Designing Biofeedback Board Games: The Impact of Heart Rate on Player Experience

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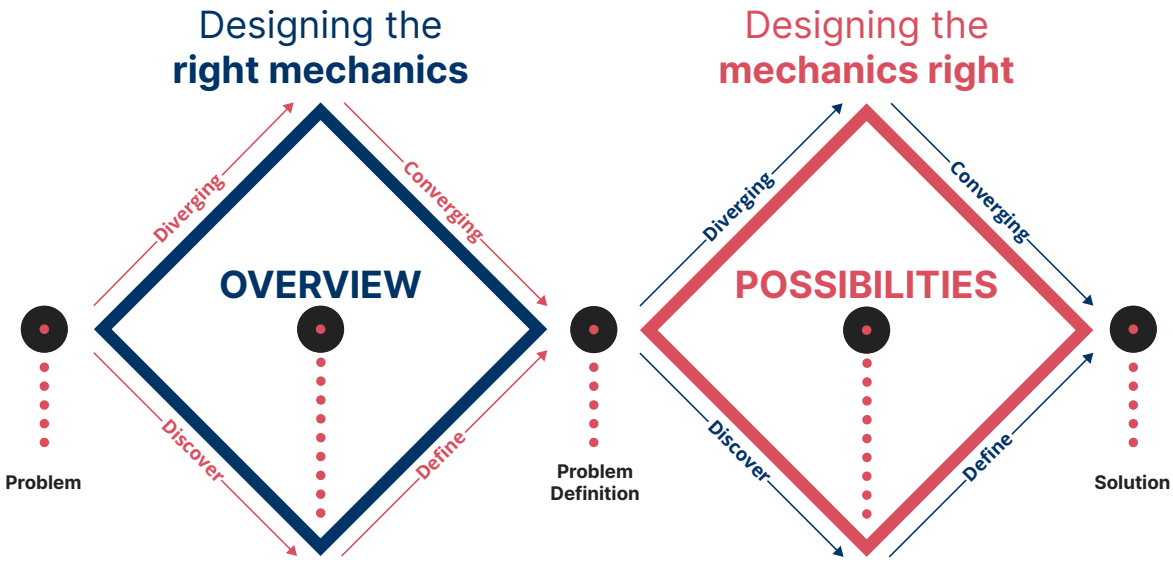


Figure 1: This double-diamond diagram illustrates our approach toward Research through Design (RtD) practices.

Abstract

Biofeedback provides a unique opportunity to intensify tabletop gameplay. It permits new play styles through digital integration while keeping the tactile appeal of physical components. However, integrating biofeedback systems, like heart rate (HR), into game design needs to be better understood in the literature and still needs to be explored in practice. To bridge this gap, we employed a Research through Design (RtD) approach. This included (1) gathering insights from enthusiast board game designers (n = 10), (2) conducting two participatory design workshops (n = 20), (3) prototyping game mechanics with experts (n = 5), and (4) developing the game prototype artifact *One Pulse: Treasure Hunter's*. We identify practical design implementation for incorporating biofeedback, particularly related to heart rate, into tabletop games. Thus, we contribute to the field by presenting design trade-offs for incorporating HR into board games, offering valuable insights for HCI researchers and game designers.

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CCS Concepts

• **Human-centered computing → HCI theory, concepts and models**.

Keywords

Board Games, Biofeedback, Design, Game Mechanics, Heart Rate, Play, Prototyping, Research through Design

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1 Introduction

Board games have begun incorporating digital elements, often called "hybrid digital games", combining non-digital and digital components to introduce new game experiences. These hybrid board games often use companion applications on tablets or phones to manage tasks like storytelling, automated actions, or progress tracking [53]. Alternatively, so-called *affective games* use players' physiological signals, or biofeedback, to directly influence the experience [75]. These games can adapt the gameplay itself (e.g., control mechanics, enhance difficulty) [78, 82] or promote self-awareness of emotional and physical states through a fun and engaging approach [2, 70]. Digitally incorporated biofeedback, such as heart rate (HR), has been studied in Human-Computer Interaction (HCI) as a tool to understand and improve the player experience in games [23, 45, 67, 126]. However, the integration of HR into board games, particularly in multiplayer contexts, remains largely unexplored. While HR mechanics have been studied in digital single-player settings, there is a striking lack of established methods or frameworks for embedding biometric data into analog multiplayer experiences. From a design perspective, this challenge encompasses not only the task of *"getting the design right"* but *"making the right design"* [18]. This involves determining how to effectively interpret HR data in the context of turn-based gameplay while considering how to integrate HR with the social interaction in these games.

Board games are not just about entertainment; they also provide a valuable space for social engagement and interaction [129], education [46, 85], and bonding experiences [93]. The game design space is constantly changing, with board game designers and practitioners exploring new ways to create more engaging and immersive experiences [8, 107, 109]; and seeking innovative ways to modernize classic interactive game mechanics [61]. Board game design has a rich history built on core components like cards and dice [114]. However, biotechnological devices in board games could create a more dynamic experience similar to other forms of gameful media [50, 89, 131]. For instance, HR can be used to adjust game difficulty [49], or create shared moments of tension and excitement among players [32].

In our research, we preserve the tactile interaction inherent in board games. We chose HR as the exclusive biofeedback measure in our research, enabling us to maintain the tactile nature of board games by avoiding the digitization of physical game pieces. By using a single sensor, we ensure that players are still engaging with the gameplay experience [5], rather than being distracted by the novelty of complex biofeedback systems [113]. Thus, we focused on three main research goals:

(1) **Game Perceptions:** We investigated how game designers perceive using their HR data within board games. This involved understanding their comfort level, potential concerns, and the impact on their overall enjoyment.
(2) **Heart Rate And Board-Game Integration:** We investigated practical approaches for incorporating heart rate into board games using design principles. Our goal is not to include HR as a "flashy gimmick" but to ensure its integration serves a *clear design purpose* and enhances the gameplay experience [96] such as social play within seating arrangements.
(3) **Game Prototype Artifact Creation:** To gain practical insights, we consulted with experts to create a game prototype artifact, *One Pulse: Treasure Hunter's* which incorporates heart rate biofeedback as a core game mechanic. This prototype allowed us to assess the effectiveness of the implemented mechanics and identify potential areas for improvement for future research.

To understand HR integration in board games, we employ a Research through Design (RtD) process [133] because it allows for iterative user testing, the creation of tangible prototypes, and the generation of reusable design assets – all crucial for successfully integrating biofeedback mechanics into board games in a player-centered and meaningful way (see Figure 1). To achieve this, we implemented three key research phases (which lasted for 18 months): (1) gather preliminary insights from enthusiast analog board game designers, (2) participatory design workshops, (3) prototyping game mechanics with board game experts using a game prototype artifact called *One Pulse: Treasure Hunter's* (see Study Overview). In our paper, we document our design process to serve as a valuable resource for other board game designers and practitioners tackling similar challenges. Our goal was to understand how players perceive HR data and how to integrate it into board games, which creates a solid foundation for future biofeedback game mechanics that account for multiplayer experiences. In short, our key contributions to HCI research are:

(1) We provide design philosophies that highlight the impact of playing space **(Unified Versus Non-unified Seating)** on social interaction, the importance of biometric data display, and the learning curve in integrating HR data into gameplay, alongside novel HR display concepts that enhance biofeedback integration, offering diverse design directions for immersive, interactive gameplay and informing the development of user-centered prototypes that bridge physiological data with game mechanics to foster engagement and strategic depth.
(2) We provide expert feedback to refine the game mechanics incorporating HR data, select appropriate technologies like the Polar H10 heart rate sensor and smartphone displays, and iterate on design decisions to improve gameplay dynamics, particularly in social deception. These insights inform the development of our game prototype artifact, *One Pulse: Treasure Hunter's*.

(3) We offer design trade-offs for integrating HR biofeedback into board games, supporting both HCI researchers and game designers. This includes exploring potential HR-triggered game events.

We present this research as an opportunity to reimagine the boundaries of tabletop gameplay, positioning HR as a vital, personal, and adaptable physiological element for play, strategy, and social interaction. Through RtD, we examine how HR enriches multiplayer experiences, uncovering new dimensions of engagement and social dynamics, and how this contributes valuable methodologies for involving experts and designers in gameplay innovation.

2 Related Work

A common misconception is that traditional game design primarily relies on intuition and limited user feedback [108]. However, this perspective overlooks the practical aspect of experienced judgment and iterative development in established game design practices. Professional game designers bring extensive knowledge and refined intuition, developed through years of practice and successful project execution [8, 38, 99]. Drawing inspiration from methodologies employed in previous HCI research, we explore this approach and its applications in the context of hybrid board game design [11, 17, 47].

2.1 Biofeedback and Games

Recent studies showed that biofeedback technology can be a powerful tool for *game designers*, enabling them to craft innovative mechanics and experiences [81, 120]. While existing research on biofeedback and games offers valuable insights, it primarily focuses on how biofeedback data can be used for emotion regulation [4, 39, 66], stress relief [81, 92, 130], mood stimuli [90, 97, 121] or to modulate anxiety [1, 102] within a digital game context [119, 121]. As for hybrid board games, Rogerson et al. [96] suggests that we should avoid solutions that feel like an awkward afterthought and instead create a seamless and intuitive experience for players, primarily noting digital elements in board games. In addition, current research offers little direction on transforming physiological data into meaningful mechanics within this social, physical space. We specifically focus on user experience in our work, building on Wollmann et al. [126]'s usability work (for us, it would be the hybrid board game experience). This is because much of the existing research in biofeedback integration prioritizes the technical aspects over how *users* actually *experience* and *interact* with the technology. Thus, for board games, a design-centered approach that prioritizes usability and gameplay experience is important [133].

Research by Cunningham et al. [30] suggests that exploring the advancements in biofeedback technology, especially within game controllers, can inspire the development of novel game interaction techniques. This aligns with the ongoing pursuit of board game designers who constantly seek innovative ways to engage players and create unique experiences. For instance, Huang and Luk [49] developed *Heartbeat Jenga*, a game that dynamically adjusts difficulty based on real-time HR. When the player's HR increases, the platform holding the blocks shakes, and the room dims, making the game more challenging. More specifically, studies have examined how having a lower HR allows players to make better decisions [37, 65]. On a practical level, D'Souza et al. [32] explores how biofeedback can heighten social interaction differently. Their research examines a social deception dice game called *Mia*[1] where biofeedback is used to enhance bluffing and detection of bluffs among players. While these biofeedback board games offer unique experiences, they typically rely on just one player's biofeedback, which might not be ideal for traditional board game design where multiple players interact.

Research in digital games has explored biofeedback systems that use physiological data streams as a novel form of game input [54, 78, 110, 111, 127]. These systems integrate physiological signals into gameplay, enabling dynamic and adaptive interactions [60, 71, 77]. The core of biofeedback systems lies in the *biocybernetic loop* [34, 91]. This loop involves sensors capturing physiological data from the user, like HR or muscle activity. The system then processes this information and provides feedback based on the results. For physiologically controlled games, there are two key design considerations suggested by Nacke et al. [78]: *direct* physiological sensor readings should be translated into actions within the game world in a way that feels natural to the player, whereas *indirect* physiological data is best used to create dramatic moments that impact the game environment, rather than directly control gameplay. It is important to acknowledge that the distinction between *direct* and *indirect* control can be nuanced and may shift depending on the context. For instance, some mechanics might combine elements of both approaches [25, 69]. However, these considerations primarily focus on digital games with built-in interfaces. There is a gap in understanding how to effectively integrate biofeedback mechanics into multiplayer board games, which involves unique design challenges and social interaction aspects.

2.2 In-direct and Direct Game Mechanics

Studies investigated how to measure the overall player experience during gameplay by analyzing the same physiological measures (electromyography, electrodermal activity, etc.) [78–80]. However, their focus was on the flow between various emotional states, such as anxiety, apathy, and boredom. Similarly, Perez Martínez et al. [88] explored the generalizability of using physiological features for emotion detection across different games. Using two dissimilar games, their study found that minimum and average heart rates were reliable indicators of players' emotional state [88]. These studies highlight the potential of using physiological data, particularly HR, to gauge game player experience. For this reason, we have chosen to focus on *heart rate (HR)* as one of the primary *design tradeoffs* (choices that necessitate striking a balance between two or more desirable but often competing criteria) for our game artifact prototype. HR monitoring typically requires simpler and less intrusive wearables compared to other physiological measures like electromyography (EMG) or electrodermal activity (EDA) [22, 26]. This is crucial in the context of board games, where the core experience revolves around physical interaction with the game pieces [95]. We want to avoid introducing overly complex biofeedback mechanisms that could disrupt the physical play experience [113].

Direct game mechanics use real-time physiological data from players, such as HR. Biometric sensors or other monitoring devices

[1] *Mia* is a dice game for three or more players that relies on bluffing and detecting bluffs to win, similar to "liar's dice" or "cheat".

collect this data, and the game uses it to adjust elements like the environment or gameplay itself. Essentially, direct mechanics directly measure emotions through physiological responses, influencing the game dynamically [3, 112]. For instance, research by Kim and Doh [57] explored techniques for detecting patterns of players' emotional responses based on physiological data, allowing games to tailor gameplay experiences accordingly. Indirect mechanics focus on inferring player emotions without needing biometric sensors. Instead, they analyze in-game actions, behaviours, and interactions. This could involve studying player movements, decisions, gameplay patterns, or other behavioural cues. By interpreting these cues, the game indirectly estimates the player's emotional state and adapts the environment accordingly [42, 116].

2.3 Design Challenge With Board Games

Board games pose distinct design hurdles due to their physical tangible elements and focus on social interaction.

2.3.1 Why Only Heart Rate (HR). Board games are inherently social activities, often bringing people together for a shared experience. Building on existing research, HR data offers valuable insights into individual player engagement. However, incorporating too many live biofeedback streams from multiple players could become quite complex to analyze and process in real-time [5, 113]. Employing HR allows us to explore the potential of biofeedback integration in board games while maintaining a manageable data set for our research goals.

2.3.2 Adapting Digital Biofeedback Board Game Mechanics. While both direct and indirect mechanics have been explored in digital games to enhance player experience, translating these approaches to physical board games presents unique challenges. Board games lack the built-in interfaces and continuous player monitoring typically found in digital games. Additionally, the physical space and social interaction aspects inherent to board games necessitate careful consideration when integrating biofeedback mechanics. For example, by adjusting the game's difficulty dynamically with HR, the game could become more challenging or introduce new obstacles [49], or possible social interaction by creating shared moments of tension or excitement among players [32].

2.3.3 Balancing Play in the Physical Space. We need to consider the balance between biofeedback integration and the core aspects of physical board games. The introduction of biofeedback mechanics should not detract from the physical interaction with game components or disrupt the social dynamics of face-to-face play [94]. We explore how to seamlessly integrate biofeedback using HR into the physical space of board games while preserving the core gameplay experience and social interaction that defines board games. As noted by Lara-Cabrera and Camacho [64], by integrating this technology, game designers could create innovative *game mechanics* that redefine player interaction with the game.

3 Study Overview

Our study received ethics approval by the Research Ethics Board (REB) at the University of Waterloo (#44615). Our study investigates the various perspectives of players, game designers, and game user researchers regarding the integration of HR biofeedback in board games. We employ a Research through Design (RtD) approach [133], which allows for continuous reflection and potential reframing of the project's core situation and goals. This iterative process aligns well with the nature of design, as it encourages us to not only understand the present state of board games but also to actively explore and design for future possibilities. Kultima [62] argues for design research frameworks in game studies to bridge the theory-practice gap. Our approach echoes this, going beyond existing design principles to explore and experiment with biofeedback mechanics and experiences.

3.1 Research Phases

We recognize the dynamic nature of RtD methodologies, so we structured this approach that divides the study into distinct "*research phases*". This clarity is complemented by a "critical analysis of theoretical outcomes" [101], ensuring a robust connection between our design exploration and its theoretical foundation [134]. The research phases follow the structure of the double-diamond approach as seen in Figure 1. The Double Diamond design process [6] uses two distinct phases: divergence and convergence. In the divergence phase, we explore a broad range of possibilities through methods like brainstorming and mind mapping. This fosters creativity and allows for the generation of new ideas and solutions. Following this exploration, the convergence phase focuses on refining and selecting the most promising solutions. Here, we rely on convergent thinking to evaluate and choose the best option based on specific criteria.

Our research employs a cumulative approach across three phases spanning 18 months (Jan 2023—July 2024). Research Phase 1 (RP1) focused on board enthusiasts with game design experience, exploring their attitudes toward digital integration. Research Phase 2 (RP2) involved HCI experts with experience in hybrid board games, using participatory design workshops to refine ideas through player feedback and visual mockups. This phase also developed HR mechanics within board game dynamics. Research Phase 3 (RP3) combined insights from the previous phases, bringing them to experts to design the game and explore design trade-offs and strategic alignment. Each phase includes a distinct analysis, a description of the design philosophies, and a critical reflection document, with the first author making final design decisions.

In particular, RP1 explored the attitudes toward digital integration with enthusiast analog board game designers. These insights guided RP2's participatory design workshops, which refined ideas via player feedback and visual mockups with experts in digital integration with computer systems. RP2 then shaped HR mechanics within board game dynamics. These insights informed RP3's expert discussions, enabling design trade-off exploration and strategic alignment by combining feedback from RP1 and RP2. These reflections serve as a guide for progression to the next research phase (Figure 2), ensuring that each phase builds on the findings and design implications of the previous one.

3.2 Positionality Statement

We acknowledge that our research could be biased based on our position as researchers. As this is an 18-month project, the first and last authors were involved in each of the research phases;

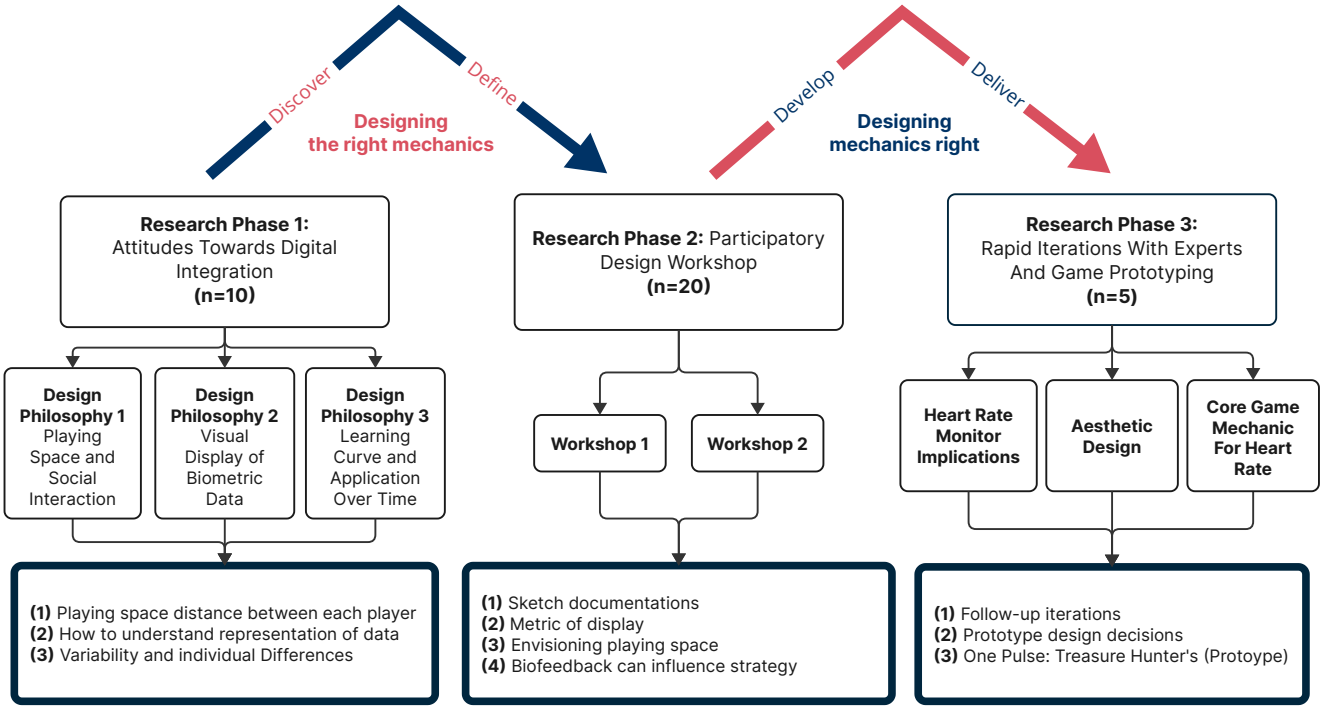


Figure 2: An overview of the research phases for integrating heart rate mechanics into board game design, highlighting the Discover, Define, Develop, and Deliver stages and the corresponding activities, participants, and outcomes at each phase.

two additional research assistants joined for RP2, (ethics revisions were made to include these additional assistants). Our research team brings together expertise in game user research with unique perspectives from the world of fine arts and public installations. The first, fourth, and last authors have backgrounds in design and experience working with board game companies, which allows us to consider the user experience not just through a research lens but also with an understanding of game development's creative and practical realities. The first and last authors have worked with biofeedback data; in addition, they specialize in HR measures.

The first author is responsible for overseeing the design artifact consideration; we acknowledge that this is a considerable bias and can skew the final design of our game artifact. These include mediation or ideas from the participants that are currently not feasible or within the design philosophy. For example, one participant suggested that this idea could be a promising direction for augmented reality (AR) design. We do think this could be part of future opportunities or research avenues. The first author is also responsible for programming the game system. We acknowledge the power dynamics between researchers and participants and fostered an inclusive environment where all voices were valued. Participants were encouraged to share ideas freely, ensuring no single perspective dominated discussions.

All authors frequently play board games, both as a leisure activity and as a means of understanding player experiences. This shared engagement not only contributes to our critical perspective on game design but also reinforces the value of board games as a medium for social interaction and a healthy work-life balance.

4 Research Phase 1 (RP1): Attitudes Towards Digital Integration in Board Games

4.1 Methodology

The first phase of this study (RP1) focuses on gathering initial data on attitudes towards digital integration from board game designers (n = 10). These participants are primarily analog board game designers, known for their frequent enjoyment of traditional, non-digital board games. We deliberately chose this demographic for the first phase to gain insights into the perception of digital integration from the perspective of players who primarily engage with non-digital games. Additionally, all participants identify as avid board game enthusiasts with a strong passion for playing. We conducted interviews both offline and online to accommodate remote participants. Interview questions explored how integrating physiological indicators, interactive displays, and accurate measurement technologies can enhance immersion, social interaction, and strategic complexity in social deception board games.

The focus of the interviews was on attitudes toward designing innovative mechanics that leverage HR data, shared or individual displays, and spatial dynamics to heighten tension, deception, and player engagement (see supplementary material)[2]. A semi-structured interview (average 28:54 minutes) allowed us to collect new exploratory data relevant to our design philosophy. At the end of the study, participants were given a thank-you letter and

[2]Supplementary material is hosted on Open Science Framework: https://osf.io/vyurg/

Table 1: This table presents demographic information in Research Phase 1.

Participant ID	Gender[1]	Game Design Experience[2]	Location	Interview Time
BGE01	Male	5–10 years	Europe	20:30 minutes
BGE02	Female	1–4 years	North America	17:12 minutes
BGE03	Female	5–10 years	North America	21:44 minutes
BGE04	Male	1–4 years	North America	21:04 minutes
BGE05	Female	1–4 years	North America	23:37 minutes
BGE06	Male	5–10 years	North America	28:23 minutes
BGE07	Female	1–4 years	Europe	32:53 minutes
BGE08	Male	5–10 years	North America	58:27 minutes
BGE09	Female	1–4 years	Europe	26:10 minutes
BGE10	Female	1–4 years	Europe	39:02 minutes

[1] *Gender was self-reported.*

[2] *Game design experience was self-reported and grouped into ranges for anonymity.*

informed to contact the researchers if any information needed to be retracted before publication.

4.2 Analysis

The interview data was analyzed using a thematic analysis approach [12] in Dovetail[3], where both hybrid tags were created [98]. Using sticky notes, we categorized these tags (including selected quotes to support each cluster) for card-sorting and identifying players' initial perceptions of integrating HR as an analog game mechanic. This process allowed us to uncover what analog board game designers actually want, highlighting key pain points and preferences that align with our primary research goals.

4.3 Design Philosophies

Design Philosophy 1 (DP1): Playing Space Design on Social Interaction. Our findings indicate that the physical layout of the playing space in a social deception board game significantly impacts social interaction, deception strategies, and social cues, including potential physiological responses, as highlighted in previous research by Newn and Klarkowski [84]. In larger open spaces, players often struggle to notice subtle social cues, such as body language and physiological changes. As one participant articulated, *"[y]ou want to have enough space that each person has like a place on the table. And then you have the board in the middle. The board needs, needs to be reachable by every player"* (BGE06).

In these settings, players may shift their focus towards verbal communication as a means to build trust or manipulate others. On the other hand, in more confined spaces, where players are in close proximity, there is a heightened sense of intimacy, as one participant noted, *"[l]ike it became very claustrophobic, became very cramped. All of us had a joint goal, but we all had singular goals"* (BGE08). In these settings, proximity can intensify social dynamics and power imbalances. Another participant mentioned, *"When you're the only one not sharing a side, then it feels like a power dynamic problem"* (BGE02), illustrating how spatial arrangements can influence players' perceptions of their roles within the game.

Design Philosophy 2 (DP2): Visual Display of Biometric Data. Our participants suggest that effectively representing data in games is crucial for enhancing gameplay and player experiences. The choice of display medium—whether a large screen, mobile phone, or wearable device—can significantly influence how players interact with and interpret the data. For instance, BGE05 suggested a design where "*[t]he board game could come with a stand that fits phones, and maybe then you can download an app on your phone. You stand your phone up, facing away from you. And then there are some wearable devices. I don't know, like a watch or a thing that goes over your finger. I don't know how heart rate technology works.*" Additionally, the visibility of this information—whether it is a shared experience where all players can see the metric, limited to certain roles, or only visible to the individual player—affects how data is perceived and used.

Design Philosophy 3 (DP3): Learning Curve and Application. Our findings suggest that integrating HR can add a new layer of dynamism and engagement to social deception board games, aligning with Fang et al. [35]'s work. Participants recognized the potential of HR to provide real-time information for assessing emotional states, manipulating situations, and reacting more intuitively. This continuous flow of physiological data minimizes downtime between turns, keeping players actively engaged in interpreting both explicit actions and implicit cues. However, BGE05 raised a concern, "*I don't know if that's an advantage or disadvantage, because if you're so focused on trying to control your own heart rate, you might not be able to keep track of other people's heart rate*". This highlights the potential challenge of balancing self-regulation with awareness of other players' physiological cues.

[3]Dovetail: https://dovetailapp.com/

Table 2: A summary of our design philosophy, associated with potential barriers and things to consider for Research Phase 2.

Design Philosophies	Potential Barriers to Entry	Things To Consider For RP2
Playing Space Design on Social Interaction	Spacious Layouts v.s. Confined Spaces	Playing Space Distance Between Each Player
Visual Display of Biometric Data	Icons, Colour, and Numerical Displays	How To Understand Representation of Data
Learning Curve and Application	Social and Deception Strategies Between Players	Variability and Individual Differences

In addition to these concerns, participants expressed apprehension about integrating HR into analog games. They noted the learning curve associated with adopting biofeedback mechanics, which may deviate from traditional gameplay, potentially alienating long-time board game enthusiasts. As BGE03 mentioned, "*[t]he strategy wouldn't be like a one-game strategy, but it would change over the course of multiple games*", suggesting that players would need time to adapt to these new mechanics.

Despite these challenges, participants emphasized that incorporating physiological responses could enhance the replayability of social deception games. Each game session would become unique, offering players opportunities to develop new strategies and hone their ability to interpret physiological signals in conjunction with traditional game mechanics. As BGE01 explained, "*[p]eople can give fake news [and or] information easily. Also, people who are accused, for example, are a good character in Avalon*[4] *can check out [their heart] rate and change their behaviour according to the feedback*". This adaptability could lead to more dynamic interactions, reinforcing engagement and adding depth to the overall gaming experience.

4.4 Critical Reflection on Research Phase 1

Although these findings may seem obvious to game design experts, it remains important to confirm them with enthusiasts who design analog board games as part of the RtD process. Validating these design decisions ensures that our insights align with real-world player experiences and preferences. For instance, gauging player interest in biofeedback's ability to heighten emotional engagement is crucial.

However, exploring how inaccurate readings might disrupt gameplay or social dynamics is equally important [94]. In this phase, we primarily focused on analog board game designer perceptions. Thus, we hypothesize that equi-distant seating could improve players' ability to perceive social cues, fostering a more inclusive and engaging environment (DP1) when digital elements are incorporated. This raises important questions about the best methods for visualizing information in games: should we use numerical data, icons, or colours (DP2)? While accurate metrics can help players instinctively recognize changes, it's important to consider what these changes actually mean; and perhaps their cognitive ability to process information during gameplay [31, 33, 72].

In the context of a board game, displaying biofeedback data could be *diegetic*[5] if it is shown within a game's attributes that all players can see. We hypothesize the design should be *non-diegetic*[6] as the biometric data can displayed on a separate screen or device that only the player can see, thus not directly interacting with the game world [86]. This approach could ensure that the data is accessible without disrupting the game's narrative flow and can lead to increased social interactions among players (DP3).

5 Research Phase 2 (RP2): Participatory Design Workshops

5.1 Methodology

Our second research phase, a participatory design workshop (Phase 2), included a total of 20 participants across two workshops (see Table 3). In this phase, we aimed to 1) understand the ideal playing environment for games incorporating HR, this could involve factors like table size, the proximity of players, and potential distractions in the surrounding area; 2) explore how players prefer to see HR information during gameplay, including options like individual displays, shared screens, or subtle visual cues integrated into game components; and 3) better understand player preferences and potential implementations, we asked participants to incorporate drawings or mockups illustrating how HR might be integrated visually within the board game setting.

The findings from this phase provide valuable design implications for crafting a new game system that incorporates HR mechanics. We chose HCI researchers for Phase 2 because of their expertise in player-computer interaction (workshop), and interactive systems (workshop), along with their prior experience with hybrid board games. Their skill in converting player insights into actionable designs, coupled with their technological proficiency, made them perfect for the *defining* and *developing* stages of the double diamond approach (Figure 1).

At the beginning of each workshop, the facilitator (first author) asked the participants for verbal consent. After completing the administrative duties, participants convened around a table with writing utensils and a page from the workbook. The instructions for the workshop included:

(1) How do you envision your playing space? (Please provide multiple sketches)

[4] *Avalon* is a social deduction board game where players take on secret roles as loyal servants of King Arthur or spies, using deception and deduction to secure victory for their team.

[5] Diegetic Display: UI elements that can be seen or heard by the character and fit within the story's context.

[6] Non-diegetic Display: UI elements that exist outside of the game or story and that only the player sees.

Table 3: This table presents demographic information in Research Phase 2.

Participant ID	Gender[1]	Experience	Workshop[2]
WSA01	Male	Professor	
WSA02	Female	Graduate	
WSA03	Male	Professor	
WSA04	Female	Graduate	
WSA05	Male	Graduate	
WSA06	Male	Postdoc	
WSA07	Male	Graduate	
WSA08	Male	Graduate	
WSA09	Female	Graduate	
WSA10	Male	Graduate	
WSA11	Female	Graduate	
WSA12	Female	Graduate	
WSA13	Male	Graduate	
WSB01	Male	Professor	
WSB02	Male	Graduate	
WSB03	Male	Graduate	
WSB04	Male	Graduate	
WSB05	Male	Graduate	
WSB06	Male	Graduate	
WSB07	Male	Graduate	

[1] *Gender was self-reported.*

[2] *are mainly from CHI Play, and are from ACM DIS and Haptics committee.*

(2) How would you want to display it? (Please provide multiple sketches or text)
(3) What kind of game mechanics could you see this being used for? (Please provide multiple sketches or text)

The order of the tasks was deliberately designed to closely align with the design phases to see if there are new perspectives from a researcher's point of view. First, envisioning the playing space establishes the core concept and atmosphere of the board game, providing a foundation for subsequent decisions. This visualization can inspire ideas for game mechanics and the display of elements within the space. Next, focusing on how to display the space allows for thoughtful consideration of materials, colours, and layout, directly influencing gameplay through visual representation. Finally, game mechanics are tailored to the established space and display, ensuring that the mechanics, objectives, and overall experience are cohesive and contribute to a unified game.

5.1.1 Focus Group Discussion. We initiated the focus group by inviting each participant to showcase their sketches and elaborate on their design concepts. We stressed the value of all ideas, ensuring every perspective, whether from a professor or a student, is equally important. The facilitator used a whiteboard to summarize their ideas and stimulate further discussion, encouraging participants to share additional thoughts. We recognize that this approach might have been less equitable for the last participant to speak. However, we did not encounter any problems in either workshop.

5.2 Analysis

We analyzed the sketches to identify design patterns using a thematic analysis (TA) approach [12]. This was conducted primarily by the first author in consultation and discussion with the other authors (see Positionality Statement). To capture the essence of each game mechanic for practical implementation, commonly sketched implementations were documented by frequency in Miro[7] (summarized in Table 4).

5.3 Sketch Documentations

The participatory design workshop yielded seven different heart rate (HR) display concepts based on participant presentations and our observations during the workshop (see Figure 3). From these concepts, we extracted design sketch implications (DSI) displays to guide our design process. In this section, we mainly report findings related to the three goals of the workshop.

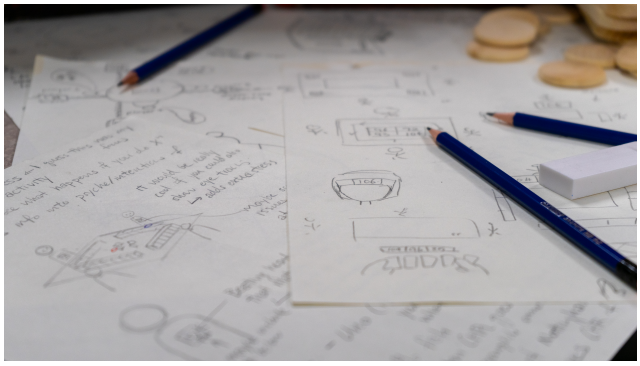


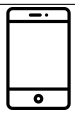
Figure 3: This figure illustrates some of the participant drawings in Research Phase 2.

Heads-Up Display (DSI 1). Our participants articulated that in a board game, players might wear miniaturized helmets or virtual reality (VR) headsets as part of their character costumes. The helmet could display the player's HR, adding an immersive experience by showing real-time stress or excitement levels. For example, in a futuristic combat game, a character's health status might be indicated by the glowing numbers on their helmet, signalling how close they are to defeat or how calm they remain under pressure.

Smart Watch Display (DSI 2). Our findings show that players could use smartwatches as part of the game to track not only in-game actions but also their own physiological responses. For instance, in a game where players make decisions based on fear or

[7] Miro is a digital collaboration platform designed to facilitate remote and distributed team communication and project management through white-boarding.

Table 4: This table articulates the design sketch implementations based on the participant's design description quotes. All of our participants are HCI researchers. Thus, they recommended design concepts that are particularly relevant to HCI.

Sketch Concept	Design Sketch Implementation	Documentation Count[1]	Participant's Design Description Quote	Design Concepts From HCI Literature
	**DSI1:** Heads-Up Display	n = 3	"It's like that Ellen game[2], but with your heart rate attached. Maybe it can flash colours."	[14, 132]
	**DSI2:** Smart Watch Display	n = 2	"The vibrations on the watch can be used to trigger in-game events, such as if your HR reaches over the number threshold."	[124, 128]
	**DSI3:** Shirt Display	n = 7	"Maybe put a lightning display on the chest spot of a shirt and display the heart rate with that. LED light might be a good choice."	[10, 28]
	**DSI4:** Smart Phone Display	n = 18	"You could create a prop that you put the phone into or whatever it is to fit whatever the board game design."	[58, 87]
	**DSI5:** Board Display or Interactive Surfaces	n = 10	"Take some players to a different room and leave the whiteboard display available for the other players. This would be interesting if you get players to move around."	[59, 73, 100]
	**DSI6:** Game Props Display	n = 3	"Your damage gets multiplied based on your HR percentage, like a war cry in LARPing[3]."	[16, 44, 52]
	**DSI7:** Card Display	n = 7	"In UNO[4], if someone has one card left, you might be able to figure out what colour it is based on the heart rate (on the back of the card)."	[20]

[1] *The frequency of the sketches grouped from both workshops.*

[2] *Heads Up is a word-guessing game where players guess the word on their card based on friends' clues before time runs out.*

[3] *LARPing (Live Action Role-Playing) is a game where participants act out characters in a fictional setting, using costumes, props, and immersive scenarios.*

[4] *UNO is a card game where the objective is to be the first player to get rid of all your cards.*

anxiety, the smartwatch could display their HR, influencing gameplay. A player might have to complete a challenge while keeping their HR below a certain threshold, adding an extra layer of difficulty. As demonstrated by Dirk's WatchThru [124], innovative interaction techniques like *Pop-up Visuals*, *Second Perspective*, and *Peek-through* could be used to enhance the board game experience, providing more immersive and engaging gameplay.

Shirt Display (DSI 3). A participant proposed that incorporating an LED light display on a shirt could serve as an innovative and interactive method to visualize HR data during a board game. This could create a more immersive experience as if the player's HR were being directly displayed. For instance, this concept could leverage existing HCI research, like Boehm et al. [10]'s 12-Lead ECG T-Shirt and Fitted Heart Rate Garments [28], adapting them for a board game context instead of medical applications [56].

Smart Phone Display (DSI 4). Most participants recommended displaying biometric data on the phone, allowing everyone to view a player's HR. This approach helps prevent players from entering a biofeedback loop [78], as studies indicate that observing one's own HR can increase it [103]. Additionally, participants noted that using a phone, a familiar object for many board games with companion applications, lowers the barrier to implementation [58].

Board Display (DSI 5). Some participants (mainly those who play tabletop role-playing games such as *Dungeons and Dragons*[8]) prefer to have an interactive display on the table; that way, the

[8] *Dungeons and Dragons* is a tabletop roleplaying game where players create characters that embark on imaginary adventures in a fantasy setting. One player takes on the role of the Dungeon Master (DM), who acts as the storyteller and referee, describing the world and its inhabitants, and guiding the narrative. The other players control individual characters, making decisions and taking actions that influence the story.

experience is shared among all [73]. Conversely, some participants suggested it would be intriguing to design a game where players must stand up and move around to view another's HR. One participant noted that a player's stats could fluctuate based on their HR or biometric feedback.

Game Props (DSI 6). Participants also suggested that it would be intriguing to display HR on game props. In live-action role-playing (LARPing) games, players could perform a war cry to boost their own or their party's damage. This same mechanic could be applied to existing board games, adding an interactive and dynamic element to the gameplay.

Card Display (DSI 7). Our participants proposed embedding cards with RFID technology to display HR on a screen, triggering events. These events could unlock or open certain elements, similar to an escape room [118].

5.4 Metric of Display

From our workshops, all participants agreed that a numerical display is the most effective for our prototype. However, we also discussed the implications of this choice. We hypothesize that the effectiveness of numerical displays may vary among participants because of differences in resting HR—some players may have a notably high resting HR, while others may have lower ones. This raises further questions to explored in the research phase 3 (RP3): How do we account for variances in baseline metrics? In addition, considering that each HR monitor has its limitations, we need to determine which device is best suited for this design.

5.5 Envisioning Playing Space

Our findings suggest that players experience **unified** and **non-unified** seating arrangements differently. In a unified seating arrangement, where players are seated equidistantly, they often experience heightened emotional intensity. This setup encourages reliance on nonverbal cues, allowing players to detect subtle physiological changes in others more easily. In a non-unified seating configuration, where distances vary, nonverbal communication may become less effective. The physical separation can make it difficult to pick up on subtle cues, potentially reducing the intensity of emotional exchanges. Players may need to rely more on verbal communication to understand each other's feelings and intentions.

5.6 Impact of Biofeedback Integration Can Influence Strategy

Our participants noted that there are advantages and disadvantages of different measurement devices (e.g., chest strap vs. wristband) and suggested that we explore how this information might impact fairness, strategy development, and the analysis of deceptive behaviours, primarily in games. For example, this could involve biofeedback training techniques that help players recognize physiological changes associated with deception and develop coping mechanisms to suppress or modulate their HR during critical game states. Research from Laborde et al. [63] shows that a player who is lying might attempt to slow their HR to appear calm and collected.

5.7 Critical Reflection on Research Phase 2

We encouraged participants to create drawings and mockups, further enriching the feedback process [27]. This allows for rapid exploration and refinement, enabling us to visualize different design directions and player experiences. Similar to the "Crazy 8s" [9] method, sketching allows participants to quickly visualize diverse design directions and player experiences without getting too attached to their initial ideas. This encourages a broader exploration of solutions, pushing beyond the first (often least innovative) concept towards *designing the right mechanics* and *designing the mechanics right*.

The resulting illustrations, mockups, and user interface prototypes serve a dual purpose. They not only solidify design concepts for us, but also function as powerful communication tools when analyzing design prompts from the player's perspective. We argue that these creative outputs provide valuable insights for designers and researchers (like us) to consider when developing a biofeedback board game's user interface and overall aesthetic in line with Sharp [105]'s recommended practices for user-centered design practices.

6 Phase 3: Rapid Iteration with Experts and Game Prototyping

6.1 Methodology

In our third phase, we conducted an expert review [117] with five industry individuals to guide our game design process (see Table 5). These professionals, from diverse backgrounds in the gaming industry, provided nuanced insights and critical feedback on our evolving design concepts. We evaluated the design implications from research phases RP1 and RP2, and created several simple game mechanics that integrate HR features suitable for board games. These mechanics are intentionally basic to ensure smooth integration, maintain strategic or thematic elements [107], and align with the player experience framework of Nacke and Drachen [76]. We then presented our seven design sketch implementations (DSIs) derived from RP2 to the experts for feedback, which later helped transform it into a game prototype.

6.2 Initial Feedback From Experts

Although we were aware from our documentation count that the smartphone display (DSI4) and board display (DSI5) appeared the most frequently, we chose not to share this information with the experts to avoid biasing their responses and to gauge whether they had insights that differed from the HCI researchers. However, our experts—particularly the one who owns the board game café—preferred the idea of a board display. From a cost-profit perspective though, using a smartphone proved to be more practical, as *"everyone has a smartphone these days"* (Expert 2). The experts emphasized that smartphones are a more feasible solution due to their ubiquity, ease of integration, and the fact that they already include the necessary hardware and software capabilities.

Additionally, the experts appreciated the idea of using card displays for HR, suggesting that these might be better suited for smaller spaces, like those in demographic locations where players might

[9] Crazy 8's is a rapid ideation technique where participants sketch eight different ideas in eight minutes to encourage creative thinking.

Table 5: This table presents demographic information in Research Phase 3.

Participant ID	Game Relative Knowledge	Industry Level Background[1]	Hours of Expert Review(s)[2]
Expert 1	Board Games	Level Designer	4 hours (over two iterations)
Expert 2	Tabletop RPG	Board Game Cafe and Game Designer	8 hours (over four iterations)
Expert 3	Card Games	Publisher	2 hours (one iteration)
Expert 4	Tabletop RPG	Fine Artist and Designer	2 hours (one iterations)
Expert 5	Board Games	Level Designer	4 hours (over two iterations)

[1] *Expert roles are self-reported by the expert.*

[2] *Each iteration with the expert lasted an average of approximately 2 hours.*

not have room to set up a traditional board game at home—*"that's why they come to my board game café"* (Expert 2). Based on the initial round of feedback, we chose to move forward by iterating on the design idea of a smartphone as the primary display for HR (DP4), as it the most efficient way to test our prototype.

Heart Rate Monitor Implications. Based on our consultation with experts, the design trade-offs for the HR monitor are primarily centered on three key factors: price, accuracy, and comfort. We settled on the Polar H10 Heart Rate Sensor[10] because it is known for its accuracy and comfort. We discussed with experts on the use of smartwatches for monitoring HR, but Expert 1 and Expert 5 noted that players often use their hands to move pieces in board games. As a result, a chest strap was deemed more practical because it minimizes movement and reduces measurement artifacts. In addition, the Polar device has an API system[11], which allows the creation of custom variables for the game mechanics and system. We also used Pulsoid's[12] HR widget, which is mainly used for live streaming. We adapted the API system to *stream* individual player heart rates, which are displayed in conjunction with the game prototype artifact.

Aesthetic Design Expert 4 noted "*the design needs to fit your game [...] you can use 3D assets to prototype quickly.*" They suggested ways to paint 3D models to enhance the thematic atmosphere [51, 107]. We used the Black Scrolls [13] stereolithography (STL) file as a basis for our game's phone stand.

Core Game Mechanic For Heart Rate. From our discussion, all our experts emphasized the importance of an intuitive on-boarding experience for board games, especially during the setup phase. In the HR board game design, the initial turns guide players through the core mechanics, gradually introducing rules and objectives within the game's narrative. The setup includes pre-packaged components and instructions that are revealed as players progress. This method eliminates the need for a separate, rulebook-heavy on-boarding phase, making the learning process intuitive and engaging.

[10]The Polar H10 is a chest strap HR sensor that uses ECG technology.
[11]Polar API Access Portal: https://www.polar.com/en/developers/
[12]Pulsoid: https://pulsoid.net/
[13]Black Scrolls Games: https://www.blackscrollsgames.com/

6.3 Follow-up Iterations

Expert 2, the board game café owner, notably participated most frequently, showing significant interest in our concept and how it could fit within their playing space. We also engaged with game-level design experts (Expert 1 and Expert 5) to explore narrative integration into the game. While these sessions were conducted in person, Expert 3 and Expert 4 provided additional insights on launching Kickstarter campaigns, though this was beyond the primary focus of our research. Thus we only report expert review sessions relevant to our research goals, as shown in Table 5.

Prototype Design Decisions. From these sessions, we decided to develop a social deception board game that integrates players' HR data into gameplay. The design features one phone per user, on a stand positioned away from the players, showing the group's average HR rather than individual players' HR; as derived from findings in RP1 and RP2. Drawing inspiration from the thematic suggestion of Shipp [107], we set the game in a ruined-forest-like environment where players can use portals to "jump" to different spaces, adding an element of spatial interaction to complements the physical arrangement. Following frameworks that incorporate social aspects [13, 74], we opted for a social deception game, integrating HR mechanics through both direct and indirect interactions as outlined by Nacke et al. [78]. Game mechanics were further inspired by popular social deduction games like *Werewolf* and *Avalon*, to enhance emotional engagement and strategic deception through biometric feedback and social dynamics.

In addition to the HR display, we carefully considered the spatial dynamics of the game. Findings from RP1 and RP2 highlighted how seating arrangements and the physical setup influence gameplay and social interaction. For this prototype, we opted for a **unified seating** arrangement, where players are equidistant from one another, evenly enhancing nonverbal communication and fostering an intimate atmosphere. The positioning of the phones away from the central play area reinforces the physical separation between the data source and the players, adding an element of mystery and requiring players to rely on the collective interpretation of the shared HR data.

Based on our findings from RP1 and RP2, and following frameworks that incorporate social aspects [13, 74], we developed a social deception board game that integrates players' HR data into the gameplay. The game features five phones—one per player—placed

on stands with screens positioned away from the players. This setup preserves an element of mystery, requiring collective interpretation of physiological responses rather than individual readings. The game incorporates HR mechanics through both direct and indirect interactions, as outlined by Nacke et al. [78]. To enhance emotional engagement and strategic deception, we drew inspiration from social deduction games like *Werewolf* and *Avalon*, leveraging biometric feedback to heighten social dynamics. Inspired by the thematic suggestion of Shipp [107], we set the game in a ruined-forest-like environment where players use portals to "jump" between different spaces (game states), adding spatial interaction to complement the physical setup. Findings from RP1 and RP2 also emphasized the impact of seating arrangements on gameplay and social interaction. For this prototype, we implemented a **unified seating** arrangement, where players sit equidistantly to foster an intimate atmosphere, enhance nonverbal communication, and encourage collaborative decision-making.

6.4 Game Prototype Artifact: One Pulse: Treasure Hunter's

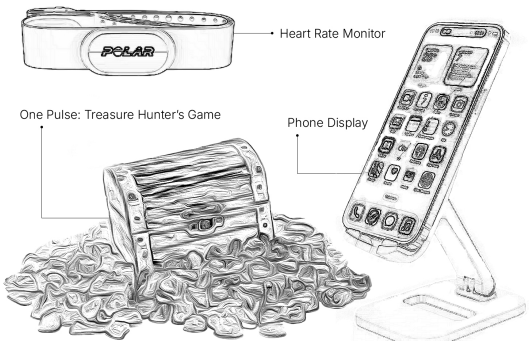


Figure 4: This figure presents an initial prototype of the *One Pulse: Treasure Hunter's* game, developed to evaluate the proof-of-concept.

Our game prototype artifact, *One Pulse: Treasure Hunter*, is a social deduction board game that uniquely integrates HR with strategic gameplay (see Figure 4). Designed for five players, the game divides players into two teams: three Hunters and two Guardians (spies). This is determined by randomized player cards at the start. The Guardians act as spies, working to uncover the Hunters while completing critical missions. Meanwhile, the Guardians attempt to sabotage the Hunters' efforts through manipulation and deception. Each player wears a Polar H10 heart rate monitor, which connects via Bluetooth to an iPhone 7 [14], displaying real-time HR data on the mobile phone. The game begins once players tap their character token into the phone.

As shown in Figure 5, *One Pulse: Treasure Hunter* is played on a round table, with each player's HR readings (e.g., hidden, 134, 149, etc.) displayed on individual 3D-printed phone stands. While players can check their own HR, doing so requires them to lean forward—an action that is visible to others, adding a strategic layer to deception and deduction mechanics.

6.5 Objective

The Hunters' primary objective is to complete **three missions** while identifying and exposing the Guardians (spies) within the group. To accomplish this, they must navigate complex social interactions while staying under the radar and avoiding detection. Meanwhile, the Guardians are focused on sabotaging the Hunters' mission success by causing them to fail or by manipulating the Hunters' stress levels. If the Hunters' combined heart rate surpasses a critical threshold—defined as their total resting heart rate plus ten beats per minute—and remains above this level for more than 30 seconds, the mission fails, and the Guardians win the round. For example, if Hunter 1's resting HR is 80, Hunter 2's is 90, and Hunter 3's is 100, the threshold would be 300 BPM. If the Hunters synchronize their heart rates within a 10-beat difference for 10 seconds, they will successfully conceal all players' heart rate data for the next mission.

We recognize that further balancing is needed; however, our study focuses on testing this proof of concept in alignment with the research goals. While we acknowledge that board games often feature special characters to add depth to gameplay, our priority is to first ensure that heart rate integration functions effectively at its most basic level before introducing more complex characters and roles. Additionally, we hypothesize that these metrics may need to be based on percentages of HR.

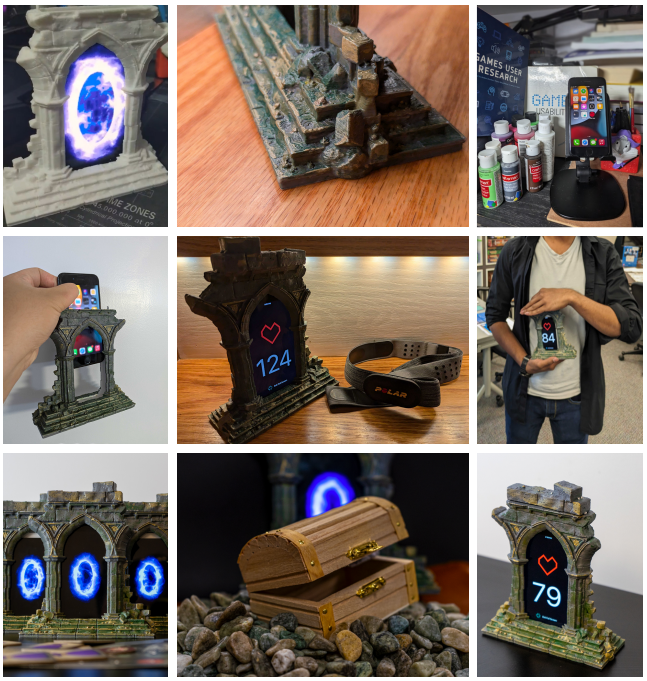


Figure 5: The figure shows the iteration phases throughout *One Pulse: Treasure Hunter's* metric display.

[14]We repurposed old devices to prevent them from ending up in landfills.

Table 6: The mechanics and game dynamics related to HR integration.

Mechanism	Game Dynamics Related to Heart Rate
Balancing Loop	**Synchronous Heart Rate Ability:** Hunters synchronize their heart rates for 10 seconds. Success hides all players' heart rates for the next round, requiring coordination to manage stress levels together.
Stress Indicator	**Heart Rate Threshold:** Hunters must stay calm under pressure. If a Hunter's heart rate exceeds the threshold for 30 seconds, they "explode," causing the mission to fail.
Manipulation Tactic	**Provocation Actions:** Hunters can provoke Guardians (e.g., "Taunting" them can increase a Guardian's heart rate), influencing their physiological responses.
Visibility Control	**Treasure Unlock:** The player who unlocks the treasure can hide any player's heart rate for one minute, adding deception and surprise during key moments.



Figure 6: This figure illustrates one of the players engaging in starting the mission, but their heart rate is hidden.

Hunter Victory: The Hunters win by successfully completing three missions while maintaining their HR threshold.

Guardian Victory: The Guardians win either by causing three mission failures or by pushing the Hunters' heart rates past the critical threshold.

6.6 Treasure Hunt Mission

The game is played over five rounds, with each round consisting of a mission phase where both the Hunters and Guardians collaborate to complete a series of tasks, all while managing their strategic objectives and physiological responses. At the beginning of each round, players select a captain who draws a "Treasure Card." The objectives of the mission are then determined through a majority vote, requiring agreement from at least three players. For each mission, the captain selects three players to participate. These chosen players must work together to complete the task while keeping an eye on their HR data, which may expose whether they are under stress or attempting to deceive others.

Treasure Card missions may include the following: Hold your breath for 30 seconds; Remain still for 30 seconds; Stare at your heart rate display for 30 seconds (optimal for sending Guardians rather than Hunters); Hold hands for 30 seconds (optimal for Hunters that figure out who are the Guardians); All players must flip at least two coin token with heads showing for 30 seconds and Jump twice within 30 seconds (ideally spaced out). Upon completion of the mission, the three players involved receive the Treasure Unlock card, which allows them to hide their HR data for one minute. This is activated by holding the treasure chest for 5 seconds to register the unlock (see Figure 6).

6.6.1 Playtesting. We conducted a follow-up playtest with the help of Expert 2 and their pool of board game players. From our observation data, we summarize this into three *key insights* broken down into specific game phases:

Key Insight 1. The social interactions among players predominantly centred around the HR displays. We noticed a recurring pattern where one or two players tended to dominate discussions and influence the group's decisions, effectively controlling the social interactions within the game. This tendency highlighted the manipulation aspect of the social dynamics. The HR display, while offering valuable insights into players' physiological states, had a significant impact on the playing experience. The display diverted some players' attention away from the gameplay itself, as they became focused on monitoring and interpreting their HR data. This attention shift sometimes detracted from strategic decision-making. However, it also sparked social interactions, with players discussing and attempting to interpret the displayed data, influencing their gameplay dynamics. This added an additional layer of social interaction, where HR became both a tool for deception and a source of social tension, further complicating the interactions within the game.

Key Insight 2. During the mission phase, players exhibited two distinct behavioural patterns. Firstly, there was a prevalent sense of urgency among players, driven by their fear of failing the mission. This urgency often led to hasty decision-making. Secondly, some players expressed concerns about their HR data, arguing that their naturally high or low heart rates should not be factored into negotiations and gameplay events. This disagreement suggests that the HR mechanic was perceived differently by various players, influencing their approach to in-game negotiations.

Key Insight 3. Our observation revealed a clear pattern in players' HR responses that aligned with their in-game roles and behaviour. Specifically, players who were not engaging in deceitful behaviour, typically those on the "Hunters" team, exhibited lower average resting heart rates. In contrast, players who were lying, generally those on the "Guardians" had higher average heart rates.

Players on the "Guardians" team, engaged in deception, seemed more aware of their heart rates, likely due to the stress and cognitive load of maintaining a lie. Their elevated heart rates might also reflect anxiety. In contrast, players on the "Hunters" team, who did not need to deceive, were more focused on the game, resulting in lower, more relaxed heart rates. However, it also raises questions about the ethical implications and the reliability of using such data to determine honesty or deception, especially in a social context where players' awareness of the technology might influence their behaviour.

6.7 Critical Reflection on Research Phase 3

Various game design frameworks informed our iterative process. For example, Mueller et al. [74] categorizes bodily interplay into coupling, physical space, and virtual space, while Bergström and Björk [9] introduce eight spectra for comparing computer-augmented analog games with their fully digital and analog counterparts. Additionally, Buruk et al. [13] proposes a framework for playful wearables emphasizing performative, social, and interactive aspects.

Despite the utility of these frameworks, most are grounded in the Mechanics-Dynamics-Aesthetics (MDA) framework [51], which divides game design into mechanics (rules and algorithms), dynamics (player-game interactions), and aesthetics (resulting emotional experiences). Recognizing the limitations of relying on a single framework, we synthesized relevant elements from these frameworks within our Research through Design (RtD) methodology. While our focus remains on enhancing the tabletop player experience, these design decisions were primarily informed by our overarching research goals: integrating HR mechanics and creating a game artifact that leverages physiological data to enrich social interactions and deception dynamics. As these are initial key insights, we plan to evaluate our prototype further in future work, considering how factors like seating arrangements and HR display settings may influence players' roles and behaviours during the game.

7 Discussion

As the contribution in RtD often lies in documenting the process and the resulting prototype, this section provides additional context relevant to our research goals [133]. By extending the RtD method with 35 participants, we identified key design implications and themes, enabling the extraction of generalizable game mechanics that incorporate HR into board games. We revisit our research goals (RG) to discuss insights from board game enthusiasts, the outcomes of our participatory design workshops, and how these informed the development of a prototype artifact leveraging HR game mechanics. Additionally, we explore the design trade-offs of visual displays, balancing player perceptions with the social dynamics of the game space.

7.1 Unified Versus Non-unified Seating

To address our first research goal (RG1), insights from RP1 revealed that the spatial design of play areas—particularly seating proximity and arrangement—shapes social dynamics. This includes how far or close players sit from each other. We define unified seating as configurations where players are equally spaced from one another and aligned symmetrically around the play area's central point.

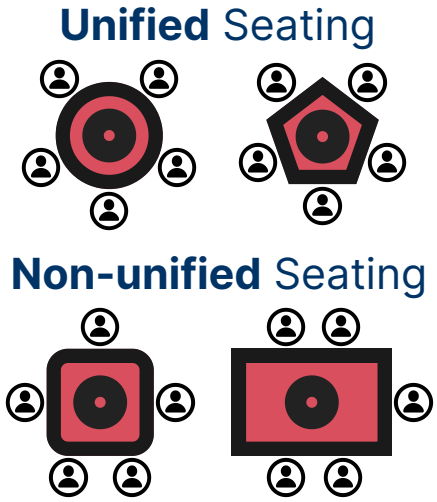


Figure 7: This figure shows the difference between unified and non-unified seating. We included quotes from Research Phase 1 that align with this finding in Research Phase 2.

This setup may foster a sense of equality and balance, potentially encouraging more open and cooperative interactions. In contrast, non-unified (unevenly spaced) seating can introduce perceptions of hierarchy or exclusion, altering how players interpret social cues or strategize.

From our RP2, we hypothesized that unified seating arrangements would foster a sense of equality and balance among players, leading to more open and cooperative interactions based on the findings of DP1. Conversely, we expected non-unified seating with uneven spacing to create feelings of hierarchy or exclusion, influencing players' strategies and social cues. Our actual results largely aligned with these expectations. In unified seating arrangements, participants exhibited more collaborative behaviours and reported feeling more connected to their peers. These outcomes mirror existing work linking equitable spatial proximity to improved group cohesion and communication [21], reinforcing the role of physical design in mediating social interaction.

Room size and layout further influence the player experience. In larger rooms, players might feel more isolated, which can affect their ability to communicate and collaborate effectively. Smaller, more intimate settings can foster a sense of closeness and immediacy, enhancing the social aspects of the game [106]. Building on HCI research, Geiskkovitch et al. [40]'s findings, introducing technology like a phone display in similar contexts can have comparable impacts on interaction dynamics and perceptions. The placement and accessibility of such technology can influence how people engage with it and each other, potentially affecting collaboration and communication in both human-computer and human-human interactions.

For instance, going back to RP3, a whole team could intentionally raise their heart rates during a critical accusation to appear as if everyone is hiding something, making it difficult for opponents to single out the true deceiver. Or, players might intentionally let their heart rates spike during less tense moments to throw off opponents

Table 7: Design trade-offs in Unified vs. Non-unified seating arrangements for playing spaces.

Aspect	Unified Seating	Non-Unified Seating
Social Interaction	Promotes a sense of equality and balance among players.	May create feelings of hierarchy or exclusion.
Collaboration	Facilitates open and cooperative interactions.	Can lead to competitive or strategic behaviour.
Player Proximity	Close physical proximity enhances group cohesion.	Uneven spacing can distance players, weakening cohesion.
Communication	Encourages clear and effective communication.	Potential for communication challenges due to spacing.
Role Differentiation	Minimizes role distinctions, promoting equal participation.	Supports role distinctions, e.g., Dungeon Master in RPGs.
Game Dynamics	Supports collaborative and cooperative game dynamics.	Can introduce power dynamics and influence strategies.
Technology Integration	May limit visibility of shared digital displays for all.	Allows for strategic placement of displays for visibility.
Player Experience	Enhances feelings of connection and shared experience.	Can introduce varied experiences based on seating.
Application in Games	Ideal for board games requiring equal participation.	Beneficial for roleplaying or augmented reality games.
Group Cohesion	Strengthens group identity and unity.	May weaken cohesion if not managed carefully.

and misdirect attention away from the real moments of deception. Our findings align with the research by Von der Heiden et al. [122], which shows that distributing physiological cues among all team members makes it difficult for opponents to identify the actual deceiver. However, in terms of group communication, Tilton [115] note that specific social deceptions can shape group dynamics, with dominant individuals steering discussions and potentially influencing game outcomes. Strategic seating arrangements in non-unified setups can amplify this effect by reinforcing hierarchical dynamics. For example, a "dominant" individual can control the game's outcome by steering discussions, and strategic seating arrangements can further enhance their influence in non-unified seating. We emphasize the importance of considering seating arrangements as a design tradeoff in board game design. In our summary, we compare the design tradeoffs between unified and non-unified seating arrangements derived from RP1, RP2 and RP3 (see Table 7).

7.1.1 Seating Arrangements in Roleplaying Games. Interestingly, roleplaying games like Dungeons and Dragons could benefit from non-unified seating, as the roles of the Dungeon Master (DM) are separate and should be distanced from the players to maintain clarity and authority. This setup is also beneficial for shared gaming experiences [55, 125] or augmented tabletop games [29, 68], where technology displays need to be visible to all players. Non-unified seating in these contexts supports role differentiation, allowing the DM or key players to effectively manage the game's narrative or strategic elements. This setup can also accommodate diverse player needs by ensuring that critical resources—whether narrative cues, digital interfaces, or physical game elements—are appropriately distributed. Furthermore, non-unified arrangements enable the integration of technologies such as smartphones or augmented reality displays in ways that enhance the social and collaborative aspects of the game while preserving each player's unique role in the gaming experience. Additionally, playing these games in a non-isolated environment (such as a board game café, live-streams, etc) introduces new dynamics, as spectators and external factors—such as the psychological effect of being watched—could influence players' heart rates and behaviours. This raises interesting design considerations, as social presence and environmental context could further impact deception strategies and team coordination.

7.2 Towards Designing Various Biofeedback Input Modalities For Board Games

The integration of advanced technology is anticipated to bring innovative game mechanics to traditional analog games [14, 68]. For example, Nenonen et al. [83] introduces an innovative approach to using real-time HR data to control a biathlon computer game, combining skiing and shooting. From our initial RP3 game prototype artifact, we noticed that, instead of using companion applications like in traditional hybrid tabletop games, integrating biofeedback metrics directly into the game mechanics can trigger specific events. Integrating HR biofeedback into game mechanics can significantly enhance the excitement in various situations, as supported by Baqai et al. [7]. Using our current system, this could be adapted to existing social board deception games. If we were to integrate biofeedback metrics into existing tabletop games, a high HR could represent increased stress levels, which might weaken a player's ability to do an action. This would create a more immersive and challenging experience, similar to how a high HR destabilizes aim in digital games [123]. Using the game Battleship[15] as an example, the analog dynamics could follow principles of stress shots (if a player's HR is high, their shots could be less accurate, representing the difficulty

[15]Battleship is a strategy game where players try to sink each other's fleet of ships.

of making precise decisions under stress), succession hits (players with a lower HR could get a bonus turn or more accurate shots, simulating the advantage of staying calm under pressure), or panic mode (if a player's HR spikes significantly, they might have to reveal the location of one of their ships, adding a high-stakes element to the game).

By monitoring others' *(and their own)* HR fluctuations, players can gain a strategic advantage, either by deceiving opponents about their intentions or by interpreting subtle physiological cues. Drawing on insights from RP3, we observed that participants may deliberately provoke or stress rivals to induce detectable HR shifts, capitalizing on these physiological cues for competitive advantage. This interplay heightens tension in social deception games, amplifying emotional engagement through real-time biofeedback dynamics [43]. To maintain composure, players often suppress outward signs of stress, such as reducing breathing intensity. Biofeedback inputs might incorporate breath detection (akin to the Nintendo DS's microphone-based sensory design [19]) or action-driven sound intensity metrics [36]. However, to avoid suspicion, players could employ controlled breathing or relaxation techniques to mask physiological responses. Such hybrid strategies align with Buruk et al. [15], who demonstrated how embodied interaction—via wearables and adaptive movement—can deepen immersion in tabletop role-playing contexts.

From our observations during RP3 playtesting sessions, we noted several important considerations for integrating HR into game mechanics because HR often only increases during gameplay, it is essential to include game events that allow players to reduce their HR. For example, the ability to hide a player's HR display can provide a moment of relief, helping them to calm down and lower their HR. In addition, as noted from our RP2 findings, although most HCI researchers suggested that the numerical HR metrics would be great to implement, we argue that this is still insufficient. We note that players instinctively used tactics such as falsely claiming that "your HR is rising" to induce others to check their displays, which fed into the biofeedback loop [34]. These cues can help players better understand and react to their physiological states without relying solely on numbers or estimating the player's emotional state and adapt to the game environment [41, 42, 116].

7.3 Design Trade-offs For Integrating Prototypes

Current game design frameworks encompass diverse approaches from the design of playful wearables emphasizing performative, social, and interactive elements [13]; mechanics-dynamics-aesthetics (MDA), which focuses between the designer and player [51]; and social exertion play [74]. However, these frameworks primarily address design language and artifact outcomes. Our research argues that design trade-offs are also significantly influenced by the underlying research goals. For example, during our iteration stage, we plan to incorporate haptic feedback as a game mechanic to notify players of hidden in-game events that are invisible to others. This approach aligns with existing design artifacts like WEARPPG and Social Wearables for Larp (SW4LARP) [16], and it fits within the design frameworks discussed earlier. Design frameworks offer a starting point, but we argue that actively addressing the inherent design trade-offs, especially those shaped by research goals, is equally crucial from conception to completion.

Drawing upon previous studies, we believe that integrating HR biofeedback into board games can be a significant step forward. Prior research suggests that such biofeedback can enhance the connection to the game's immersive experience, which can improve player engagement [48]. However, previous studies have not explored these concepts with implemented technology in the context of board games. To better understand how HR biofeedback can alter the board game experience, we designed a new game system and developed mechanics that incorporate HR data, enabling a more interactive and engaging gameplay experience. For example, biofeedback can enhance social interaction by adding new layers of strategy and deception.

We note that from findings from RP1, having HR streamed in real-time might make some players feel uncomfortable or overstimulated, especially if they know others are watching their physiological responses. We argue it can lead to increased anxiety, particularly in stressful moments, as supported by work done by Chanel et al. [24]. On the downside, this added pressure can be tough for players who have trouble managing stress. They might find it hard to keep their heart rates steady, which could make the game more stressful than enjoyable, as noted by work from Sehrt et al. [104]. This constant focus on managing physiological responses might overshadow the fun aspects of the game, making it less engaging for some players. The strategic depth added by incorporating HR data introduces a resource management element based on stress levels. Players must balance their in-game actions with their physiological state, making decisions that can either calm or elevate their heart rates. While this adds a unique and complex layer to the gameplay, it can also be unfair to players who have difficulties with stress management. Higher heart rates might disadvantage these players, making it harder for them to succeed and potentially leading to social frustration, as noted by Tilton [115].

In terms of social deception dynamics, players need to manage not only their verbal and non-verbal cues but also their physiological responses to avoid being detected. This adds a layer of complexity and immersion to the game, where controlling one's HR becomes as important as crafting a convincing story (primarily denoted in social deception games). From our work, we argue the added pressure to keep a steady HR can lead to more intense and engaging interactions as players try to read each other's heart rates to spot deception. Players with naturally higher heart rates or who struggle with stress may be unfairly penalized. The need to stay calm under observation can be particularly challenging for these players, potentially making the game less fair. To address these concerns, we suggest implementing options to accommodate different physiological responses and ensuring that the game maintains a balance between its strategic, social, and physiological elements to avoid overshadowing one aspect over the others derived from our initial observations in RP3.

There are also concerns regarding accessibility and the perceived fairness of these mechanics. Players with certain health conditions or those who have difficulty managing their physiological responses may feel disadvantaged, even if the gameplay itself does not explicitly create imbalances. We suggest clearly communicating that

Table 8: Design considerations with respect to trigger events and tradeoffs in board games.

Consideration	Trigger Event	Trade-offs
Over Simulated Experience	Could heighten urgency in high-stakes situations	May cause anxiety; players may feel overexposed
Strategic Depth	Adds resource management based on stress; encourages careful decision-making	Higher heart rates may unfairly penalize some players; could disadvantage players with stress-management difficulties
Social Deception Dynamics	Introduces new psychological layers to deception; adds depth to social deduction mechanics	Increased pressure to maintain calmness; players may be unfairly targeted based on physiological responses
Accessibility & Fairness	Ensures informed consent for biofeedback use; provides opt-out options for players	Some players may feel disadvantaged due to physiological differences; requires clear communication about HRV metrics

HRV is a standardized metric used for the unique game mechanics and that individual variations in HR or emotional control are not indicative of a player's skill or potential to succeed in the game. This transparency can help mitigate perceptions of unfairness and make the game more accessible to a broader audience (see Table 8). Moreover, we would articulate that these implications should be considered an initial stepping stone to exploring biofeedback design implications within board games. Thus, our understanding of biofeedback design is constantly evolving, and these implications may change as we conduct more studies, get feedback from users, and even explore new applications within board games.

7.4 Limitations and Future Works

We acknowledge that RtD approach can be inherently subjective, as it often relies on the researchers' interpretations and creative processes. This subjectivity can lead to biases and may affect the generalizability of the findings. Additionally, the iterative nature of design research can be time-consuming and resource-intensive, potentially limiting the scope and scale of the studies conducted (this research took more than a year to complete). Regarding participants, we acknowledge that the sample size and diversity can significantly impact the validity of the research. For example, small or homogenous participant groups may not provide a comprehensive understanding of the broader user experience. Furthermore, participants' familiarity with biofeedback and board games can vary, influencing their engagement and feedback. However, we argue that our experts helped justify our design decisions, although they were primarily decided by the first author.

Future work should aim to reduce player anxiety and stress by looking into adaptive difficulty levels or relaxation techniques to improve the gaming experience. It's important to design inclusively, allowing for different physiological responses through customizable settings or alternative feedback methods. Continuously adjusting the balance between strategy, social play, and physiological feedback through user studies and ongoing improvements will create a more enjoyable and inclusive gaming experience. We plan to evaluate other prototypes that did not converge through this RtD stage.

8 Conclusion

In conclusion, our research brings into focus a pathway toward a new generation of tabletop games, where biofeedback is an integral component. To understand how to do this, we studied player perceptions and mapped design integration. We also developed a proof-of-concept artifact biofeedback tabletop game for further exploration. Our findings emphasize that biofeedback serves a clear design purpose and improves gameplay without overstimulating players. The guidelines and mechanics we propose are a starting point, inviting research and design peers to explore this promising emerging domain at the intersection of technology and traditional board gaming. In conclusion, we believe this research offers game designers essential design trade-offs for incorporating biometric feedback, such as HR, into their tabletop games, creating immersive, interactive, and at the end of the day, these human experiences should foster *game design decisions with no gimmicks.*

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