adults	No user study
2	Barathi et al.[16]	2024	Symmetric	Asynchronous	Competitive	Ghost	General Adults	Quantitative
3	de Souza et al.[17]	2016	Symmetric	Synchronous	Cooperative	Real People	General Adults	No user study
4	Michael and Lutteroth[18]	2020	Symmetric	Asynchronous	Competitive	Ghost	General Adults	Mixed
5	Koulouris et al.[19]	2020	Symmetric	Asynchronous	Competitive	Ghost	General Adults	Quantitative
6	Márquez Segura et al.[3]	2021	Both	Synchronous	Cooperative	Real People	General Adults	Qualitative
7	Barathi et al.[20]	2018	Symmetric	Asynchronous	Competitive	Ghost	General Adults	Quantitative
8	Guo et al.[21]	2024	Asymmetric	Synchronous	Co-presence	Real People	General Adults	Quantitative
9	Ameri et al.[22]	2023	Asymmetric	Synchronous	Competitive	NPCs	General Adults	Mixed
10	Farrow et al.[23]	2022	Symmetric	Both	Competitive	NPCs vs. Ghost	General Adults	Quantitative
11	Kojić et al.[24]	2019	Symmetric	Synchronous	Competitive	Real People	General Adults	Quantitative
12	Wünsche et al.[25]	2021	Symmetric	Synchronous	Competitive	Real People	General Adults	Quantitative
13	Guo et al.[26]	2024	Asymmetric	Synchronous	Co-presence	Real People	General Adults	Mixed
14	Zhang et al.[27]	2011	Symmetric	Synchronous	Competitive	Real People	General Adults	Quantitative
15	Rings et al.[28]	2020	Asymmetric	Synchronous	Cooperative	Real People	Rehabilitation Patients	Mixed
16	Numan et al.[29]	2019	Symmetric	Synchronous	Competitive and Co-presence	NPCs	General Adults	Quantitative
17	Macaluso et al.[30]	2024	Asymmetric	Synchronous	Cooperative	Real People	Rehabilitation Patients	Mixed
18	Feltz et al.[31]	2016	Asymmetric	Synchronous	Competitive	NPCs	Astronaut	Quantitative
19	Béraud-Peigné et al.[32]	2024	Symmetric	Synchronous	Competitive vs. Cooperative	Real People	General Adults	Mixed
21	Mendez et al.[33]	2022	Asymmetric	Synchronous	Cooperative	Real People	General Adults	Mixed
22	Shah et al.[34]	2022	Symmetric	Synchronous	Cooperative	Real People	Older Adults	Mixed
23	Wang et al.[35]	2018	Asymmetric	Synchronous	Competitive	NPCs	Rehabilitation Patients	Qualitative
24	He et al.[36]	2024	Asymmetric	Synchronous	Cooperative	NPCs	General Adults	Mixed
25	Shah et al.[37]	2023	Symmetric	Synchronous	Cooperative	Real People	Older Adults	Mixed

Table 1 continued from previous page

ID	Paper	Year	Symmetric/Asymmetric	Synchronous/ Asynchronous	Competitive/ Cooperative/ Co-presence	Object	Target Populations	Evaluation Method
26	Høeg et al.[38]	2023	Symmetric	Synchronous	Cooperative	Real People	Older Adults	Mixed
27	Lai et al.[39]	2022	Asymmetric	Synchronous	Cooperative	Real People	Rehabilitation Patients	Mixed
28	Kalaitzidou et al.[40]	2021	Symmetric	Synchronous	Competitive	Real People	General Adults	No user study
29	Lange-Nawka et al.[41]	2023	Symmetric	Both	Competitive	NPC vs Ghost	General Adults	Mixed
30	Shaw et al.[42]	2012	Symmetric	Both	Competitive	NPC vs Ghost	General Adults	Mixed
31	Haller et al.[43]	2022	Asymmetric	Synchronous	Competitive and Co-presence	NPCs	General Adults	Quantitative
32	Palmieri and Deutsch[44]	2022	Symmetric	Both	Competitive	NPC vs Ghost	General Adults	Quantitative
33	Bahrin et al.[45]	2021	Symmetric	Both	Competitive	NPC vs Ghost	General Adults	Mixed
34	Xu et al.[46]	2023	Asymmetric	Synchronous	Competitive and Co-presence	NPCs	General Adults	Quantitative
35	Keller et al.[47]	2020	Symmetric	Synchronous	Competitive	Real People	General Adults	Mixed
36	Vlahovic et al.[48]	2022	Symmetric	Synchronous	Competitive	Real People	General Adults	Quantitative
37	Wang et al.[49]	2023	Symmetric	Synchronous	Cooperative	Real People	General Adults	Mixed

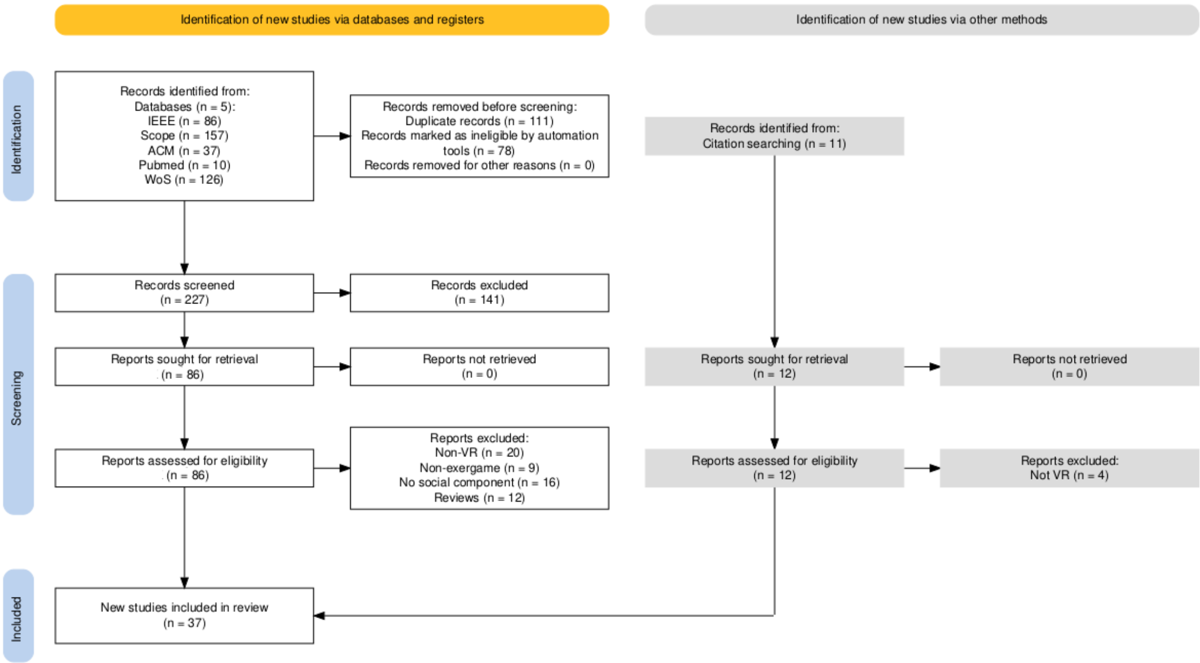

Figure 3: PRISMA-style flow diagram illustrating study identification, screening, and inclusion.

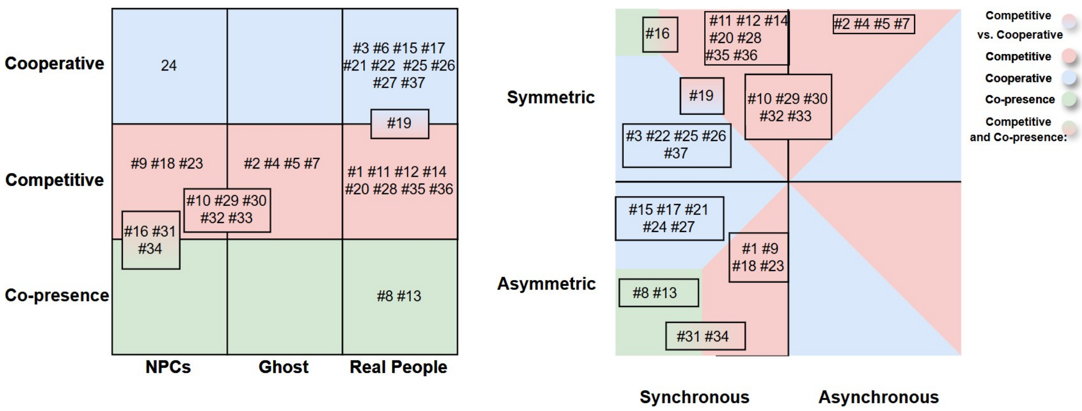

Figure 4: Study-level mapping of the 37 included papers across (left) social mechanism × agent representation and (right) synchrony × symmetry. Each numbered box corresponds to a study ID listed in Appendix 1.