Xplosive Collision: Designing a Noise-Oriented Networked Music System Based on Dyadic, Interdependent Game Mechanics

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ABSTRACT

This paper presents *Xplosive Collision (XC)*, an interactive networked music system for two players. Implemented as a web application for smartphone browsers over a wireless local network, the system interconnects participants' devices. It uses competitive game logic to elicit dyadic interaction within a noise/experimental music paradigm. Game mechanics have been grounded in the timbral quality of the generated sound. The system has been evaluated through an exploratory study with seven pairs of players. Data have been collected through a post-session questionnaire, supported by system logs and optional open comments. The study examines how participants interact with the system and with one another, and how they engage with its game mechanics and sonic outcomes. Results indicate that participants effectively relied on sound to orient themselves within the system, intentionally used game mechanics to guide their actions, and remained predominantly focused on the game objective.

1. INTRODUCTION

In the field of Computer Music, the term *network music* refers to both the conceptual and technical dimensions of musical networking, reflecting the communicative and social aspects of music-making [1]. In this context, networks are understood as both symbolic structures and technological infrastructures: they not only transmit data or sound, but also encompass the protocols, connections and symbolic exchanges through which sound is encoded, transmitted, interpreted, and organised [2, 3]. The network topology determines the musical outcome, distributing agency across nodes and relations. In this sense, networks create and shape interactions, and generate aesthetic and cultural paradigms for musical practice [1]. Focusing on interdependent relationships, Weinberg's concept of *Interconnected Musical Networks* (IMNs) [3] posits that the network itself functions as an ecosystem whose architecture conditions the modes of interaction, agency, and sociality possible within the system, thereby affecting musical form.

A suggestive lens for structuring these interactions is game design. In game studies, Juul [4] defines games through six core features: rules, variable and quantifiable outcomes, the valorisation of those outcomes, player effort, emotional attachment, and negotiable consequences. Salen and Zimmerman [5] emphasise the notion of *artificial conflict* in describing the competitive nature of games. They also introduce the concept of *meaningful play* as a balance between possibility and limitation, "between too much and too little freedom," where constraints provide enough, but not excessive, challenge for players.

Game studies also offer a complementary perspective on interdependence. In multiplayer games, with mutually affecting actions, interdependencies can enhance the social experience by fostering communication and increasing players' sense of social presence [6]. Juul [7] identifies three social considerations that organise multiplayer experience: *goal orientation* (the desire to win), *game experience* (the maintenance of outcome uncertainty between players to preserve engagement), and *social management* (the regulation of the social situation among players). Together, these considerations show how outcome structures and rule-based constraints shape not only strategic behaviour but also the quality of interpersonal interplay. Within this framework, interdependencies can be deliberately designed to scaffold multiplayer interaction.

Game elements have long been used in musical practice to structure musical form and inter-player interactions without fully predetermining their outcomes [8, 9]. Applying game mechanics to networked music systems involves using rules, rewards, and objectives to establish structures and interdependencies distributed across players [10]. Within this framework, scholars have examined the gamification of musical performance through, for example, interactive scores [11, 12] and mobile-based musical applications [13, 14].

However, timbre-based objectives and sound-dependent game mechanics remain under-explored. Thus, we are interested in investigating how competitive, noise-oriented gameplay can support interpersonal interaction and shape music-making. In particular, we focus on game settings that foster dyadic interplay and interdependent relations within a co-located musical network. To this end, we developed *Xplosive Collision (XC)*, an interactive networked music system for two players based on competitive and interdependent game mechanics and objectives, and evaluated it through an exploratory study. The primary aim of the study is to investigate how participants interact with the proposed system and how the sound-based game mechanics influence their dyadic interactions.

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2. BACKGROUND

2.1 Interconnected Musical Networks and Networked Co-located Music Practices

Networks have long attracted interest in music because of their intrinsic capacity to establish relationships and transmit information [1]. In particular, computer networks played a significant role in the development of computer music, fostering diverse musical practices and stimulating research in the field. Notably, Weinberg popularised the concept of *Interconnected Musical Networks* (IMNs), defining them as "live performance systems that allow players to influence, share, and shape each other's music in real time" [3]. Their intrinsic interdependence can therefore foster social interaction among performers.

Although antecedents of IMNs can be traced back to twentieth-century electroacoustic works - such as Cage's *Imaginary Landscape No. 4* (1951) and Stockhausen's *Mikrophonie I* (1964) - the rise of digital technologies significantly expanded networked musical ecosystems by enabling distributed communication, real-time data exchange, and algorithmic mediation [15]. Early examples of this development include the experiences of the League of Automatic Music Composers or The Hub [16].

Nowadays, the development of network infrastructures and technologies has given rise to various tangent forms of sound installation and networked music performance, including collaborative live coding environments [17], laptop orchestras [18], and technology-mediated audience participation practices [19]. In particular, IMNs increasingly exploit web and mobile infrastructures to enable distributed performance ecologies, giving rise to the notion of *distributed music systems* (DMSs). Following distributed systems theory [20], in which computing is performed on multiple interconnected computers, DMS defines an ensemble of decentralised devices whose coordinated operation functions as a single coherent system. DMSs thus constitute a specific computer-network configuration through which IMNs take shape. The development of DMSs has been supported by open-source frameworks, e.g., *soundworks* [21] and *Collab-Hub* [1]. These frameworks have enabled projects such as *Mo.No.DeC* [22], which integrates participants' smartphones into distributed sound-diffusion systems composed of microcomputers and small loudspeakers as point-source nodes, allowing participants to spatialize, transform, and contribute sound in real time.

In this context, Matuszewski *et al.* reframe specific co-located IMNs' practices as *Situated Networked Music Systems* (SNMS), in which participants interact in the same space via web-based technologies [2]. Examples of SNMS include the design of distributed musical instruments for collective free improvisation [23], augmenting vocal ensemble practices through smartphone-generated electronic sounds [24], and fostering participation by distributing sound generation across participants' devices [2]. This perspective foregrounds social interaction and treats each actor in the network as a node whose relations can be composed.

[1] https://www.collab-hub.io/

2.2 Game Elements in Music

Game logics have been used in rule-based systems for composition [8, 25], for generating data within sonification paradigms [26, 27], and in improvisation frameworks [9]. In Western music traditions, game-oriented approaches can be traced back to Renaissance canons and contrapuntal puzzles [28], and later to early chance-based compositional techniques, such as the eighteenth-century *musical dice games* [25].

Rule-based systems have increasingly been employed to structure musical form since the twentieth century. This is evident in practices of indeterminacy, such as Cage's chance-based compositions [29], e.g., the I Ching-derived *Music of Changes* (1951), as well as in competitive rule frameworks found in open-form, combinatorial works like Xenakis's *Duel* (1959) and *Stratégie* (1962) [8]. Similar approaches emerge in guided improvisation practices, where rules structure interaction and shape the musical outcome. In particular, *game pieces*, such as John Zorn's *Cobra* (1984), privilege relationships among performers over sound material: their rules activate exchanges, regroupings, interruptions, and shifts, so that the music emerges from structured social interaction [30].

More recently, games - in particular video games - have become increasingly intertwined with musical practices, from the appropriation of digital game aesthetics and elements in audiovisual performance [31] to the implementation of game mechanics in interactive music systems [32]. For example, Michalakos [33] explored how a video game-like interactive audiovisual system can guide a solo improvisation on an augmented drum; or Studley *et al.* [34] discussed the implications of applying competitive game mechanics for real-time, single-player music composition. Game elements have also been used to foster interaction in multiplayer settings. For example, Koszolko and Studley [35] propose gamification strategies to engage audiences and environments through site-specific sampling and digital mobile technologies; both Fukuda [11] and Franklin and Bergeron [12] examined the application of game elements to interactive *screen-scores* [36] supporting real-time performer competition, strategy and decision-making.

With specific regard to networked systems (see 2.1), Çamcı *et al.* [10] discussed how game mechanics facilitate multi-agent collaboration in networked music performance through an audiovisual software; Carson [13] developed a creative-based musical game that uses a distributed smartphone speaker system to enable participatory ambient-oriented music-making; or Studley [14] proposed a gamified music performance system that shifts from a collaborative music-making orientation to a competitive interaction between the performer and audience members. While game-based interactive systems have recently attracted growing research interest, the use of explicit competitive multiplayer mechanics based on the timbre of sound to structure interaction in interconnected music systems remains largely unexplored.

3. DESIGN OVERVIEW

In this section, we introduce *Xplosive Collision* (XC), a networked music system for two players, situated within the noise music paradigm. Building on the previous *B3-H4RSH* prototype [37], *XC* is conceived to investigate bidirectional interdependence and dyadic interaction mediated by game mechanics. The system consists of a browser-based infrastructure supported by a Wireless Local Area Network (WLAN), with mobile phones serving as both control interfaces and sound-diffusion devices. The web application implements an audio synthesis engine based on a digital no-input feedback loop that generates noise-oriented sounds locally on each device. Participants interact with the system by moving their phones: the accelerometer controls the position of a dot on the screen, which is mapped to instrument parameters and, in relation to the other player's position, shapes the resulting audio. The system is gamified through a score-oriented objective and interdependent mechanics.

For conciseness, the following subsections provide a summary of *XC*'s main components. Further details and a video example can be found in the open repository: `https://github.com/lucamorino/xplosive_collision`

3.1 Game Mechanics, Rules, and Goals

3.1.1 Game Mechanics

Game mechanics constitute the core of the project, as they define the dynamics of play and structure the interaction among participants. The primary mechanism consists of collecting points: a local score-counter runs continuously, computing points from the timbral analysis of the generated audio. Thus, producing sounds with specific timbral characteristics (see 3.2.2) makes the player earn points faster. Inter-player mechanics depend on the relative position of the two players, who are thereby encouraged to track one another guided solely by sound, since the interface provides no visual information about the other player's location (see 3.2.1).

We also defined three game states:

- **Periphery and proximity**: when a player is near (*periphery* state, 30-15%) or close (*proximity* state, 15-5%) to the opponent, sound modulations are activated.
- **Collision**: moving very close to the opponent (*collision* state, <5%) triggers a collision event that randomly modifies the instrument's internal parameters, affecting sound generation.
- **Alarm Mode**: if a collision occurs while Alarm Mode is active, an "*xplosive collision*" is triggered, generating a disruptive, high-scoring sound event. Moreover, it also swaps the players' scores.

The last mechanic — players can exchange their scores — adds uncertainty to the final result and gives players a tool for overturning the standings. It is conceived to encourage the emergence of game dynamics and strategies.

3.1.2 Game Rules and Goals

The only formal rule is that the game session continues until one player reaches 10 points. The objective is, therefore, to collect 10 points before the opponent does. Beyond this, no further rules are embedded in the system, and players are free to explore, move, and act. However, for experimental purposes and to ensure that interaction occurs exclusively within the system, participants are subject to additional restrictions: during the game, they cannot see one another, speak, or otherwise communicate.

3.2 The Web Application

Overall, the web application was developed in JavaScript (apart from the Sound Module; see 3.2.2) and deployed over a dedicated WLAN, with the server hosted on Node.js [2]. In addition, we used the *soundworks* [3] API, which provides *SharedState* abstractions for sharing data and synchronising game states across all the nodes of the application. These abstractions expose both global and user-specific parameters to all clients and to the server, which manages the game logic. Each player's position, in particular, is continuously updated in a dedicated shared state that the server uses to evaluate the distance between players in real time and to activate inter-player mechanics. A separate global shared state, in turn, manages the different game modes and properties.

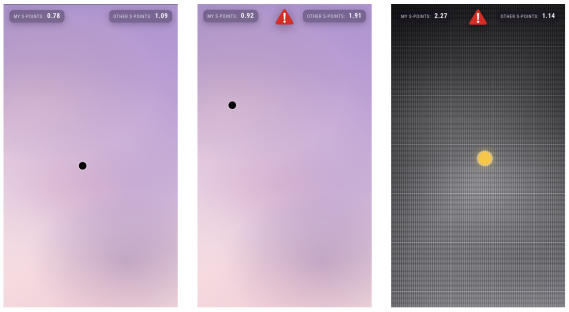


Figure 1. The web application mobile interface. Left: default mode. Middle: alarm mode. Right: *xplosive collision* event.

3.2.1 The Player Interface

The player interface is deployed as a browser-based web page through which the player shapes sound and interacts with the system. It is designed to be as minimal as possible, presenting only essential information (Fig. 1). The entire page is conceived as the playground. Two counters at the top of the screen display the player's own score and the opponent's. A black dot represents the player's position, moved with hand gestures: accelerometer data – ranging from -10 to 10 on both the x and y axes – are mapped to the page coordinates and, in turn, to the synthesis parameters. By rotating the smartphone, the player moves the dot, thereby subtly altering the sound. The web interface also provides feedback on game states: when *alarm mode*

[2] https://nodejs.org/en
[3] https://soundworks.dev/

is active, a red danger icon appears. It further signals inter-player interactions (see 3.1.1): when a *collision* occurs, the dot turns yellow; when an *xplosive collision* occurs, the background becomes a greyscale, sound-reactive texture.

3.2.2 The Sound Module

The Sound Module is developed in RNBO [4] and is dedicated to sound generation and analysis; the audio starts when the web page loads. Inspired by the no-input mixing-desk practice [38], the synthesis algorithm implements a digital no-input feedback loop and is modulated by filters, delays, and distortions. The output is then optimised for smartphone speakers. The engine is largely based on our previous prototype. A detailed description of the sound synthesis can be found in the *B3-H4RSH* project [37].

The current version of the Sound Module also implements an analysis stage that continuously evaluates the signal's sharpness. Sharpness drives the rate of point accumulation (see 3.1): the higher the sharpness, the faster the point-counter runs. Sharpness S, expressed in *acum*, is a psychoacoustic metric that describes the extent to which a sound's energy is concentrated in the higher regions of the spectrum, based on the distribution of specific loudness along a 0-24 Bark scale [39]. Computed according to DIN 45692, it is defined as

$$S = k \frac{\sum_i N'_i \, g(z_i) \, z_i}{\sum_i N'_i} \tag{1}$$

where N'_i is the loudness at critical band z_i (in Bark), $g(z_i)$ is a weighting function emphasising high-frequency contribution, and the constant $k = 0.11$ is a scaling factor yielding 1 *acum* for a reference sound. The analysis algorithm is ported to RNBO from the MATLAB *Sound Quality Analysis Toolbox* [5] developed by Greco *et al.* [40]. Computing points from sharpness grounds the game mechanics in a specific timbral feature that can characterise distorted and noise-oriented sounds.

4. METHODS

4.1 Experimental Setting

We evaluated *Xplosive Collision* through an exploratory study involving pairs of participants. The study aimed to assess the dyadic interaction emerging from interdependence and game states. In total, we involved 14 participants across 7 sessions. The experimental sessions were conducted in a controlled environment, i.e. an empty room or a university lab. Since the system is strongly sound-based, with much of the information carried by the sound of both devices, we selected acoustically neutral environments, as excessive reverberation or external noise could bias the study outcomes. Participants' own smartphones were used as experimental devices via the browser-based application. At the beginning of the experimental session, each participant was asked to read, complete, and sign the privacy documentation. We then provided a brief description of the system, and the game instructions were read aloud. Participants were subsequently invited to connect to a local private network and open the web-based application. Each participant could first test and familiarise themselves with the functionality, exploiting the "training mode" for a while, with assistance from the experimenter. When both players were confident with the system, the evaluation session began, and they played until one of them reached 10 points. During this session, participants were asked to sit back-to-back, preventing visual contact with one another or with their devices.

4.2 Data Collection

During the evaluation session, both the server and the client implemented a logging system that recorded interaction data and the game's various states. At the end of the session, two files were generated: one documenting global parameter changes, the other tracing per-user event states, including score progression and collision events.

Immediately after the game session, participants were asked to complete an anonymous questionnaire individually. The questionnaire used a 5-point Likert scale to collect quantitative data and was structured into two sections: 1) a general background section; and 2) a system-evaluation section based on rating scales. The first section (8 questions) assessed participants' overall familiarity with music, smartphones, and digital games. The second section (14 questions) examined participants' perceptions of the system, along with their experience and interaction during the session, focusing on application and system affordances (Q1–5), game elements (Q6–8), the influence of the other player (Q9–12), and the overall perception of the system (Q13–14). We also included an optional open-ended questionnaire to collect general opinions on the experience.

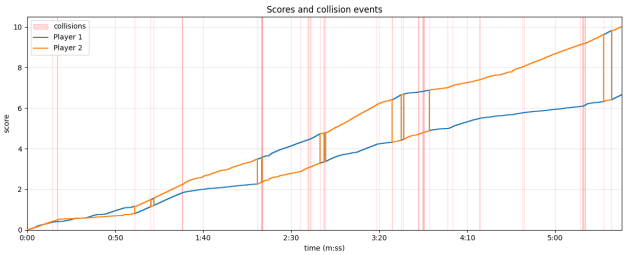


Figure 2. An example of a session between two participants, reporting their score evolution and collision events over time.

5. RESULTS

Overall, informal open-ended feedback suggested a generally positive experience with the system, characterising the interaction as both enjoyable and engaging. Analysis of log data from both server and client devices revealed that sessions lasted an average of 6:19 minutes (range 5:37–6:42). Collision events averaged 54 per session (range 45–69), while *xplosive collision* events averaged 20 per session (range 15–28). Figure 2 illustrates the

[4] https://rnbo.cycling74.com/
[5] https://github.com/ggrecow/SQAT

temporal evolution of players' scores alongside the collision events throughout a session.

Likert-like question - General Background	Mean ± SD
1. I have received formal or informal training in music.	3.93 ± 1.07
2. I am familiar with experimental, electroacoustic, or noise-based music practices.	3.64 ± 1.01
3. I am familiar with music technology and digital sound processing.	4.21 ± 1.05
4. I am familiar with smartphones.	4.29 ± 0.61
5. I frequently use a smartphone for interactive or creative tasks.	3.36 ± 0.84
6. I am familiar with motion-based interaction on smartphones (e.g., tilt, rotation, gesture control).	3.21 ± 1.05
7. I am familiar with video games.	3.93 ± 1.21
8. I am familiar with music-based video games or game-like musical interfaces.	3.43 ± 1.34

Table 1. Questions and results (mean ± standard deviation) of the post-session background questionnaire (on a 5-point Likert-type scale: 1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Considerably, 5 = Very much).

Likert-like question - System Evaluation	Mean ± SD
1. I felt able to understand how my movements affected the sound produced by the system.	3.79 ± 0.80
2. I felt able to control the sonic outcome intentionally.	3.21 ± 0.58
3. I constantly focused on the sound of my device.	3.93 ± 0.73
4. I primarily used the sound produced to orient myself.	3.86 ± 0.86
5. I primarily relied on the visual cues on the screen to orient myself.	3.36 ± 0.84
6. I remained focused on the game objective.	4.64 ± 0.63
7. I used specific strategies to earn points.	3.79 ± 0.58
8. I intentionally employed the interactive game mechanics to achieve the goal.	4.21 ± 0.89
9. I focused on the other player's sound.	2.71 ± 1.07
10. The other player's sound influenced how I behaved.	3.00 ± 1.04
11. I focused on the global sonic outcomes.	2.93 ± 1.07
12. The overall sonic outcome influenced my behaviour.	3.00 ± 1.11
13. I perceived the system as a musical instrument.	3.93 ± 1.27
14. I perceived the system as a (music) game.	4.50 ± 0.85

Table 2. Questions and results (mean ± standard deviation) of the post-session system-evaluation questionnaire (on a 5-point Likert-type scale: 1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Considerably, 5 = Very much).

The background questionnaire (Table 1) shows that most participants reported solid musical training (Q1) and good familiarity with experimental practices (Q2). They also reported considerable experience with smartphones (Q4). However, more specific forms of technological engagement for creative purposes were comparatively limited (Q5, Q6). Finally, most participants were familiar with video games, whereas only a subset had substantial experience with music-based video games.

Regarding the system-evaluation questionnaire (Table 2), participants reported a moderate-to-high sense of understanding and control (Q1, Q2), despite the degree of indeterminacy introduced by the feedback-based synthesis module and the stochastic logic governing collision events. Participants' responses further suggest that interaction was primarily framed in terms of gameplay: high scores for focus on the game objective and for intentional use of the interactive mechanics (Q6, Q8) indicate that participants engaged with the system in a strongly goal-oriented manner. This is reinforced by the perception of the system as a game rather than a musical instrument (Q13, Q14). At the same time, sound played an important role in supporting interaction. Participants reported consistently focusing on the sound of their own device (Q3, Q4), slightly more than on visual cues on the screen (Q5), suggesting that sonic feedback was meaningful in guiding their actions.

However, this attention remained largely individual, centred on participants' own devices, with comparatively limited focus on the other player and the shared sonic environment (Q9–Q12). Thus, while the system successfully supported individual sonic orientation, we argue that its game-oriented structure may have reduced participants' attention to collective musical outcomes.

6. DISCUSSION

Networked musical systems can be understood as a specific subset of interactive digital musical systems lying on networks, in which inter-player interaction unfolds within a designed space of constraints.

We presented *XC* embodying both the technical and symbolic dimensions of network music [1], not only connecting devices infrastructurally, but also organising relations through game mechanics.

Recalling Magnusson's reflections on *subjective*, *objective*, and *cultural* constraints delimiting possible actions and enabling creative exploration in such systems, [41], we can retrace these features in *XC*: players develop strategies (*subjective*), the system structures relations (*objective*), and mechanics and sonic outcomes reflect aesthetic context (*cultural*). These conditions define a bounded yet unpredictable space of action.

In particular, score-oriented goals, collision dynamics, and score-exchange events impose strong objective constraints. By design, sound changes only marginally when a player acts independently. By contrast, dyadic mechanisms such as periphery, proximity, and collision events produce significant sonic changes. Log data and participants' reports on their intentional use of the game mechanics suggest that interdependent relations effectively constituted a central mode of engagement within the system. This resonates with Weinberg's broader definition of Interconnected Musical Networks [3].

Although the system was conceived as strongly co-located, in line with Situated Networked Music Systems [2], results indicate that interplay does not primarily unfold at the sonic level. Participants reported limited attention to the opponent's sound, exerting relatively little influence on individual behaviour. Instead, dyadic interactions emerge in game competition, consistent with Salen and Zimmerman's *artificial conflict* [5] and Juul's account of multiplayer experience [7]. Sound thus functioned mainly as feedback rather than as a shared musical outcome.

Additionally, we can speculate that participants' backgrounds may also have influenced their experience. Their familiarity with experimental and electroacoustic music indeed suggests sensitivity to timbral variation (sharpness), as interaction with digital musical systems is shaped by prior experience and sociocultural context [42].

6.1 Music Game or Gamified Music System?

The results suggest that *XC* was perceived as both a musical instrument and a game, but the game dimension emerged as slightly more prominent, consistent with the overall structure of the system and the experimental setting. On the one hand, participants appreciated the sonic component and used sound as an important cue for orientation. On the other hand, their inter-player interaction was primarily motivated by the objective of reaching 10 points and shaped by the score-exchange mechanism and by the strategic use of collision-related dynamics. In this sense, the system was experienced mainly through gameplay, with sound functioning as a central, but not exclusive, medium for action and feedback.

The specific context can also inform this interpretation of the study. Unlike related works that examine gamified networked music systems in public or performance-oriented settings [10,11,14], the present evaluation focused on players' experience in a controlled laboratory setting independent of the presence of an audience. Within this setting, the competitive structure of *XC* appears to have foregrounded reward-oriented behaviour and attentional focus on rules and objectives. We argue that this may also be influenced by the specific design choices of the competitive game mechanics themselves, similar to other works such as *Duel* and *Strategie* [8]. While Xenakis makes the two orchestra directors compete on pre-composed musical materials, we grounded the competitive mechanics in the timbral evaluation of the produced sound: this can add a further layer of ambiguity between music-making and a sonic playground.

Indeed, these findings suggest that *XC* occupies an in-between position, retaining the variable and quantifiable outcomes of games [4], but also the openness and unpredictability of *game pieces* [30] and networked musical systems. This resonates with Weinberg's observation: "it would be a difficult task to design a musical network that would lead to the creation of an interesting, well-structured composition while players are trying to win a musical game" [3].

6.2 Limitations

We acknowledge several limitations in our study. First, the evaluation involved a relatively small sample of participants (14), which limits the generalisability of the findings and other statistical treatments. In addition, the background questionnaire indicated that participants, overall, had substantial musical training and familiarity with experimental music practices, potentially introducing bias into the results. Second, this explorative study provides an initial quantitative analysis of how the systems have been perceived and interacted with; thus, a more extensive study based on these results could provide additional insights. Third, the experimental setting was intentionally constrained: participants were sitting back-to-back and were not allowed to speak or otherwise communicate outside the system. These conditions, introduced to isolate system-mediated interactions, may have slightly amplified the role of sonic cues in the game.

7. CONCLUSION AND FUTURE WORK

This paper has presented *Xplosive Collision (XC)*, an interactive networked music system for two players, based on competitive, interdependent mechanics within a noise-oriented sonic framework. The exploratory study with 14 participants suggests that *XC* effectively supports dyadic interaction and that sound orients players' actions; furthermore, the system was engaged primarily through its game objectives and score-based mechanics. Although *XC* was also perceived as a musical instrument, the game dimension emerged as prominent, indicating that competitive structures strongly shaped attention and behaviour.

Future work will further investigate the design of different gamification strategies for such systems and evaluate them in public and performative settings. From an artistic perspective, the research may lead to outcomes such as gamified electroacoustic or noise performances, audience-participation formats, interactive sound installations, and broader participatory practices. It may also support the development of games in which sonic interaction becomes the primary medium for navigation, play, and expression.

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8. REFERENCES

[1] J. Rohrhuber, "Network music." *The Cambridge companion to electronic music*, vol. 8, pp. 140–155, 2012.

[2] B. Matuszewski, N. Schnell, and F. Bevilacqua, "Interaction topologies in mobile-based situated networked music systems," *Wireless Communications and Mobile Computing*, vol. 2019, no. 1, p. 9142490, 2019.

[3] G. Weinberg, "Interconnected musical networks: Toward a theoretical framework," *Computer Music Journal*, vol. 29, no. 2, pp. 23–39, 2005.

[4] J. Juul, "The game, the player, the world: Looking for a heart of gameness," in *Proceedings of DiGRA 2003 Conference: Level Up*, 2003.

[5] K. Salen and E. Zimmerman, *Rules of Play: Game Design Fundamentals*. The MIT Press, 2003.

[6] K. Emmerich, "Designing player interdependence to enhance players' social experience in multiplayer games," in *The Digital Gaming Handbook*. CRC Press, 2020, pp. 19–36.

[7] J. Juul, *A casual revolution: Reinventing video games and their players*. MIT press, 2012.

[8] I. Xenakis, *Formalized Music: Thought and Mathematics in Composition*, ser. Harmonologia series. Pendragon Press, 1992.

[9] D. Goldoni, *Chapter 19 Indeterminacy and Vagueness in Improvisation and in Experimental Music*. Berlin, Boston: De Gruyter, 2024, pp. 331–346. [Online]. Available: https://doi.org/10.1515/9783110785845-020

[10] A. Çamcı, C. Çakmak, and A. G. Forbes, "Applying game mechanics to networked music hci systems," in *New directions in music and human-computer interaction*. Springer, 2019, pp. 223–241.

[11] T. Fukuda, "Super colliders: A gamified screen-score," in *Proceedings of the International Conference on Technologies for Music Notation and Representation*, 2020, pp. 158–168.

[12] A. Franklin and M. A. Bergeron, "Plétude: New paradigms for notation with game engine-based scores," in *Proceedings of the 20th International Audio Mostly Conference*, ser. AM '25. New York, NY, USA: Association for Computing Machinery, 2025, p. 199–206.

[13] T. Carson, "Mesh garden: A creative-based musical game for participatory musical performance," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2019, pp. 339–342.

[14] T. Studley, "Swimtunes: A gamified music performance system for co-creating with a novice audience," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2025, pp. 415–421.

[15] Á. Barbosa, "Displaced soundscapes: A survey of network systems for music and sonic art creation," *Leonardo Music Journal*, vol. 13, pp. 53–59, 2003.

[16] G. Weinberg, "The aesthetics, history and future challenges of interconnected music networks," in *International Computer Music Conference (ICMC 2002)*, 2002.

[17] D. Ogborn, J. Beverley, L. N. del Angel, E. Tsabary, A. McLean, and E. Betancur, "Estuary: Browser-based collaborative projectional live coding of musical patterns," in *International Conference on Live Coding (ICLC)*, vol. 2017, 2017.

[18] L. Wilde and C. White, "Laptop orchestra: a model postdigital resonant educational space," *Postdigital Science and Education*, vol. 7, no. 3, pp. 939–964, 2025.

[19] O. Hödl and L. Turchet, "The tmap framework: Describing the design space of technology-mediated audience participation in live music," *IEEE Access*, vol. 13, pp. 38 593–38 608, 2025.

[20] M. Van Steen and A. S. Tanenbaum, "A brief introduction to distributed systems," *Computing*, vol. 98, no. 10, pp. 967–1009, 2016.

[21] B. Matuszewski, "A web-based framework for distributed music system research and creation," *AES-Journal of the Audio Engineering Society Audio-Accoustics-Application*, 2020.

[22] N. Hwang and A. T. Marasco, "Monodec: the mobile node controller for audience-involved sound diffusion," in *Proceedings of the 49th International Computer Music Conference*, 2024, pp. 146–149.

[23] A. Golvet, B. Matuszewski, and F. Bevilacqua, "Designing a distributed musical instrument for collective improvised interaction," in *Proceedings of the 19th International Audio Mostly Conference: Explorations in Sonic Cultures*, 2024, pp. 405–420.

[24] L. Turchet and M. De Cet, "A web-based distributed system for integrating mobile music in choral performance," *Personal and Ubiquitous Computing*, vol. 27, no. 5, pp. 1829–1842, 2023.

[25] S. A. Hedges, "Dice music in the eighteenth century," *Music & Letters*, vol. 59, no. 2, pp. 180–187, 1978. [Online]. Available: http://www.jstor.org/stable/734136

[26] F. Dal Rì and R. Masu, "Zugzwang: Chess representation combining sonification and interactive performance," in *Proceedings of the 16th International Audio Mostly Conference*, 2021, pp. 89–92.

[27] S. Thon, "Go to music-move 37," in *International Computer Music Conference, ICMC 2024*, 2024, pp. 26–29.

[28] F. Fitch, *Canons, puzzles, games*, ser. Cambridge Introductions to Music. Cambridge University Press, 2020, p. 197–222.

[29] M. G. Jensen, "John cage, chance operations, and the chaos game: Cage and the i ching," *The Musical Times*, vol. 150, no. 1907, pp. 97–102, 2009. [Online]. Available: http://www.jstor.org/stable/25597623

[30] O. Nesterenko, "Open work one step further: From john cage to john zorn," *Perspectives of New Music*, vol. 55, no. 2, pp. 199–217, 2017.

[31] M. Ciciliani, B. Lüneburg, and A. e. Pirchner, *Ludified: Artistic Research in Audiovisual Composition, Performance & Perception*. The Green Box, 2021, vol. Vol. 1:.

[32] R. Rowe, *Interactive music systems: machine listening and composing*. MIT press, 1992.

[33] C. Michalakos, "Designing musical games for electroacoustic improvisation," *Organised Sound*, vol. 26, no. 1, pp. 78–88, 2021.

[34] T. Studley, J. Drummond, N. Scott, and K. Nesbitt, "Can competitive digital games support real-time music creation?" *Journal of Sound and Music in Games*, vol. 3, no. 1, pp. 1–35, 2022.

[35] M. K. Koszolko and T. Studley, "From site-specific sampling to gamification: An exploration of performative engagement with the environment," *Organised Sound*, vol. 28, no. 3, pp. 338–351, 2023.

[36] C. Hope and L. Vickery, "Screen scores: New media music manuscripts," in *Proceedings of International Computer Music Conference 2011*. The International Computer Music Association, 2011.

[37] L. Morino, N. Conci, and F. Cifariello Ciardi, "B3-h4rsh: A noise-based multiplayer game for mobile music-making," in *International Computer Music Conference, ICMC 2026*, 2026.

[38] T. Mudd, "Playing with feedback: Unpredictability, immediacy, and entangled agency in the no-input mixing desk," in *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, Hamburg, 2023, pp. 1–11.

[39] E. Zwicker and H. Fastl, *Psychoacoustics: Facts and models*. Springer Science & Business Media, 2013, vol. 22.

[40] G. F. Greco, R. Merino-Martínez, A. Osses, and S. C. Langer, "Sqat: a matlab-based toolbox for quantitative sound quality analysis," in *INTER-NOISE and NOISE-CON congress and conference proceedings*, vol. 268, no. 1. Institute of Noise Control Engineering, 2023, pp. 7172–7183.

[41] T. Magnusson, "Designing constraints: Composing and performing with digital musical systems," *Computer music journal*, vol. 34, no. 4, pp. 62–73, 2010.

[42] L. Hayes, "Enacting musical worlds: Common approaches to using nimes within performance and person-centred arts practices," in *Proceedings of the International Conference on New Interfaces for Musical Expression*. International Conference on New Interfaces for Musical Expression, 2015, pp. 299–302.