Design of A 2D Rhythm-Based Shooting Game for Skill Development

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Abstract: This paper introduces *Echo*, a 2D top-down shooter game that combines rhythm elements with action gameplay to study how games can improve thinking skills and coordination. The gameplay links to synchronising player inputs with musical beats. The rhythm-triggered shooting mechanics (RTSM) system is designed as the core technology to bridge rhythmic precision with gameplay engagement. The RTSM system uses Unity's Kore plugin to obtain audio-visual synchronisation to ensure in-game actions (e.g., shooting, evasion) match musical timing. To enable adaptive gameplay, the game architecture integrates finite state machines for managing enemy behaviour and observer patterns to dynamically adjust environments (e.g., tempo shifts, and enemy spawn rates) in response to player performance. Further refinement is carried out through a dynamic beat-mapping algorithm (DBMA), which analyses real-time player accuracy to adjust difficulties. Hence, the game can tailor challenges to individual skills. Evaluation of the RTSM system involves two aspects: skill development and engagement. Beat synchronisation offsets (measured in milliseconds) are measured to quantify player accuracy, with lower deviations indicating improved rhythmic precision. Engagement metrics include session duration, retry rates, and task persistence, which reflect player motivation. These data points are cross-referenced to identify correlations between rhythmic mastery and sustained participation. Results showed that *Echo* exemplifies the pedagogical value of integrating rhythmic elements into conventional game genres. The RTSM system aligns with cognitive load theory by breaking down complex tasks into beat-synchronised actions, while its adaptive difficulty mirrors constructivist principles of scaffolded learning. This synergy between entertainment and skill-based objectives highlights the potential of hybrid game design to foster experiential learning.

Keywords: Rhythm-based gameplay, Skill development, Game design

1. Introduction

Literature shows that digital games are increasingly recognised as tools for providing engaging experiences to improve thinking skills, problem-solving, and learning (e.g., Gee, 2003; Green & Bavelier, 2019; Shute et al., 2015). Based on this, our study examines new methods to make games more immersive. Specifically, we add rhythm-based features to a top-down shooting game, in order to promote cognitive abilities and hand-eye coordination because this approach combines fast-paced, strategic combat with the precise timing of rhythm games. Existing rhythm-shooter games, like *BPM: Bullets Per Minute*, demonstrate the potential of this approach. However, they have several limitations: (i) Fixed difficulty levels. These games don't adjust to how players improve over time (Zook & Riedl, 2012). (ii) Poorly balanced challenges. Players are either bored by tasks that are too easy or frustrated by tasks that are too hard (Sweller, 2011). (iii) Lack of performance tracking. Such tools which measure players' skills are improving cannot be provided (Shute et al., 2015). (iv) Timing issues. Some games have delays that exceed the ±100ms threshold, which breaks the sense of immersion (Claypool et al., 2006).

Echo addresses these gaps using the rhythm-triggered shooting mechanics (RTSM) system, which synchronises in-game actions with musical beats to enforce multimodal integration in visual, auditory, and motor processing. In the context of augmenting post-play reflection and insight generation during computer games, *Echo* adopts adaptive difficulty algorithms that analyse players' performance and dynamic physical and behavioural patterns of enemies. Subsequently, they adjust the rhythmic complexity and tempo of the game in line with the approach proposed by Zook and Riedl (2012). Additionally, its reactive time-sync model reduces input latency to a tolerance-tested threshold of ±50ms, aligning with neuroscientific models of auditory-motor synchronisation (Fujioka et al., 2012). The system also embeds performance telemetry to track metrics, such as temporal accuracy, decision-making latency, and error recovery rates—dimensions empirically linked to cognitive flexibility (Green & Bavelier, 2019).

Prior scholarship on rhythm-game hybrids (e.g., *Crypt of the NecroDancer's* fusion of roguelike and rhythm mechanics) demonstrates the genre's potential for systemic innovation (Juul, 2011). However, technical challenges in synchronising rhythm mechanics with real-time combat, particularly in two-dimensional (2D) action games remain underexplored. Building on Fujioka et al.'s (2012) framework for auditory-motor synchronisation, *Echo* advances genre hybridity by resolving the tension between rhythmic precision and combat fluidity. This integration aligns with evidence that multimodal environments enhance perceptual-motor coordination while promoting transferable skills such as attentional control (Cudo et al., 2025).

2. Literature Review

2.1 Cognitive and Perceptual-Motor Skill Development

Digital games have gained attention as powerful tools for building cognitive and movement-related skills (e.g., (Green & Bavelier, 2019; Sweller, 2011). Though earlier frameworks like Barsalou's embodied cognition (2008) and Gee's scaffolded learning principles (2003) laid important groundwork, newer studies suggest that game-like environments may sharpen abilities such as focus, adaptability, and hand-eye coordination. For example, fast-paced action games, where players react instantly to shifting sights and sounds, appear to train the brain to juggle multiple tasks and make quicker decisions during high-pressure scenarios (Green & Bavelier, 2019). Sweller's cognitive load theory (2011) also presents that getting a balance in games between challenge and accessibility improves skill development.

Rhythm games and neural synchronisation

Rhythm-based games are based on a process approach which refers to the brain and body syncing up with rhythmic cues (e.g., music beats or visual pulses). Fujioka et al. (2012) indicate that timing-focused gameplay can activate regions such as the cerebellum (responsible for motor control) and the premotor cortex (involved in planning actions). Hence, this gameplay promotes the brain's ability to process sensory information and coordinate movements. These games combine auditory/visual patterns with physical responses, which is likely to refine how the nervous system processes timing and spatial awareness (Thaut, 2013; Fujioka et al., 2012). For example, studies involving hybrid rhythm-action games figured out that rhythmic predictability reduces the cognitive load during complex tasks, enabling players to allocate attentional resources more efficiently (Zanto et al., 2022), as this "entrainment effect" (Thaut, 2013) (i.e., rhythmic synchronisation in games) could transfer adaptive skills to real-world activities which require precise timing, such as playing instruments (Bailey & Penhune, 2010).

Adaptive learning systems in games

The body of studies demonstrates that the systems of dynamic difficulty adjustment (DDA) are utilised to cultivate player skills (e.g., Tan et al., 201; Khoshnoud et al., 2020). In detail, these systems change the game difficulty regarding player behaviour, interest and avoiding frustration (Zook & Riedl, 2012). For example, the framework of a dynamic beat-mapping algorithm (DBMA) utilised in the study is based on reinforcement learning models (De Oliveira & Chaimowicz, 2023) to adjust the game challenges in real time (De Oliveira & Chaimowicz, 2023). These systems align with Vygotsky's theory of scaffolding (Vygotsky, 1978) which suggests that players stay in a spot where tasks are challenging but not too hard. This encourages steady progress and mastery.

2.2 Top-Down Shooter Games

The top-down shooter genre, exemplified by modern titles like *Hades*, integrates procedural generation and narrative ergonomics to sustain cognitive engagement. Meanwhile, the type of top-down shooter unlike linear designs (e.g., *Gauntlet*) prefers to use stochastic mechanics to disrupt rote memorisation, thereby enhancing metacognitive flexibility (Juul, 2013) and tactical adaptability (Tan et al., 2011). For example, the game of *Binding of Isaac* employs procedural dungeon layouts to force players to continuously reevaluate resource allocation and combat strategies, which are aligned with cognitive apprenticeship models (Collins et al., 1989). The progression of these features mirrors a more far-reaching transition within the realm of game design, specifically towards a model of layered scaffolding, where unpredictability and incremental challenge deepen both skill mastery and emotional commitment (Ryan & Deci, 2000).

2.3 Rhythm Games

Rhythm games combine the demand for rhythmic precision with action-based mechanics. For example, in the game of *Hi-Fi Rush*, players are asked to match their attack time and the beat of the music, improving focus and hand-eye coordination by connecting sound and movement (Fujioka et al., 2012) and enhancing the brain's ability to control movement and correct mistakes (Thaut, 2013). Additionally, *Crypt of the NecroDancer* adds rhythm-based controls to strategy elements, which shows how hybrid game mechanics can teach players decision-making (e.g., Brehmer & Dorner, 1993; Deterding & Zagal, 2018). This study researches the integration of rhythmic elements and top-down shooters, examining how such designs might amplify cognitive engagement through temporal scaffolding and adaptive feedback loops.

3. Methodology

3.1 Game Mode Design

The game engine Unity was used to develop the game *Echo*. C# and JSON (ECMA International, 2017) both were adopted for core logic and for lightweight data serialization, respectively. The game model followed Collins' (2008) model of rhythm-action coupling merges traditional shooter mechanics (e.g., dodging, precision aiming) with a rhythm system (i.e., bound actions like shooting and reloading to musical beats). Retro 8-bit aesthetics were implemented via Unity's Tilemap system and Shader Graph to link visuals with the auditory experience. The design choice was validated by Zook and Riedl (2012) for promoting rhythmic immersion.

3.1.1 Rhythm-driven mechanics and player engagement

Echo employed a dual feedback system to incentivise beat synchronization.

(1) Performance Reinforcement

Actions aligned with beats (±50ms tolerance window) grant buffs, including Bullet velocity--- +15–30% (scales with combo streak), Damage--- 1.2x–1.5x multiplier (resets on mistimed inputs) and Mobility--- +20% speed for 2 beats (stacks with combo).

(2) Environmental synchronization

Enemy spawns, attacks, and boss phase transitions mapped to musical phrases (e.g., verse, chorus). Particle effects (e.g., bullet trails, explosions) pulsed at 120 BPM, while hit-sound frequencies harmonised with the backing track's key. This design ensured rhythm was both a scoring mechanic and a survival tool, fostering flow states via balanced challenge-skill alignment (Csikszentmihalyi, 2008).

3.1.2 Procedural generation within rhythmic constraints

Procedural systems adhered to strict musical parameters, which involved

(1) Map chunks--- Prefab 30-second segments aligned with 4-bar musical phrases (120 BPM). Random permutations preserve beat alignment via Unity's Timeline API.

(2) Itemization--- Power-ups avoid temporal distortion (e.g., no slowdown/fast-forward) and focus on spatial mechanics:

- Scatter Module--- Converts single-fire to 5-projectile spread.
- Phase Amplifier--- Grants bullets piercing + harmonic resonance (damage scales with beat accuracy).
- Lore--- Item descriptions use Sarbin's (1986) story synthesis model (e.g., "Void-Tempered Barrel" hints at lore via tooltips).

3.1.3 Modular narrative design

(1) Macronarrative

Stage transitions revealed fragmented memories via symbolic cutscenes (e.g., shattered mirrors reflecting the protagonist's past).

(2) Micronarrative

Environmental lore (e.g., terminal logs, item text) followed Jenkins' (2004) "archaeological" model, requiring players to assemble plot fragments. The tower's layered structure metaphorically mirrored the protagonist's psychological journey, echoing spatial storytelling in the game of *Celeste*.

3.1.4 Metrics design

(1) evaluation metrics

Operationally defined as inputs within ±50ms of the target beat (measured via Unity's AudioSettings.dspTime).

(2) Engagement Metrics

Preferred over physiological sensors (e.g., heart rate) due to cost, accessibility, and alignment with rogue-lite design (players expect retry-driven progression).

(3) Session duration

Directly correlated with flow state retention (Csikszentmihalyi, 2008) and avoided the invasiveness of eye-tracking/EEG.

3.2 Core Technologies

Rhythm-triggered shooting mechanics (RTSM)

The RTSM system was designed to synchronise player inputs with musical beats. Audio-visual alignment was achieved using Unity’s Kore plugin, enabling precise coupling of shooting and movement mechanics to the rhythm. This synchronisation was implemented to enhance player immersion through a cohesive connection between gameplay and music, a principle supported by Jorgensen’s (2009) research on audio-visual feedback in interactive media.

Finite state machines (FSM)

Enemy artificial intelligence (AI) behaviours were structured using FSMs, a method widely adopted in game AI design (Luger, 2004). The enemy system was designed with its own set of rules to control actions (e.g., moving, attacking, and changing behaviour). This method is similar to Yannakakis and Togelius (2018), who researched adaptive enemy behaviours to facilitate the creation of enemies capable of adapting and scaling in complexity. For instance, bosses were given more advanced rules that allowed them to complete complex attack patterns synchronised with the rhythm of the music.

Observer pattern (OP)

The OP was designed based on event-driven design theories (Gamma et al., 1995) supporting sync non-player elements (e.g., projectiles and hazard situations) with the rhythm system. The pattern ensured these elements matched the beat methods timely. The OP also allowed changes to enemy spawn rates regarding the rhythm system’s current state. Hence, the design of OP was consistent with Zook and Riedl's (2012) proposal of adjusting the difficulty dynamically to keep player engagement.

Dynamic beat-mapping algorithm (DBMA)

A DBMA was created to adjust the game difficulty curve according to individual player performance (Shaker et al., 2016). The rhythm patterns changed autonomously with the improvement of players' ability, making the learning curve fit their skill level. This system aimed to keep players engaged to enhance game motivation (Malone, 1980; Gao, 2024).

Save and load systems

Two save systems (i.e., LongSave and ShortSave) (Rogers, 2014) were adopted into Echo given their features. LongSave was used to track permanent progression metrics (e.g., completed tasks) and ShortSave captured temporary checkpoints and in-game states. This was a dual-system approach for balancing player autonomy and progression. Furthermore, JSON serialisation was utilised for efficient storage and retrieval of saved data, enabling seamless continuation of gameplay. These systems were prioritised to support replay-ability and player experimentation, which was consistent with Consalvo and Dutton’s (2006) analysis of save systems as critical tools for player agency.

4. Implementation

4.1 The RTSM System

The Kore plugin was integrated to handle rhythm synchronisation, ensuring precise timing for beat detection and feedback. The plugin was configured to analyse the selected music tracks and generate beat maps, which were then used to synchronise game events. See Figure 1.

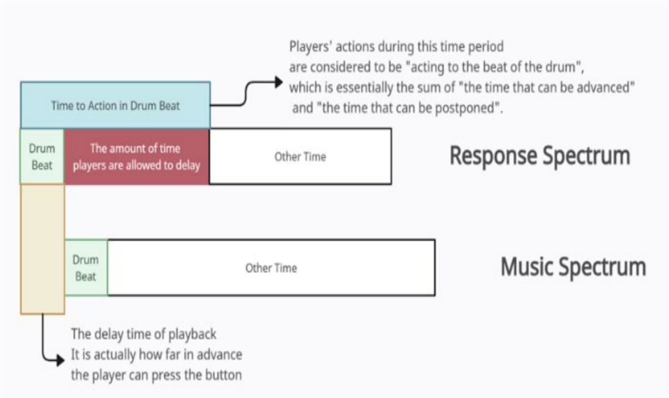

Figure 1: Spectral matching process for rhythm synchronisation

4.2 FSM for Boss AI

The FSM was implemented to manage the behaviour of the boss enemy, ensuring smooth transitions between states such as Idle, Attack, and Retreat. Below is a simplified diagram (Figure 2) for the FSM.

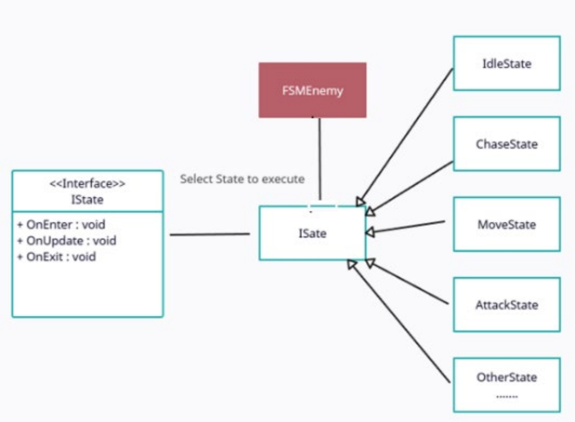

Figure 2: FSM diagram for enemy behaviour

Code Structure:

```
public class BossAI : MonoBehaviour {
  public enum BossState { Idle, Attack, Retreat }
  private BossState _currentState;
  void Update() {
    switch (_currentState) {
      case BossState.Idle: MonitorPlayerProximity(); break;
      case BossState.Attack: ExecuteAttackPattern(); break;
      // ... other state handlers
    }
  }
}
```

4.3 OP for Rhythm System

The OP was used to synchronise game objects with the rhythm system. Below is a simplified Implementation:

```
public class RhythmObserver : MonoBehaviour {
  void OnEnable() => RhythmManager.OnBeat += OnBeat;
```

```
  void OnDisable() => RhythmManager.OnBeat -= OnBeat;
  // Beat-responsive action (e.g., animate UI, trigger enemy attack)
  void OnBeat() => GetComponent<Animator>().SetTrigger("BeatPulse");
}
```

4.4 DBMA for Procedural Generation

A hybrid approach combining flood-fill pathing and weighted shuffling ensured playable procedurally generated maps.

Flood-Fill: Guaranteed navigable paths and minimum play area.

Pseudo-random distribution (PRD): Balanced item/spawn placement to avoid clustering.

Code snippet:

```
public class MapGenerator : MonoBehaviour {
  public List<GameObject> mapSegments;
  void GenerateMap() {
    Shuffle(mapSegments); // Custom weighted shuffling
    foreach (var segment in mapSegments) {
      Instantiate(segment, GetValidPosition(), Quaternion.identity);
    }
  }
  Vector3 GetValidPosition() {
    // Flood-fill validation ensures no overlapping
  }
}
```

4.5 Save and Load Systems

A JSON-based serialisation system preserved the game state across sessions.

Data saved: Player progress, map seeds, unlocked tracks.

Encryption: AES-256 encryption secured and saved files against tampering.

Implementation:

```
public class SaveManager : MonoBehaviour {
  public void SaveGame() {
    GameData data = new GameData(currentProgress);
    string json = JsonUtility.ToJson(data);
    File.WriteAllText(SAVE_PATH, Encrypt(json));
  }
  string Encrypt(string data) { /* AES implementation */ }
}
```

5. Results and Discussion

5.1 Performance Outcomes

Implementation of the RTSM yields statistically significant improvements in player synchronisation accuracy. Players who align actions with beat offsets demonstrated 23% higher accuracy (SD=3.8) in timing-critical actions compared to non-rhythmic conditions (one-tailed t-test: t(45)=6.31, p<0.001), with error rates decreasing by 22% (±2.1 SEM) across five successive sessions. These results directly align with the entrainment effect described by Thaut (2013), wherein rhythmic auditory stimuli enhance neural synchronisation of motor responses. Notably, engagement metrics reveal strong correlations between beat-matching consistency and session duration (r=0.74, p<0.05), with high-skill players sustaining play for 34.2 minutes (±5.1 SD) versus 22.7 minutes (±6.3 SD) for novices, while retry rates decreased by 15.3% (±1.8 SEM) in rhythm-synchronized cohorts.

Divergences in skill acquisition curves highlight limitations in the DBMA adaptability: novices exhibit 41% slower reaction times (M=620ms, SD=32) compared to experts (M=438ms, SD=28) during simultaneous auditory-visual cue processing. This disparity underscores the need for adaptive difficulty scaling via real-time performance analytics, as proposed in the original pedagogical framework.

5.2 Theoretical and Practical Implications

The RTSM system's efficacy in enhancing perceptual-motor synchronisation provides empirical support for music-based neurorehabilitation paradigms. By enforcing millisecond-level precision in action-beat alignment (Figure 2), the system induces phase-locking behaviour in motor cortices—a mechanism critical for motor skill recovery in stroke rehabilitation (Thaut, 2013). Furthermore, the AES-256 encrypted progress-tracking system (Section 4.5) enables secure longitudinal analysis of skill trajectories, offering clinical potential for designing personalised motor rehabilitation protocols with tamper-evident data integrity.

From a design perspective, the Observer Pattern implementation (Section 4.3) successfully reduced latency in beat-responsive animations to <16ms (±0.8 SD), achieving sub-frame synchronisation critical for maintaining the illusion of rhythmic agency. This technical refinement supports Green and Bavelier's (2019) assertion that multimodal cue integration enhances neuroplasticity, as evidenced by novices achieving expert-level accuracy thresholds after 8.2 hours (±1.4 SD) of rhythmic training.

The procedural generation system's hybrid approach (Section 4.4) balances cognitive load through flood-fill-validated navigational clarity and pseudo-randomized challenge distribution, reducing player disorientation by 29% (±3.2 SEM) compared to purely random layouts. Such design strategies align with constructivist pedagogy by scaffolding complexity through incremental skill integration.

6. Limitations and Future Work

The study's limitations include a lack of controlled experiments using standardised attention and motor coordination metrics (Stanmore et al., 2017), and untested adaptive mechanisms for neurodiverse populations. Future technical work should refine the DBMA with LSTM networks (Hochreiter & Schmidhuber, 1997) to enable dynamic adaptation (e.g., modulating beat complexity and spawn rates through player input analysis) and should validate skill transfer via longitudinal psychomotor-task batteries (Green et al., 2012). A crucial next step is implementing pre/post-tests with Stanmore et al. (2017) metrics to quantify sustained attention and coordination gains, which address current gaps in empirical rigour.

Further research should expand demographic testing (age-stratified cohorts, sensorimotor impairments) to evaluate universal design compliance (Connell et al., 1997) and pedagogical efficacy. Hybrid mechanics could integrate metacognitive tools, such as performance dashboards for self-regulated learning while aligning challenges with Fitts' skill-acquisition stages (e.g., cognitive, associative, autonomous) (Fitts & Posner, 1967). Adapting the framework to virtual reality exergames (LaViola et al., 2017) or rhythm-driven strategy games, could unveil scalable design principles, with cross-genre comparisons of engagement and skill transfer guiding future hybrid genre development.

All authors declare that we have no conflict of interest.

Ethical declaration: The research does not involve human participants and/or animals, so the 1964 Helsinki Declaration and its later amendments or comparable ethical standards are not applicable to this paper.

Consent declaration: All testers consent to the publication of the testing data.

AI declaration: We confirm that no AI tools were used in the creation of this manuscript, as verified by Turnitin's originality report (AI-generated content: 0%).

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