Towards Understanding the Design of Shared Bodily Control via Exoskeleton-based Play

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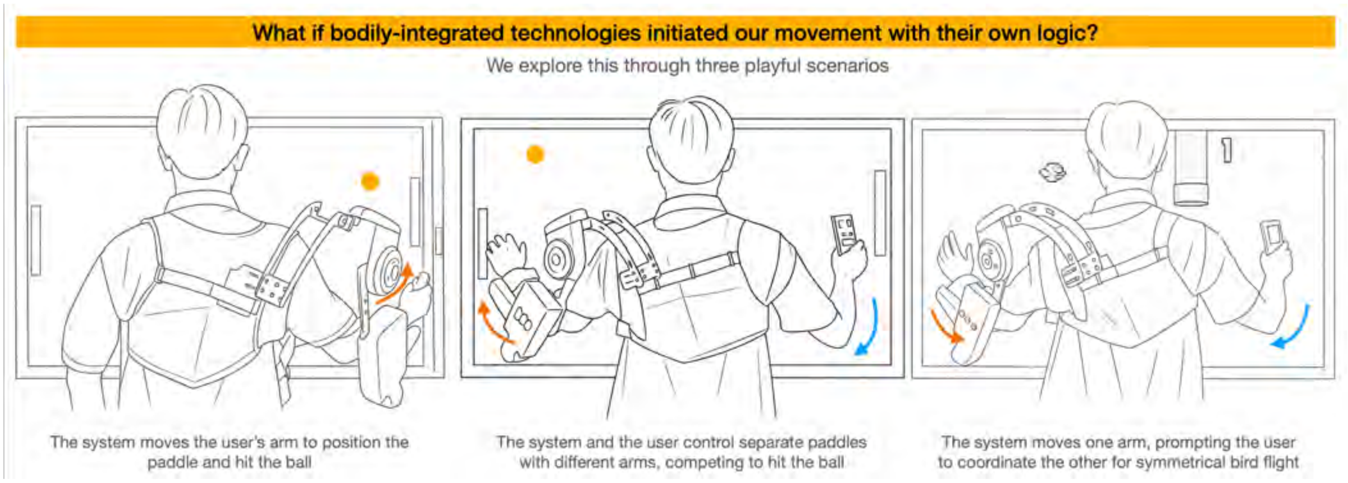

Figure 1: This work explores what happens when bodily-integrated systems initiate movement with their own logic. We designed three playful exoskeleton scenarios: *Proxy Pong*, where the system moves the user's arm to position the paddle and hit the ball on the user's behalf; *DualForce Pong*, where the system and user control separate paddles and compete to hit the ball; *SyncedWings*, where the system moves one arm and the user coordinate the other for symmetrical flight. These designs investigate different relational framings of shared motor performance—proxy, opposition, and cooperation.

Abstract

Emerging technologies such as exoskeletons and electrical muscle stimulation can initiate movement within the human body, blurring the boundary between user and machine. While prior research has explored how such systems augment bodily action, most focus on movement execution rather than decision-making. In this work, we investigate what happens when a bodily-integrated system acts

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with its own logic and initiates bodily movement alongside users. We present three game scenarios where an exoskeleton controls one arm while the user controls the other, designed to evoke different relational framings: proxy, collaboration, and opposition. Through a qualitative study (N = 16), we examine how users interpret such interactions, and how shared bodily control shapes bodily experience and human-machine relationship. We further contribute a set of implications for designing bodily technologies that decide and move together with users, opening up design possibilities for systems that share bodily control, not merely actuate on users' behalf.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**; *Interaction design.*

Keywords

Bodily play, Human-computer integration, Shared Bodily Control, Human-AI collaboration, Exoskeleton

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1 Introduction

As technologies become increasingly entangled with human bodies, the notion of shared control is evolving [15]. Traditionally, shared control describes how humans and machines coordinate to manipulate external tools, such as robotic arms or autonomous vehicles [42]. In these models, the human body acts as a unified agent, and the machine as an external assistant [14, 40]. However, emerging technologies such as exoskeletons and electrical muscle stimulation (EMS) now allow control to be shared within the human body itself [23]. These systems can directly initiate bodily movement, blurring the boundary between user and machine [1, 24, 50]. Recent works in bodily-integrated technologies have explored how machines can support or override human movement [54]. These systems typically focus either on functional augmentation—enabling actions users could not perform alone [66]—or on experiential provocation, such as evoking surprise through unexpected bodily control [58]. To realize such focus, much of this work emphasizes the execution of movement and hence physical actuation in predefined or reactive ways.

Yet human movement is not only an act of execution—it is preceded by perception and contextual decision-making [13]. Humans continuously interpret their environment and choose how to act. Even when pursuing a similar high-level goal, it might generate distinct motor trajectories [82]. What happens when a bodily-integrated system also engages in this process—when it moves our body not merely in reaction, but according to its own logic? In such cases, the experience may shift: from feeling mechanically assisted to feeling as though one's body is co-occupied by another agent that generates movements based on its own internal rules.

To explore this idea, we designed three playful interaction scenarios in which an intelligent exoskeleton controls one of the user's arms, while the other remains under human control. We implemented three embodied games: "Proxy Pong," "DualForce Pong," and "SyncedWings." Each game enacts a different relational mode of human and machine: acting on behalf of, in coordination with, or in opposition to the user. Rather than building truly intelligent agents, we used structured control logic to evoke the experience of internal, semi-autonomous decision-making. We conducted a user study (N = 16) to understand how participants experienced these different forms of localized control. In this study, we focused on the experiential, relational, and interpretive dynamics that emerge when a system appears to move with its own embedded logic. The qualitative study resulted in four themes: 1) Bodily Experiences with System Co-performing Movements; 2) Experiencing the System as a Bodily-integrated Partner; 3) Ethical Reflections; 4) Limitations and Future Potentials. We further reflected on the results and design process to propose a design space and design implications to guide the future design of bodily co-performance with machine-initiated bodily movements.

Our work makes the following contributions. First, we present a novel system that explores the experience with bodily-integrated technologies that can express internal logic through movement. Our three embodied scenarios represent different framings of shared motor decision-making. Second, we report empirical insights into how users experience such interactions. Third, we propose a conceptual design space and design implications for bodily-integrated systems through the lens of bodily co-performance. This work may benefit a wide range of audiences. For interaction designers, it offers new ways to frame human–machine collaboration as bodily and relational. For wearable developers, it opens up possibilities for designing systems that feel like co-performers rather than tools. For HCI researchers, it provides a conceptual foundation for investigating how bodily technologies with their own motor decision process shape lived experience. This work may also inspire future applications in areas such as rehabilitation, assistive technologies, or expressive movement systems, where bodily agency is shared. We hope this contributes to ongoing conversations in HCI and design research around embodied interaction, human–machine entanglement, and speculative futures of humanized technology.

2 Related Work

2.1 Human-Machines Intertwinement

Human-machine intertwinement explores how technology can be incorporated into bodily experiences to foster intimate and embodied relationships with users [49, 52]. Early visions including Wiener's concept of cybernetics [80], Licklider's Man-Computer Symbiosis [36], and Engelbart's augmentation of human intellect [12], proposed tightly coupled feedback loops between humans and machines. Later philosophical perspectives, such as cyborg relations [64] and Haraway's rejection of rigid human–machine boundaries [18], further articulated how technology can become experientially integrated into the body.

Recent HCI research extends these ideas through diverse forms of bodily integration. Some projects explore body extension, for example, wearable robotic arms that feel like natural body parts [66].

Others emphasize internal interfaces [33], from ingestible sensors that merge internal and external bodily interactions [32, 35] to implantable devices [19]. Another stream of research examines how technological interference with bodily actions via electrical muscle stimulation (EMS), shaping or triggering movements in training, tactile perception, or repetitive tasks [54, 73, 74]. Beyond physical actuation, virtual environments also demonstrate how shared or merged avatars affect bodily boundaries [16, 27].

Outside HCI, contemporary body arts have explored shared bodily control. For example, the performance "Inferno" uses exoskeletons to turn people into puppets, creating a "forced rave" that challenges bodily agency [59]. Similarly, Stelarc's "Ping Body" integrates robotic limbs and Internet connectivity to enable remote control, confronting traditional body autonomy [75]. These artistic explorations emphasize the experiential dimensions of human-machine intertwinement.

Theoretical frameworks provide additional accounts of how technologies become experientially fused with the body. Mueller et al.'s "fusion paradigm" [49] envisions a future where technology can be physically integrated into the body to extend one's body. Relatedly, Leigh et al. [29] introduced "Symbiotic Human-Machine Interfaces", which augment human abilities by blending machine functions seamlessly into bodily experience. Broader perspectives on human augmentation [62] highlighted how technology enhances sensory, cognitive, and motor capacities, offering another view on how bodily experience can be expanded.

Other accounts focus on experiential and perceptual integration. Danry et al.'s "Experiential Integration" [11] explored how users perceive integrated technology as an extension of their self. Similarly, Inami et al. [20] investigated how bodily and technological integration allows users to control or delegate control of both their natural body and its technological extensions across physical and virtual spaces.

Playful approaches add yet another dimension. Research on "playful body extensions" [5, 56] investigated augmentations such as additional limbs, emphasizing how they evoke novel and playful bodily experiences beyond mere functional replacement. Similarly, work on "Bodily Integrated Play" [47] used interactive technologies embedded in or attached to the body to encourage playful experimentation with altered forms of embodiment. These playful configurations highlight how integrated technologies can disrupt normative bodily boundaries and promote new ways of sensing, acting, and understanding one's body.

Despite the rich foundation, much of this work approaches the body as a unified acting entity or focuses on how movement is executed. Far less attention has been given to how technologically integrated systems might contribute partial or localized motor inputs that coexist with, diverge from, or subtly shape human motor decision-making. Understanding this more granular form of intertwinement remains an open area within the broader discourse.

2.2 Bodily Experience in Shared Bodily Control

While many bodily-integrated technologies focus on augmenting physical capabilities or improving performance, recent work in HCI and game design has explored bodily experience itself—particularly when control is shared, contested, or disrupted—as a rich source of engagement, reflection, and play [31, 39, 41, 57]. Within this space, bodily control is approached not only as a function property, but also as an experiential one [38]. Foundational work has identified agency and ownership as two central experiential dimensions in human–machine intertwinement [51].

Agency, broadly understood as the experience of controlling one's body and the external environment [37], plays a significant role in shaping self-awareness and consciousness [17]. Designers have explored how novel forms of agency can evoke intriguing bodily experiences. For example, Byrne et al. [6] used Galvanic Vestibular Stimulation (GVS) to induce vertigo sensations that alter player control in a balance game. Patibanda et al. [58] introduced "body-actuated play," using Electrical Muscle Stimulation (EMS) to partially commandeer player movement. Marshall et al. [43] explored shared autonomy in Broncomatic, where a mechanical bull reacts to the rider's breathing instead of manual controls. Theoretical frameworks further highlight the role of agency. Mueller et al. [50] presented a design framework showing how limited bodily control can enrich bodily play experiences, while Benford et al. [1] introduced the "contesting control", examining how surrender, looseness, and self-awareness can become productive design materials. Collectively, these works demonstrate how intentional disruption or redistribution of bodily control can become a meaningful design material.

Ownership refers to the feeling of "mineness" toward one's body parts, thoughts, or actions [3]. It reflects how users perceive the integration of technology with their bodies, influencing their sense of self and identity. Classic demonstrations such as the rubber hand illusion [2] reveal the malleability of ownership through aligned sensory cues, and work in virtual environments extends this to entire virtual bodies [30]. In bodily interactions, ownership has been used as design material. Krekhov et al. [28] examined how VR experiences can evoke non-human bodily ownership. Steptoe et al. [69] showed that users can incorporate additional appendages, such as tails, into their embodied sense of self, and Svanaes et al. [71] similarly examined how wearable extensions like tails and ears may blend into lived bodily experience. These explorations highlight how ownership can be flexibly shaped, extended, or reconfigured through technological mediation.

While prior work richly investigates how systems can override, guide, or modulate bodily action, much less attention has been given to how users make sense of movement that reflects a system's own locally generated motor decisions. This experiential dimension of interpreting, experiencing, or responding to a system's autonomous motor choices remains underexplored in shared control and bodily interaction research.

2.3 Human-Machine Relations

Early views of human–machine interaction often positioned technology as a tool to execute user commands. However, emerging perspectives in HCI emphasize a shift toward partnership, where systems and users are dynamically coupled and act in concert [14]. Rather than replacing human input, these systems participate in shaping actions, decisions, and experiences. Frameworks such as

Human-Computer Integration (HInt) emphasize blurring boundaries between humans and computers, transitioning from command-response to integrated partnerships [14, 78]. Everyday examples include smart alarms that adjust wake-up times based on contextual cues like weather or traffic.

A similar sense of partnership appears in everyday computational systems, where technology participates in interpreting situations and shaping user action. Conversational agents, for instance, serve not only as information providers but as companions providing emotional support and practical support [70]. Wearable health trackers similarly offer personalized interpretations of bodily data, shaping users' behavioral decisions, while intelligent writing and coding assistants offer context-aware guidance that alters cognitive workflows [25, 53]. Extending these ideas, recent work proposes a tripartite model of consciousness—conscious, unconscious, and meta-conscious to illustrate how interfaces may shape user cognition and behavior even when attention is not explicitly engaged [21]. Together, these examples demonstrate how contemporary systems increasingly act as collaborators that share in interpreting situations and guiding action.

This shift also manifests in game research, where the relationship between players and non-player characters (NPCs) has moved beyond static scripting toward dynamic and adaptive forms of interaction. In competitive play, NPCs adjust their strategies in real time—such as Role-Playing-Games (RPG) bosses that adapt to player actions [22, 44], or Multiplayer Online Battle Arena (MOBA) opponents that dynamically match skill levels [68, 85]. In cooperative games, NPCs may serve as teammates to provide strategic support by autonomously healing allies or solving environmental puzzles [86]. Beyond direct collaboration or competition, intelligent agents can also operate as proxies—handling repetitive tasks like resource gathering while leaving high-level decisions to the player [60, 61]. For players with accessibility needs, similar systems can take over partial controls while maintaining a sense of active play [8]. Across these examples, systems do not simply execute actions—they participate in moment-to-moment decision-making, enact strategic roles, and sometimes negotiate responsibility with the user.

Despite growing interest in these relational dynamics, most work examines shared control in cognitive or gameplay contexts, not in the bodily domain. How such partnership roles—collaborative, competition, or proxy through physical movement itself remains comparatively underexplored. This gap leaves open questions about how human–machine relations unfold when a system participates directly in shaping the user's bodily actions.

2.4 Summary

Prior work has explored human-machine intertwinement and associated bodily experience, and different modes of human–machine relations. However, most focus on how control is gained or lost—rather than how movement decisions are formed and interpreted. The experience when systems initiate movement based on their own internal logic remains underexplored. Understanding how people interpret such system-driven contributions—whether as cues, constraints, or intention-like actions—reveals a gap in existing accounts of shared control and bodily experience.

3 System Design

To explore how bodily-integrated systems might initiate movement based on its "own internal logic", we designed three interaction scenarios using an arm-worn exoskeleton that can actuate the user's limb[1]. By "own internal logic", we refer to decision policies that operate independently of the user's intention, which may be implemented through reinforcement learning, hand-crafted rules, or other mechanisms. The exoskeleton includes angle and force sensors to detect elbow position and interaction force, and a motor for actuation. An Arduino Nano serves as the command hub, processing sensor data and controlling the motor. The exoskeleton provides one actively powered degree of freedom at the elbow and two passively supported degrees of freedom at the shoulder, which help align the arm and transfer load. Elbow flexion and extension are actuated using a CYS S0650 servomotor (approximately 5 N·m). With around 11 cm lever arm, this corresponds to roughly 45 N of linear force at the forearm cuff, which is sufficient to move a user's forearm without voluntary effort. In practice, the system could smoothly redirect the forearm of all participants, including those presenting the highest load conditions in our sample (180 cm, approx. 100 kg), provided they did not intentionally resist. The powered movement corresponds to a nominal $0 - 90^\circ$ flexion–extension range, though the effective range in practice is slightly smaller due to mechanical tolerances and alignment. This functional arc was sufficient for all directional movements required in our game scenarios. We programmed the exoskeleton to make autonomous in-game decisions and actuate the player's limb accordingly (see Figure 1).

3.1 Why Play?

We adopted *play* as our design medium not merely for its accessibility or engagement, but for its methodological potential. Play allows for the suspension of everyday expectations around control, efficiency, and correctness—making room for ambiguity, friction, and surprise [9]. These qualities are especially valuable when exploring unfamiliar bodily relationships, such as interacting with a system that can move one's body semi-autonomously [34, 47]. Unlike task-oriented settings that prioritize performance, play provides a structured-yet-flexible context in which users are invited to interpret, experience, and make sense of actions as they unfold [63]. This is particularly critical in our study, where the system's behavior is intentionally designed to appear strategic. Thus, we believe that designing playful experiences can foreground the experiential qualities of shared bodily control and help realize the full expressive and relational potential of such devices. In this way, play helps surface how users act with the system, how they perceive its behavior and decisions, and how they experience this type of shared control in an immersive and engaging manner.

3.2 Games

We explored three interaction modes between the player and integrated technology: proxy, competition, and collaboration. In "Proxy Pong", the system takes over the player's arm as a "proxy" to achieve game goals. In "DualForce Pong", players compete against their AI-controlled arm using their free arm. In "SyncedWings", players

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[1] https://www.auxivo.com/eduexo-pro

cooperate with the system to control a virtual bird's flight, requiring synchronized movement.

3.2.1 Game 1: Proxy Pong. "Proxy Pong" is an adaptation of "Pong", where two paddles compete to hit a ball back and forth across a screen. In our version, a player's dominant arm, equipped with an exoskeleton controlled by the game's decision-making algorithm, competes against a virtual opponent (Figure 2). The non-dominant hand is free but the game does not need it to move.

Gameplay. If a player fails to return the ball, the opponent scores a point. The objective is to score 10 points first. The AI-controlled exoskeleton moves the player's paddle, competing against a computer-controlled paddle representing the virtual opponent. Players are passive observers of the match between their AI-powered arm and the virtual opponent.

To enhance engagement, the game features escalating difficulty based on flow theory [72]. The game speed increases after every four successful hits by the AI-controlled paddle. There are three difficulty levels: 1) 7 pixels/frame for both ball and paddle; 2) 10 pixels/frame for the ball and 14 pixels/frame for the paddle; and 3) 13 pixels/frame for the ball and 21 pixels/frame for the paddle .

Implementation. The game resolution is 640 x 480 pixels. We use a PC as the central hub, running the game, processing input from the exoskeleton, and translating the AI's decisions into commands to control the player's arm movements via the exoskeleton wirelessly.

For the virtual opponent, we designed a ball tracking algorithm that monitors the ball's vertical coordinate. By adjusting the position of the paddle to maintain alignment with the ball's trajectory, the algorithm ensures a prompt response to the ball's movement. For the AI that controls the player's arm, we used the Deep Q-Network (DQN) algorithm [46]. This reinforcement learning (RL) technique allows the AI to learn from experiences, much like how humans improve their skills through practice. Specifically, the system utilized a state space consisting of four consecutive raw pixel frames to capture motion dynamics. The agent interacted with the environment via three discrete actions (move up, move down, stay) to maximize a sparse reward signal: +1 for scoring a point against the opponent and -1 for missing the ball. Through minimizing the temporal difference error between predicted and target Q-values, the AI learned to associate patterns in visual game frames with effective paddle movements. After training, the AI was able to return the majority of shots and consistently outperform the virtual opponent across multiple test rounds. The training process lasted approximately 10 hours.

To translate AI's discrete decisions into bodily movement, the system mapped the paddle's vertical position in the virtual game environment to the exoskeleton's actuation space through a calibrated linear relationship. Specifically, a desired paddle position along the vertical screen axis, denoted as y_{target}, was converted into a corresponding target servo angle θ_{target} using the linear mapping $\theta_{target} = k \cdot y_{target} + b$, which related the screen's vertical range (0 – 480 px) to the effective actuation range of the exoskeleton. Due to mechanical constraints, this corresponded to approximately 28° of servo rotation, which was mechanically amplified to nearly 90° of elbow motion.

In practice, the AI's discrete action outputs resulted in incremental updates to the paddle position rather than instantaneous jumps to a final target configuration. These updates were transmitted to the exoskeleton as discrete angle commands, allowing the servo position to evolve gradually over time. A low-level position controller on the exoskeleton tracked the commanded angles, while a low-pass filtering mechanism was applied to reduce abrupt changes caused by discrete updates and communication quantization. This design ensured smooth, stable, and predictable arm motion during interaction.

Safety Considerations. Recognizing that having an external force acting on one's limb may raise concerns about comfort and safety, we have designed our system with user experience in mind. To avoid arm twisting, we have implemented safety measures. The servos are restricted to a rotation range of 0 to 90 degrees, aligning with the natural range of motion for arm flexion and extension. Additionally, to enhance safety, we have equipped the exoskeleton with an external stop button. This allows players to quickly cut off the exoskeleton's power with their dominant hand. None of our participants experienced any safety issues during the study.

3.2.2 Game 2: DualForce Pong. "DualForce Pong" introduces a direct competition between players and AI. The exoskeleton is attached to the player's non-dominant arm. Players use their dominant hand to control the paddle with a handheld controller, competing with the AI-controlled arm.

Gameplay. Similar to "Proxy Pong", the goal is to score 10 points first, with increasing difficulty as the game progresses.

Implementation. The exoskeleton utilizes the same AI algorithm as in "Proxy Pong". The handheld game controller includes: 1) an MPU 6050 JY60 IMU module, which captures angular velocity and orientation data for movement sensing; 2) two 3.7V Polymer Lithium batteries to power the controller; 3) an HC05 Bluetooth module for wireless transmission of movement data to the PC as game input.

3.2.3 Game 3: SyncedWings. SyncedWings is an adaptation of the game "Flappy Bird" (Figure 3). Players flap their arms to control the bird character's flight, with each arm corresponding to one of the bird's wings. In this setting, the exoskeleton is attached to the player's non-dominant arm and their dominant arm is free to move.

Gameplay. Players control the virtual bird to fly through onscreen obstacles, specifically pipes. Successfully navigating through a pair of pipes earns a point. A round ends if the player hits a pipe or scores 10 points. In this game, one bird's wing is controlled by the exoskeleton, and the other bird's wing by the other player's arm. For smooth gameplay, both wings need to move together. Any mismatch in this synchronized movement can lead to the bird losing balance and falling.

Implementation. The game resolution is 380 x 500 pixels. The gap between pipes is 180 pixels. To govern the exoskeleton's actions, we implemented a state-based control logic. In the "safe condition," the exoskeleton operates in a mirroring mode, passively mapping the pitch of the player's free arm (captured via controller IMU) to the exoskeleton to maintain flight symmetry. In contrast, a "non-safe state" is triggered only when two conditions are met simultaneously: the horizontal distance to the nearest pipe is critical

(a)

(b)

Figure 2: (a) In Proxy Pong, the player wears an exoskeleton on one arm. If a ball approaches the digital paddle of the human player side, the AI-powered exoskeleton actuates the player's body to strike the ball. (b) In DualForce Pong, the AI-powered exoskeleton controls one digital paddle and the player swings their arm with the controller to manipulate another paddle.

Figure 3: In SyncedWings, a player wears an exoskeleton on one arm and a controller on the other. If the AI predicts successful pipe avoidance, the exoskeleton mirrors the player's actions, maintaining symmetry. Should a collision seem likely, it alters its movement to prevent it, requiring players to adapt their gestures accordingly.

($d_x < 200$ pixels) AND the bird's vertical position indicates a collision (i.e., the bird's top coordinate is lower than the gap's bottom edge, or its bottom coordinate is higher than the gap's top edge). When this specific hazard state is detected, the bird turns red, and the algorithm overrides the mirroring signal to navigate obstacles. Specifically, if the bird risks hitting the bottom pipe (low-altitude collision), the system triggers a pre-defined actuation sequence that rotates the elbow to 60° flexion to execute a "flap" and gain altitude. Conversely, if the bird risks hitting the upper pipe, the system halts movement to prevent accidental climbing. Once the bird clears the obstacle or returns to a safe trajectory, the system releases control and reverts to mirroring mode.

3.3 Design Considerations

3.3.1 Selection of Interactive Devices. We chose to use exoskeleton in this work due to the following reasons. First, the exoskeleton provides a direct and tangible interface between the player and the AI, effectively bridging the gap between digital AI decision-making and physical player actions. Unlike standard force-feedback technologies such as haptic systems [76], which typically provide only skin surface-level feedback, an exoskeleton enables a more profound influence on player movement. This could allow players to feel as if the AI is genuinely part of their physical interactions.

Second, exoskeletons afford precision and control. While Electrical Muscle Stimulation (EMS) triggers muscle movements without precise control [58], exoskeletons can accurately and effectively translate AI decisions into more complex and precise movements. This is particularly beneficial for our research, as it allows for a more nuanced and exact execution of AI decisions in physical form.

3.3.2 Selection of Interaction Modes. We grounded our three interaction modes—proxy, competition, and collaboration—in prior work on intelligent agents in digital play as we summarized in section 2.3. These modes represent distinct relational dynamics: acting on the user's behalf [61], acting in opposition [22], and acting cooperatively [86]. By translating these roles into bodily interaction, we aimed to surface how different relational framings shape users' interpretations of control, intention, and agency.

3.3.3 The Design of Simple Game Mechanics. We adopted simple game mechanics to isolate the core experiential dynamics of bodily co-performance—specifically, what it feels like when a bodily-integrated system initiates movement based on its own internal logic. Our offer minimal cognitive and physical overhead while enabling clear, repeatable interactions. This simplicity allows users to focus their attention on the relationship between system behavior and bodily response, rather than on mastering complex gameplay rules.

We acknowledge that such simplification may raise concerns about ecological validity or generalizability to real-world interactions. However, we believe that, as a starting point, controlled, well-defined mechanics create an ideal environment to investigate how participants interpret system-driven actions—whether as cooperative, competitive, or autonomous behavior. Second, this level of simplicity aligns with the current limitations of embodied intelligent systems. While current intelligent systems can excel in closed, rule-based environments, their ability to reason and adapt in dynamic, open-ended real-world contexts remains limited [55]. Our game environments match the level of predictability required for consistent interaction—while still offering rich space for interpretation, adaptation, and meaning-making. To study more complex scenarios, future work may require Wizard-of-Oz-style simulations [10]. While such approaches offer valuable insights, they fall outside the scope of this work. Instead, we focus on the experiential qualities of sharing movement decisions: how co-performed motion is perceived and experienced.

3.3.4 Adaptation of Existing Games. In this work, we chose to adapt established games, i.e., Pong and Flappy Bird rather than create new games. This decision is supported by the findings of Yang et al. [84], which suggest that integrating familiar game mechanics can enhance user engagement and facilitate smoother adaptation to new technologies. In addition, our interest lies not in game innovation, but in investigating how bodily co-performance is perceived and experienced under different system roles. Using familiar games minimizes learning curves and isolates the effects of shared motor control.

Importantly, our choice to use two different games was intentional—not incidental. Each was selected to support a distinct mode of human-system interaction. Pong's one-dimensional, adversarial format is well suited for exploring proxy and competitive scenarios, where agency is clearly distributed or contested. In contrast, Flappy Bird's bilateral, rhythm-based control makes it ideal for testing coordination and synchrony in a collaborative setting. Attempting to force all three modes into a single game (e.g., only using Pong) would have required extensive rule modifications and compromised the ecological clarity of each interaction mode.

We acknowledge that using different games may introduce variations in game structure or difficulty. However, our focus is not on performance comparison across modes, but on how different relational framings of bodily control—proxy, competition, collaboration—are perceived and experienced. The differences between games are aligned with the qualitative nature of our inquiry: they afford distinct relational metaphors that foreground how users make sense of shared movement and co-performance.

4 Methods

To investigate how bodily-integrated systems that initiate movement based on their own logic are experienced by users, we conducted an exploratory qualitative study using three playful interaction scenarios. Our aim was to understand how users perceive, experience, and make sense of system-initiated physical actions during such shared bodily control.

This study is situated within a Research-through-Design (RtD) tradition [87] in HCI, which investigates interaction by creating and reflecting on designed artifacts rather than evaluating system performance. We treat the system's behavior as structured, context-sensitive responses—not expressions of cognitive autonomy—and explore how such behavior is interpreted in embodied interaction. The three scenarios were designed as experiential probes, deliberately framed as proxy, competition, and collaboration, to surface differences in agency, control, and coordination. In the following sections, we detail our participant recruitment, study procedure, and analysis methods.

4.1 Participants

Sixteen participants (12 males, 4 females; none identified as non-binary or self-described), aged between 21 and 30 (M ± SD: 23.6 ± 2.18 years), were involved. None of the participants had prior experience using devices that limit user control.

For participant recruitment, we used a combination of convenience and snowball sampling methods. The initial call was shared through the personal social media channels of our research team, and participants were encouraged to share the study information within their own networks. The inclusion criteria required participants to be over 18 years old, not undergoing any medical treatment, and to possess sufficient vision and basic motor abilities to control the game paddle. The study received ethics approval from the local review board. Participation was voluntary, and no compensation was provided.

4.2 Study Procedure

Upon arrival at the lab, participants received an interactive orientation session to understand the system and study. Participants were then fitted with the exoskeleton to ensure optimal function and comfort. Next, participants played three games in random order. For each game, the following steps were followed:

- Introduction: Participants were familiarized with the gameplay through an unrestricted session using the game controller. The introduction session lasted approximately 10 minutes.
- Play: For each game, participants played five rounds with the exoskeleton. The total session lasted approximately 30 minutes. The play session was conducted in a room approximately $15m^2$ in size. Participants played the games on a 24-inch screen positioned at eye level, ensuring a comfortable viewing experience. The screen was placed approximately 1.2 meters away, and participants were allowed to adjust their seating position to optimize comfort and visibility.

After all gameplay sessions, we conducted semi-structured interviews to gain insights into the participants' overall experiences. Each interview lasts about 40 minutes.

4.3 Interview and Data Analysis

Interviews were semi-structured and designed to explore five experiential domains: (1) overall game and bodily experience; (2) perceived agency, (3) sense of bodily ownership, (4) perceptions of system autonomy, and (5) emotional or ethical reactions to shared movement. Prompts included general questions like "How was it?" and more targeted questions like "Did you feel in control of your body?" or "Did it feel like the system was making decisions?" Interviewers adapted follow-up questions based on participants' responses. All interviews were audio-recorded.

Inductive thematic analysis was used to analyze the data [4, 65]. Two researchers first familiarized themselves with the data by reading it three times. They then independently began the initial coding process. To assess consistency, we compared the two coding sets across the full set of transcripts and reached 82% agreement on code boundaries and interpretations. For the remaining disagreements, the researchers held a structured resolution meeting: they reviewed each conflicting excerpt together, explained their interpretations, and discussed why certain segments should or should not belong to individual codes. Remaining discrepancies were resolved through a structured discussion process in which coders reviewed each conflicting excerpt together, clarified code definitions, examined surrounding transcript context, and iteratively refined labels until full consensus was reached. The refined codebook was then applied across all transcripts.

Afterwards, the two researchers collaboratively reviewed the codes to develop broader themes that captured the essence of participants' experiences. This involved an iterative, three-step grouping process. First, conceptually related codes were grouped together; next, each cluster was examined to identify the broader experiential idea it represented; finally, theme boundaries were refined by repeatedly checking clusters against raw excerpts to ensure internal coherence and distinction from other clusters. Through iterative clustering and comparison with raw excerpts, the initial set of 11 codes was consolidated into four themes. During the process, the authors met regularly to refine theme boundaries, merge overlapping concepts, and confirm that each theme captured a coherent experiential pattern. Any discrepancies or uncertainties were resolved through collective discussion and returning to the transcripts. Ultimately, the codes were consolidated into 11 refined labels, organized under four main themes. The final themes were reviewed against the original transcripts to ensure consistency and relevance.

4.4 Researcher Positionality

None of the researchers was involved in designing or manufacturing the commercial exoskeleton hardware used in this study. The research team includes scholars mainly from (1) human–computer interaction and (2) artificial intelligence, and the initial motivation for this work came from a researcher with prior experience in bodily interaction and human–machine intertwinement. These backgrounds and theoretical commitments shaped how we framed the study and sensitized us to experiential constructs such as agency, ownership, asymmetry, and system autonomy. At the same time, these commitments may also have predisposed us to attend to certain experiential patterns more readily than others.

To manage potential bias, we first articulated where our positionality might introduce it—particularly in how our prior experience shaped the way we framed the scenarios and what experiential qualities we expected to observe subconsciously. Making these assumptions explicit allowed us to refer back to them during analysis and question when they were subtly guiding our interpretations. During coding, we repeatedly checked our interpretations against raw interview excerpts and kept participants' own wording visible throughout the analysis process. This helped prevent us from smoothing over moments that did not fit our expectations, and ensured that the themes remained grounded in participants' descriptions rather than our conceptual vocabulary. We also deliberately attended to critical or disconfirming accounts such as frustration, discomfort, or resistance to counteract the tendency to focus on experiences aligned with our design intentions. Finally, once an initial analytic structure was drafted, all authors reviewed the themes and the written account. Their differing disciplinary backgrounds offered alternative readings that helped surface blind spots, identify overextensions, and clarify ambiguous reasoning. This cross-background review served as a check against confirmatory bias and reinforced that our interpretations were situated within the interplay of our backgrounds, design involvement, and methodological commitments.

5 Results

Overall, participants described their experience as novel and futuristic. P10 said: "*This was completely new. Unlike the usual mouse and keyboard interactions, the sensation of being under some control and feeling manipulated was unique.*" P14 added: "*It was like having dual consciousnesses - one being me, and the other the machine, blending seamlessly. It feels like the future.*" We detail our qualitative findings below, using Fx for Finding x and Px for Participant x.

5.1 Theme 1. Bodily Experiences with System Co-performing Movements

This theme explores how participants experienced their bodies when movement was partially initiated by the system across different interaction scenarios.

5.1.1 *F1. Players Experienced Agency Loss as Frustrating, Playful, and Reflective.*

All participants reported varying degrees of agency loss across the three interaction modes, with DualForce Pong consistently evoking the strongest sense of opposition. Participants reported that this agency loss might come from the cognitive dissonance when their intentions conflicted with system-initiated movement. P8 explained: "*DualForce Pong had a strong sense of opposition, unlike the other modes. In Proxy Pong, it felt like the system was leading me, and SyncedWings emphasized cooperation.*" Similarly, P4 expressed: "*I prefer working with the machine rather than competing against it. If I lost in competition, it was like my left hand was working against me, which was frustrating.*"

While most participants (10/16) preferred collaboration over competition, some found value in the competitive tension. P16 said: "*Competitive play was more playful. It was not just about confronting a digital opponent but also my own body. This was super intriguing.*" The participant added: "*While collaboration tends to be intuitive, competition adds a layer of complexity, making it more intriguing and stoking one's competitive spirit.*"

Interestingly, some described this loss of agency as prompting greater bodily reflection. P15 said: "*When the machine was in control, I felt a natural inclination to resist its actions.*" P3 described it as *a deeper dive into understanding my body, revealing unconscious responses.*" P11 compared it to computer systems: *Just like protocols run in the background of a computer, our bodily control is usually invisible—until it's disrupted.*" Some even saw potential future applications, with P14 noting: "*I think it was exciting. Envision a device handling specific tasks, allowing me to relax. The idea is interesting.*"

5.1.2 *F2. Players Experienced Bodily Ownership as Fluid and Contextual.*

Participants' sense of ownership over the system-controlled limb varied by scenario and evolved over time. Interestingly, Proxy

Pong most strongly preserved the sense of bodily ownership according to our data. P8 noted: "*Proxy Pong felt like the system was deeply connected to me, guiding my actions. It still felt like part of me. But with DualForce Pong and Synced Wings, the machine felt more like an external partner, rather than part of me.*"

In addition, participants' ownership experience evolved over time. Initially, participants reported heightened awareness of their system-controlled limb. P15 observed: "*Once my hand was under external control, I became more aware of it.*" P3 added: "*This control over my hand heightened my overall body awareness.*" As the game continued, participants began perceiving their system-controlled limb as autonomous and separating from their body. In Proxy Pong, P5 described: "*I just felt being led by an advanced player to play [. . .] The pull of the machine was strong, making me feel detached from my own hand.*" Similar experiences emerged in other modes, with P2 noting in DualForce Pong: "*My left hand did not quite feel like mine anymore.*" P7 shared: "*The game felt like confronting a digital opponent, not my own hand.*" In SyncedWings, P1 reflected: "*As I became immersed, my left hand began to feel more like a machine or a game tool.*"

Despite this perceived autonomy, some participants maintained an overall sense of bodily ownership. P11 expressed: "*Despite the machine's influence, the body remained mine. I thought I could be in control.*" Notably, participants often referred to their system-controlled limb as "it" or "the computer", but still described the overall interaction as involving "my body".

5.1.3 F3. Players Recentered Control by Focusing on the Free Limb.

Our interview revealed that participants adapted to the partial loss of agency and ownership by focusing on the part of their body they could still fully control. This adaptation helped restore a sense of coordination and agency. P4 noted: "*When my left hand was being controlled, I felt a stronger connection to my right hand, as it was free in contrast to the machine-driven left hand.*" P7 remarked: "*I learned to ignore feedback from the left hand, which sharpened my focus and strategic thinking with the right hand.*"

This focused control evolved into a symbiotic relationship with the system. P5 said: "*As I became immersed, I was so focused on my right hand and barely noticed my left. I was automatically adjusting my left without thinking, syncing with the machine.*" Participants found this symbiosis beneficial for task performance. P5 stated: "*This partnership granted me greater freedom, letting me focus on the game.*" P15 added: "*Managing two paddles simultaneously could be tiring, but with the exoskeleton's help, it was easier.*" P16 compared it to multitasking: "*It was like using both hands to do different tasks. With the machine's help, I can focus on one, like the machine drawing the circle while I draw the square.*" These experiences suggest that users not only adapted to asymmetric control but sometimes embraced it—treating the system-driven limb as a collaborator that freed up cognitive or physical resources.

5.1.4 F4. Shared Control Affected Overall Motor Coordination.

Participants reported that bodily coordination could be disrupted by system-driven movement. In DualForce Pong, some found that machine-driven movements of one hand disrupted their control of the other hand, creating a sense of imbalance. P3 noted: "*The actions of my left hand seemed to distract my right hand's coordination.*" P13 described feeling unsettled by the exoskeleton's dominance over his left hand, suggesting that "*Full control over both hands would provide a more harmonious experience.*" Interestingly, no such issues were reported with SyncedWings, possibly due to the symmetry between machine-driven and self-controlled movements.

5.2 Theme 2. Experiencing the System as a Bodily-integrated Partner

This theme explores how participants came to experience the system not as an external device, but as a bodily-integrated partner—with shifting roles, affective connections, and shared responsibility in movement.

5.2.1 F5. Participants Experienced the System as an Embodied Presence.

All participants noted that the shared bodily control felt fundamentally different from conventional human–computer interaction. The system was not operated at a distance; rather, its behavior was physically expressed through their own limbs, which blurred the boundaries between interface and bodily self. P5 said: "*We usually interact via mouse and keyboard. But here, our body became the interface, which was novel and exciting.*" This mode of engagement created a sense of intimacy and heightened awareness. P12 noted: "*While standard intelligent systems might offer suggestions without influencing your physical actions, this game draws you in. You become more engaged. This level of involvement is absent with regular AI.*"

This embodiment enabled intimate communication. P1 said: "*The communication was through the body [. . .] I could physically sense the technology's intentions and thoughts.*" The physical presence transformed the system from an external tool to an integrated partner. P7 said: "*Usually I see an intelligent agent as an independent entity. But with this, I felt the boundary between my body and AI was blurred.*" P10 shared: "*It felt like having another mind in my body. I was sharing the same body with that intelligent mind.*"

5.2.2 F6. The System Was Perceived as a Partner with Varying Roles.

Participants consistently described the system as an embodied co-player, with different roles emerging across game modes. In Proxy Pong, the system was seen as a mentor or skilled guide. P10 said: "*It felt like a professional player far better than me, it was guiding me to win the game.*" This guidance facilitated learning, as P2 described: "*During my learning session, I often missed the ball. However, in proxy mode, I noticed that it continuously predicts the ball's landing spot and adjusts the position accordingly. I later improved my performance by adopting this strategy.*" The system's assistance also reduced cognitive load. P9 said: "*I just followed its lead, so I did not have to think too much about positioning. I found observing and experiencing was also enjoyable.*"

In DualForce Pong, the system was reframed as a playful opponent, and players described internal conflict as part of the challenge. P12 shared: "*I was focused on refining my right hand's skill, treating my left as an independent player within the game.*" In Synced Wings, the system was perceived as a teammate. P3 remarked: "*It was like having a teammate.*" P6 added: "*We had to work together to succeed—it was not just me versus the machine..*" Across modes, participants valued the system's motor decision-making capabilities and expressed interest in deeper interaction. P1 expressed: "*If the machine were more like a human and could communicate with me, our bond would deepen even further.*"

5.2.3 F7. Participants Willingly Ceded Control for Performance and Experience. Despite unfamiliarity with bodily-driven systems, many participants expressed willingness to share or surrender control, particularly when doing so yielded pragmatic or experiential benefits. Some saw the system's movement as strategically helpful. P11 said: "*If the machine's control can lead to better game scores, then I am on board.*" P12 also shared: "*Usually with traditional games, I thought a lot about my moves. But with this, I found myself less preoccupied with its decisions, choosing instead to trust and let it steer me through the gameplay.*" Some envisioned broader applications, with P1 noting: "*Humans have limitations in decision-making, but machines can offer superior choices, expanding our capabilities.*"

Others emphasized the experiential value of being moved. P8 reflected: "*If the gameplay feels right, being controlled becomes less important. It is akin to a thrilling 4D ride in theme parks.*" P5 observed: *This partnership granted me greater freedom, letting me focus on the game.*" Some participants even imagined future partnerships, with the system acting as a helpful bodily assistant. P4 envisioned: "*The exoskeleton would evolve based on my inputs, creating moves tailored to me.*" P1 added: "*In the future, I see this device as an ever-ready companion, tackling mundane tasks for us.*"

5.3 Theme 3. Ethical Reflections

This theme explores how participants interpreted the ethical implications of sharing motor control with semi-autonomous systems when those behaviors are enacted through their own bodies.

5.3.1 F8. Participants Reflected on Autonomy, Safety, and Transparency. While participants generally appreciated the system's role in gameplay, many raised concerns about autonomy, safety, and long-term implications. Different relational framings—proxy, competition, and cooperation—between body and machine elicited different ethical reflections. When the exoskeleton acted as a proxy for users' own motor decisions (e.g., in Proxy Pong), participants became particularly sensitive to threats to autonomy and physical safety. The substitution of their intended movement prompted worries about unintended consequences. P2 said: "*Allowing machines to make decisions with tangible consequences poses risks. Mistakes might lead to injuries*". Participants also questioned the system's reliability. P16 mentioned: "*There is always a concern that the computer might stumble.*" Some reflected on potential long-term bodily effects. P11 said: "*Using the exoskeleton extensively could potentially weaken my body coordination*".

When the system behaved more like a partner requiring mutual coordination (e.g., SyncedWings), concerns centered more on misalignment of intentions within shared action. Participants pointed to moments when system decisions contradicted their timing or expectations. P3 stated: "*When the system's decisions deviate from how we typically think and act, the collaborative experience can become disconcerting.*" P5 added: "*I imagined it would support me, not override me. If should not overpower my intention.*"

Across framings, the most recurrent concern was transparency. Participants wanted to understand why the system acted as it did, especially when it intervened directly through their bodies. P1 said: "*I do not mind sharing control, but I must understand the computer's intentions.*" P5 articulated: "*I like the idea of a computer sharing certain control, while humans should retain ultimate authority.*" P3 concluded: "*It is essential to maintain a sense of bodily control. Feeling too detached or controlled can lead to discomfort or even perceived threats.*"

Building on their embodied experience, several participants extended these reflections to imagined societal implications. P14 explained: "*If this technology remains niche, ethical challenges might be minimal [...] But if it becomes mainstream, we are looking at numerous challenges. It is akin to introducing a new societal role; the impact on our community needs thorough examination.*"

5.3.2 F9. Participants Called for Clear Accountability and Design Standards. Based on their embodied experience with the system, participants raised questions about responsibility and technology governance, especially when shared control could lead to unintended outcomes. Several participants noted that when the exoskeleton made a successful move—such as scoring in Proxy Pong or helping the bird pass a pipe in SyncedWings—they were unsure whether to attribute the achievement to themselves or to the system. As P4 explained: "If it wins the point for me, is that my skill or the computer's?" Conversely, when the system caused a miss or mistake, some participants felt uneasy about being held responsible for an action they did not initiate. P10 reflected: "If I lose because of its movement, that does not feel like my failure." These moments highlighted that even in a low-stakes game setting, unclear authorship produced meaningful accountability concerns.

Building on these gameplay experiences, many participants extrapolated to scenarios where system-initiated actions might have physical consequences. P7 questioned: "*If the tech controls my arm, leading to a dangerous action, could it be considered self-harm?*" P10 shared: "*The challenges are similar to those with self-driving cars. When faced with undesirable outcomes, where does accountability lie?*"

These concerns led participants to call for explicit behavioral rules and clear boundaries for when and how bodily actuation should occur. P12 said: "*We need universally accepted standards.*" P1 argued: "*It is crucial to establish clear guidelines to direct the machine's behavior.*" Across responses, participants emphasized the need for transparent communication. P7 said: "*Manufacturers have the responsibility to provide clear, explainable information about how the technology works.*"

5.4 Theme 4. Limitations and Future Potential

This theme addresses both the practical challenges participants encountered and the broader possibilities they envisioned for bodily-integrated systems.

5.4.1 F10. Participants Encountered Physical and Usability Limitations. Participants' reflections pointed to several limitations of the specific mechanics of our exoskeleton, i.e., its single-DoF actuation, servo-driven torque output, and the way force was transmitted through cuffs and straps. Many comments concerned comfort and physical load at the attachment points. Because the forearm cuff concentrated the motor's force onto a small area, some participants experienced local pressure or rubbing. P7 commented: "*Wearing the exoskeleton for extended periods becomes uncomfortable.*" P5 articulated: "*I often felt poked, and the mechanical noise was distracting.*"

Participants also reacted to the character of the servo-driven movement, which tended to be strong but not always smooth. P15 observed: "*The device was powerful, and transition in force was abrupt, leading to a somewhat unsettling sensation.*" P16 said: "*The system's capability to move my arm quickly is commendable. Still, in contexts like medical applications, a more gradual, less abrupt movement would be desirable.*" While these challenges did not prevent participants from completing the tasks, they highlighted practical considerations of bodily actuation—fit, pressure distribution, smoothness of torque delivery, and sensory intrusiveness. Addressing these aspects would be essential for extending such systems beyond short interactions into longer and more demanding applications.

5.4.2 F11. Participants Imagined Applications in Accessibility, Learning, and Daily Life. Despite the challenges, participants envisioned compelling future use cases for bodily-integrated systems based on their reflections on game experiences. Because the system could reliably support or take over a movement, several participants highlighted accessibility as a natural extension. P9 said: "*I could feel how the exoskeleton supported my arm, especially in proxy mode. So I think this can extend beyond game, This technology could be useful in aiding individuals with physical limitations.*" Similarly, P2 noted: "*It shows potential to assist individuals with mobility limitations, possibly reducing the dependency on devices such as wheelchairs.*" Others imagined roles in motor learning and physical training. P2 reflected: "*As I mentioned, in Proxy Pong, I actually picked up strategies from the system and used them later myself. That made me think it could guide physical learning too, like teaching how to move or coordinate.*" Some extended these ideas to everyday contexts. P4 speculated: "*We might see this technology assisting in everyday scenarios, perhaps aiding in homework or streamlining regular tasks.*" In sum, participants did not view the system merely as a tool for functional support. Many described it as a potential bodily collaborator—one that could take on routine motor decisions, while still leaving users in control.

5.5 Positioning Constructs

In reporting participants' experiences, we use agency, ownership, and partnership in their technical senses as understood in embodiment and human–computer integration research. Our understanding of bodily agency follows the definition provided in bodily integration work [48], which conceptualizes agency as the extent to which users experience control over their bodies and the system that actuates them. This formulation was built on Braun et al.'s [3] characterization of agency as the experience of initiating and controlling an action. Similarly, our understanding of bodily ownership is drawn primarily from bodily integration research [48], which frames ownership as the extent to which system-driven movement is experienced as part of one's own body, grounded in Braun et al.'s description of ownership as the feeling of mineness toward bodily states [3]. For partnership, we adopt Farooq and Grudin's [14] framing within Human–Computer Integration, where partnership denotes a relational stance in which human and system act in coordination, each contributing capabilities within a shared activity, rather than fitting within a traditional "tool-use" model. We also want to position our findings as exploratory phenomenology. These constructs serve to situate participants' descriptions and guide interpretation, rather than functioning as variables for construct validation.

6 Discussion

In this section, we reflect on our craft knowledge and the study results, presenting design implications to guide the future design of bodily-distributed artificial intelligence in bodily games.

6.1 Designing the System's Bodily Role in Shared Control

Across the three games, a recurring pattern in interviews was how participants tried to make sense of what role the exoskeleton was playing in their body. Rather than focusing on control ratios or technical handover, they repeatedly described what the system felt like, and why it seemed to move them. Two aspects consistently shaped these interpretations: where in the body the system acted, and what it appeared to be trying to achieve.

First, where the system acts shapes how directly it is felt in one's own action. In *Proxy Pong*, where the exoskeleton moved the same arm participants would use to play, the movement was often experienced as an extension or even substitution of their own action. Small differences in timing or strength became immediately noticeable. In contrast, in *DualForce Pong* and *SyncedWings*, the exoskeleton acted on the opposite arm, separating system and user control. Participants described the experience as "body becoming the interface," with the system and the self each taking responsibility for different parts of the body to play. This difference suggests that the site of actuation determines the system's bodily role: an extension acting "as me", or a co-performer acting "alongside me".

Second, what the system aims to achieve shaped how that bodily role was interpreted. In both *SyncedWings* and *Proxy Pong*, the user and system ultimately pursued the same goal—guiding the bird safely through pipes or scoring points against a common opponent. In these cases, participants often described the system as a partner or helper, filling in for precision or absorbing effort. In contrast, in *DualForce Pong*, the system pursued a conflicting outcome. Even though it did not interfere physically with the arm the participant used to control their own paddle, this goal misalignment led participants to describe it as an opponent or even a troublemaker, disrupting their sense of control. Thus, goal alignment shapes the system's interactional role—in our study, this included being experienced as a collaborator or an opponent.

Taken together, these findings suggest that bodily-integrated systems shape experience not simply through how much control they exert, but through the combination of a bodily role ("who is acting within my body?") and an interactional role ("what is this actor trying to do?"). Designing where the system intervenes in the body and what objectives it appears to follow provides two lenses for shaping how system-initiated movement is interpreted, negotiated, and lived.

6.1.1 Applicability. We believe this implication can generalize beyond games and beyond exoskeleton-based actuation. At its core, it highlights the importance of intentionally designing where the system acts on the body and what goals it appears to pursue—two lenses that can be flexibly shaped according to context. This can inform experiential contexts: for instance, in body art, artists may deliberately actuate the same body part as the performer while assigning the system a contrasting goal, using “same part, different goal” interactions to evoke tension between human and machine.

In rehabilitation and accessibility, the "same part, same goal" framing may support shared agency by aligning system behavior with user intention. However, such systems must avoid overstepping into coercion, especially when applied to limbs with limited mobility or altered sensation. Clear goal alignment and adjustable actuation intensity are crucial for maintaining comfort and perceived control.

In physical training, asymmetrical or even oppositional setups (e.g., “different part, different goal”) might provoke bodily reflection or coordination challenges. Yet such designs require caution—they can enhance awareness, but may also disrupt balance or cause confusion without proper calibration.

These relational patterns are also relevant for other actuation modalities such as EMS. Although EMS produces more intrinsic and immediate muscle activation—which may intensify sensations of involuntariness—the same principles apply: the site of actuation and the perceived goal of the system strongly shape how users interpret system-initiated movement. However, EMS might introduce specific considerations: users cannot easily resist activation, contractions may feel sharper than mechanical motion, and misaligned goals may be experienced as more coercive. Designers working with EMS therefore need to treat bodily role and goal alignment not only as relational parameters, but also as physiological ones—carefully tuning intensity, timing, and reversibility to avoid discomfort and preserve a sense of voluntary authorship.

6.2 Leveraging Symmetry in Bodily Movements as a Design Resource

Our study reveals that bodily symmetry is not merely a biomechanical constraint—it meaningfully shapes how users experience shared motor control. When a system enacts movement through part of the body, the symmetry between human and system actions influences how control is framed, interpreted, and felt (F4, Theme 1).

In *DualForce Pong*, where the exoskeleton controlled one arm in opposition to the user's other arm, participants experienced asymmetrical movement as disorienting, disruptive to coordination, and diminishing their sense of agency (F1). In contrast, *SyncedWings* fostered bodily coordination through symmetric, goal-aligned actions, with several participants describing spontaneous mirroring and increased immersion (F6). These findings extend prior research in bodily play, which often emphasizes the value of full bodily control for engagement [63], as well as recent work suggesting that partial loss of control can support rich, affective experiences [7, 32, 50]. Unlike studies that frame symmetry primarily in terms of motor difficulty or task performance [45, 67], our work highlights its experiential significance: symmetry—or the lack thereof—affects how users interpret system behavior, and how integrated or conflicted that behavior feels within the body.

We propose that bodily symmetry can be used intentionally as a design lever in shared control systems. Designers may leverage symmetry to promote fluidity and cooperation, or intentionally break it to evoke tension, challenge, or playful resistance. The choice should align with the desired experiential outcome. For instance, symmetric co-performance (as in *SyncedWings*) can support feelings of alignment and flow, while asymmetric setups (as in *DualForce Pong*) can turn the body into a site of internal struggle, producing novel forms of embodied competition.

6.2.1 Applicability. This implication may extend beyond our game context to other bodily-integrated systems, though with important contextual boundaries.

In physical learning and training, symmetric human–system actuation may better support users in coordinating bilateral movements or practicing mirrored patterns, whereas asymmetric actuation may introduce additional cognitive load and make it harder for learners to map system behavior onto their own motor intentions.

In rehabilitation or assistive applications, strong asymmetry may risk user confusion or destabilization. Here, designers may need to constrain or clearly signal asymmetrical behaviors to preserve safety, trust, and embodied clarity.

Applicability across different actuation modalities such as EMS requires caution. EMS initiates movement through direct muscle activation rather than external mechanical force, which may lead to qualitatively different sensations of agency, involuntariness, and bodily alignment. Therefore, our findings might not be directly transferred without empirical validation. Instead, we see symmetry as a conceptual lens rather than a one-to-one guideline: future work would need to investigate whether, and how, symmetric or asymmetric muscle stimulation shapes users' interpretations of system-initiated movement.

6.3 Designing for Experiential Autonomy in Shared Motor Control

Our findings underscore the importance of maintaining a sense of human autonomy in shared motor control—particularly when system-initiated actions unfold through the user's body. Participants emphasized the need for transparency, user control, and alignment between system behavior and human intention (Theme 3, F8–F9). These concerns resonate with broader discussions about the ethics of automation and autonomy [77, 79], but also reveal unique experiential tensions introduced by bodily integration.

Prior research cautions that over-automation may reduce user trust and perceived control [83]. In bodily contexts, this effect can be even more pronounced. Participants in our study sometimes experienced system-controlled limbs as foreign or external (F2), a phenomenon well documented in research on motor augmentation and prosthetics [26]. Yet within our game-based scenarios, such alienation was not necessarily negative, but could sometimes be framed as playful, strategic, or even meaningful (F1). These findings align with prior work on “split-body” control [54], suggesting that users can adapt to partial control loss—especially when it is legible, purposeful, and embedded in a meaningful context.

We draw three design implications from these insights. First, **experiential framing matters**. Unlike technical systems evaluated solely on efficiency or accuracy, bodily-integrated systems should be evaluated through the lens of lived experience. The same motor substitution can feel empowering or threatening depending on how it is framed. For example, in *Proxy Pong*, participants accepted full motor substitution as they framed it as learning from an expert

(F6), but in rehabilitation contexts, the same behavior might feel coercive. In *DualForce Pong*, bodily opposition was acceptable as a playful challenge (F1) but could feel invasive in assistive scenarios. In *SyncedWings*, collaborative bodily coordination led participants to describe the system as a teammate; yet in high-stakes contexts where users may want full control, such coordination could become constraining. These suggest that when designing shared bodily control with machines, designers must account for not just what the system does, but how its behavior is interpreted through the body, emotion, and context.

Second, beyond experiential framing, **supportive system behavior fosters user adaptation**. Many participants willingly ceded control when the system's utility was perceptible (F3). This perception often relied on stable, legible cues that helped users anticipate and synchronize with the system's actions. In *Proxy Pong*, the intervention was accepted due to immediate performance and learning benefits. In *SyncedWings*, machine-initiated flapping created a rhythmic coordination that fostered flow and trust, thereby supporting participants' engagement. Even in *DualForce Pong* where the system acted in opposition, participants accepted its influence because the resistance was consistent and framed as a game mechanic that enhanced challenge and playfulness. These cases suggest that supportive behavior is not just about making tasks easier, but about making the machine's bodily influence predictable and coherent with user expectations. When this is achieved, users can build trust and adapt.

Third, **control boundaries should be flexible and determined by users**. We observed individual and situational variation in how much control users were willing to share, regardless of the specific mode of human–machine interaction. In *Proxy Pong*, some participants welcomed full motor substitution, while others felt disempowered to some extent. In *SyncedWings*, coordinated movement felt intuitive to some participants but was reported as frustrating when they preferred to lead the rhythm. In *DualForce Pong*, the competitive setup was engaging, yet some desired clearer boundaries to assert their own agency. These patterns suggest that shared control systems should support configurable boundaries—either explicitly (e.g., through user settings) or implicitly (e.g., by adapting to usage patterns)—to accommodate diverse and evolving user preferences.

Ultimately, designing for shared motor control requires shifting the question from "Who is in control?" to "How is control felt, shared, and made meaningful through the body?"

6.3.1 Applicability. These design implications can be extended beyond games, but require careful contextualization. In our game scenarios, participants tolerated—and even enjoyed—moments of uncertainty or surprise when the system moved their hand unexpectedly. This tolerance emerged because failure carried no real consequence and ambiguity could be reframed as a challenge or a discovery. However, when applied to functional settings such as rehabilitation, training, or accessibility, predictability and user trust become essential.

In rehabilitation, a system guiding a patient's arm through physical therapy exercises cannot rely on the same interpretive flexibility. Here, unpredictable system behavior may trigger anxiety or resistance, as users need precise feedback to gauge their recovery progress and maintain trust in the therapeutic process. The framing strategies we identified—clarifying system intention and making logic legible—become not just beneficial but essential when stakes increase.

In physical training, control negotiation could support progressive autonomy. A system might start with strong guidance and gradually shift responsibility to the user, allowing for individualized pacing and confidence building.

In assistive contexts, experiential autonomy may help users feel supported rather than overridden. Even minimal customization such as adjusting system responsiveness or movement style could foster a greater sense of agency and comfort. However, safety and reliability must remain the priority when designing for experiential autonomy.

These considerations also transfer across actuation modalities. Although EMS differs from exoskeletons in producing muscle-level rather than joint-level activation, the core experiential issues—interpreting system intention, perceiving movement support, and negotiating control boundaries—remain relevant. However, EMS may demand tighter tuning of stimulation parameters due to higher responsiveness and individual variability.

7 Limitations and Future Works

This study has several limitations, which also suggest directions for future research.

First, our participant pool was demographically homogeneous: young, mostly male, non-disabled, and largely university-affiliated. We acknowledge that experiences of bodily control may differ for older adults, women and non-binary participants, or people with disabilities. Likewise, all participants shared a similar cultural background, and norms around bodily autonomy or human–machine interaction may vary across cultures [81]. We therefore do not claim universal generalizability; rather, we present our findings as an initial step toward unpacking how people make sense of system-initiated movement. Future work should expand the demographic scope to examine how diverse bodies, motor capacities, and cultural framings shape these experiences.

Second, bodily control is shaped by physiological diversity. Individual differences in strength, flexibility, proprioceptive sensitivity, and motor coordination may all influence how system-driven movement is perceived. Our study did not systematically vary these dimensions. Future work should intentionally include a broader range of bodily capacities to examine how shared-control systems interact with, and are experienced by users with different physical capacities.

Third, our within-subjects design introduces potential order effects. Although we counterbalanced conditions, it is possible that participants' experiences in later games were influenced by strategies, expectations, or interpretations formed earlier. We did not observe consistent patterns tied to particular orderings, but we cannot rule out cross-condition contamination. Future studies could mitigate this by adopting between-subjects designs or longer washout periods.

Fourth, while the game-based context gave us the flexibility to explore diverse forms of shared motor control, it also limits the direct transferability of our findings to high-stakes contexts. We envision that the design insights may extend beyond games, but such transfer requires careful validation. In rehabilitation or industrial contexts, involuntary movement carries different meanings and consequences, and thresholds for safety, predictability, and bodily autonomy are far stricter. Future work should therefore examine how these experiential patterns hold up in settings where bodily control is consequential rather than playful.

Fifth, the study examined only short-term interactions. Longitudinal research is needed to understand how users adapt to shared motor control over time, including how perceptions of agency, ownership, and trust evolve with extended use.

Sixth, we focused on a single bodily-integrated technology—an arm-worn exoskeleton—applied to a limited body area. Future work should investigate different actuation modalities (e.g., EMS, vibrotactile, wearable robotics) and body locations to uncover a broader range of embodied experiences.

Seventh, while we gathered rich qualitative data on ethical perceptions, our analysis remained exploratory. Further work could more systematically interpret user concerns through established ethical frameworks (e.g., autonomy, responsibility, transparency).

Lastly, our system does not constitute a novel technical contribution. It combines existing technologies in a novel way to enable experiential inquiry. Rather than optimizing computing performance or control precision, our goal was to explore how partially autonomous motor behavior—when embedded into physical interaction—can reshape how users interpret and feel bodily control.

Together, these limitations reflect our positioning of this work not as a technical benchmark, but as an experiential and conceptual contribution—intended to enrich how we design and think about shared bodily control in future human-machine systems.

8 Conclusion

This paper explored how bodily-integrated systems that initiate movement based on their own logic can shape user experiences. Through three playful scenarios—proxy, competition, and cooperation—we investigated how users experience the movement that is partially initiated by a system through their own bodies.

Our findings show that shared motor control is not merely a technical interface, but an embodied form of co-performance. Participants did not passively receive control, but actively lived with it—sometimes resisting, sometimes aligning, and often reinterpreting system actions as part of their bodily experience. We identified four key themes, highlighting how bodily agency and ownership fluctuate across different relational framings; how systems are experienced as embodied partners with shifting roles; how these experiences prompt ethical reflection; and challenges and future possibilities for bodily-integrated systems.

Rather than advancing technical intelligence, our work foregrounds how motor behavior can be framed, experienced, and designed as a relational phenomenon. We contribute a set of design implications for developing bodily-integrated technologies that share control over the human body using their own intelligence in a flexible, playful, and user-centered manner. We hope this work expands how HCI, game design, and embodied interaction research conceptualize shared control—not as a handover of authority, but as a dynamic, situated process of moving and meaning-making together.

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References

[1] Steve Benford, Richard Ramchurn, Joe Marshall, Max L. Wilson, Matthew Pike, Sarah Martindale, Adrian Hazzard, Chris Greenhalgh, Maria Kallionpää, Paul Tennent, and Brendan Walker. 2021. Contesting Control: Journeys through Surrender, Self-awareness and Looseness of Control in Embodied Interaction. *Human–Computer Interaction* 36, 5-6 (2021), 361–389.

[2] Matthew Botvinick and Jonathan Cohen. 1998. Rubber hands 'feel' touch that eyes see. *Nature* 391, 756 (1998).

[3] Niclas Braun, Stefan Debener, Nadine Spychala, Edith Bongartz, Peter Sörös, Helge HO Müller, and Alexandra Philipsen. 2018. The senses of agency and ownership: a review. *Frontiers in psychology* 9 (2018), 535.

[4] Virginia Braun and Victoria Clarke. 2012. *Thematic Analysis.* American Psychological Association.

[5] Oğuz 'Oz' Buruk, Louise Petersen Matjeka, and Florian Mueller. 2023. Towards Designing Playful Bodily Extensions: Learning from Expert Interviews. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23).* Association for Computing Machinery, New York, NY, USA, Article 233, 20 pages.

[6] Richard Byrne, Joe Marshall, and Florian Mueller. 2016. Balance Ninja: Towards the Design of Digital Vertigo Games via Galvanic Vestibular Stimulation. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16).* Association for Computing Machinery, New York, NY, USA, 159–170.

[7] Richard Byrne, Joe Marshall, and Florian Mueller. 2020. Designing Digital Vertigo Experiences. *ACM Transactions on Computer-Human Interaction* 27, 3, Article 19 (May 2020), 30 pages.

[8] Gabriele Cimolino, Sussan Askari, and T.C. Nicholas Graham. 2021. The Role of Partial Automation in Increasing the Accessibility of Digital Games. *Proc. ACM Hum.-Comput. Interact.* 5, CHI PLAY, Article 266 (Oct. 2021), 30 pages.

[9] Mihaly Csikszentmihalyi and Stith Bennett. 1971. An exploratory model of play. *American anthropologist* 73, 1 (1971), 45–58.

[10] Nils Dahlbäck, Arne Jönsson, and Lars Ahrenberg. 1993. Wizard of Oz studies: why and how. In *Proceedings of the 1st international conference on Intelligent user interfaces.* Association for Computing Machinery, New York, NY, USA, 93–200.

[11] Valdemar Danry, Pat Pataranutaporn, Adam Haar Horowitz, Paul Strohmeier, Josh Andres, Rakesh Patibanda, Zhuying Li, Takuto Nakamura, Jun Nishida, Pedro Lopes, Felipe León, Andrea Stevenson Won, Dag Svanæs, Florian Mueller, Pattie Maes, Sang-won Leigh, and Nathan Semertzidis. 2021. Do Cyborgs Dream of Electric Limbs? Experiential Factors in Human-Computer Integration Design and Evaluation. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems (CHI EA '21).* Association for Computing Machinery, New York, NY, USA, Article 123, 6 pages.

[12] Douglas Engelbart. 1962. Augmenting human intellect: A conceptual framework. Summary report. *Stanford Research Institute, on Contract AF* 49, 638 (1962), 1024.

[13] Roger M Enoka. 2008. *Neuromechanics of human movement.* Human kinetics.

[14] Umer Farooq and Jonathan Grudin. 2016. Human-computer Integration. *interactions* 23, 6 (2016), 26–32.

[15] Christopher Frauenberger. 2019. Entanglement HCI The Next Wave? *ACM Trans. Comput.-Hum. Interact.* 27, 1, Article 2 (Nov. 2019), 27 pages.

[16] Rebecca Fribourg, Nami Ogawa, Ludovic Hoyet, Ferran Argelaguet, Takuji Narumi, Michitaka Hirose, and Anatole Lécuyer. 2020. Virtual co-embodiment: evaluation of the sense of agency while sharing the control of a virtual body among two individuals. *IEEE Transactions on Visualization and Computer Graphics* 27, 10 (2020), 4023–4038.

[17] Shaun Gallagher. 2002. Experimenting with introspection: Comment from Shaun Gallagher. *Trends in cognitive sciences* 6, 9 (2002), 374–375.

[18] Donna Haraway. 2013. A cyborg manifesto: Science, technology, and socialist-feminism in the late twentieth century. In *The transgender studies reader.* Routledge, 103–118.

[19] Christian Holz, Tovi Grossman, George Fitzmaurice, and Anne Agur. 2012. Implanted user interfaces. In *Proceedings of the SIGCHI conference on human factors in computing systems.* 503–512.

[20] Masahiko Inami, Daisuke Uriu, Zendai Kashino, Shigeo Yoshida, Hiroto Saito, Azumi Maekawa, and Michiteru Kitazaki. 2022. Cyborgs, Human Augmentation, Cybernetics, and JIZAI Body. In *Proceedings of the Augmented Humans International Conference 2022 (AHs '22).* Association for Computing Machinery, New York, NY, USA, 230–242.

[21] Abhinandan Jain, Adam Haar Horowitz, Felix Schoeller, Sang-won Leigh, Pattie Maes, and Misha Sra. 2020. Designing Interactions Beyond Conscious Control: A New Model for Wearable Interfaces. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 4, 3, Article 108 (Sept. 2020), 23 pages.

[22] Hyeon-Chang Jeon, In-Chang Baek, Cheong-mok Bae, Taehwa Park, Wonsang You, Taegwan Ha, Hoyoun Jung, Jinha Noh, Seungwon Oh, and Kyung-Joong Kim. 2024. RaidEnv: Exploring New Challenges in Automated Content Balancing for Boss Raid Games. *IEEE Transactions on Games* 16, 3 (2024), 645–658. https://doi.org/10.1109/TG.2023.3335399

[23] Shunichi Kasahara, Jun Nishida, and Pedro Lopes. 2019. Preemptive action: Accelerating human reaction using electrical muscle stimulation without compromising agency. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15.

[24] Shunichi Kasahara, Kazuma Takada, Jun Nishida, Kazuhisa Shibata, Shinsuke Shimojo, and Pedro Lopes. 2021. Preserving agency during electrical muscle stimulation training speeds up reaction time directly after removing EMS. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 194, 9 pages.

[25] Majeed Kazemitabaar, Runlong Ye, Xiaoning Wang, Austin Zachary Henley, Paul Denny, Michelle Craig, and Tovi Grossman. 2024. CodeAid: Evaluating a Classroom Deployment of an LLM-based Programming Assistant that Balances Student and Educator Needs. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 650, 20 pages.

[26] Paulina Kieliba, Danielle Clode, Roni O. Maimon-Mor, and Tamar R. Makin. 2021. Robotic hand augmentation drives changes in neural body representation. *Science Robotics* 6, 54 (2021), eabd7935.

[27] Daiki Kodama, Takato Mizuho, Yuji Hatada, Takuji Narumi, and Michitaka Hirose. 2023. Effects of collaborative training using virtual co-embodiment on motor skill learning. *IEEE Transactions on Visualization and Computer Graphics* 29, 5 (2023), 2304–2314.

[28] Andrey Krekhov, Sebastian Cmentowski, and Jens Krüger. 2019. The Illusion of Animal Body Ownership and Its Potential for Virtual Reality Games. In *2019 IEEE Conference on Games (CoG)*. 1–8. https://doi.org/10.1109/CIG.2019.8848005

[29] Sang-won Leigh, Harpreet Sareen, Hsin-Liu (Cindy) Kao, Xin Liu, and Pattie Maes. 2017. Body-Borne Computers as Extensions of Self. *Computers* 6, 1 (2017).

[30] Bigna Lenggenhager, Tej Tadi, Thomas Metzinger, and Olaf Blanke. 2007. Video Ergo Sum: Manipulating Bodily Self-Consciousness. *Science* 317, 5841 (2007), 1096–1099.

[31] Zhuying Li, Tianze Huang, Rakesh Patibanda, and Florian Mueller. 2023. AI in the Shell: Towards an Understanding of Integrated Embodiment. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 28, 7 pages.

[32] Zhuying Li, Rakesh Patibanda, Felix Brandmueller, Wei Wang, Kyle Berean, Stefan Greuter, and Florian Mueller. 2018. The Guts Game: Towards Designing Ingestible Games. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '18)*. Association for Computing Machinery, New York, NY, USA, 271–283.

[33] Zhuying Li, Yan Wang, Josh Andres, Nathan Semertzidis, Stefan Greuter, and Florian Mueller. 2023. A Design Framework for Ingestible Play. *ACM Trans. Comput.-Hum. Interact.* 30, 4, Article 58 (Sept. 2023), 39 pages. https://doi.org/10.1145/3589954

[34] Zhuying Li, Yan Wang, Jacob Sheahan, Beisi Jiang, Stefan Greuter, and Florian Mueller. 2020. InsideOut: Towards an Understanding of Designing Playful Experiences with Imaging Capsules. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference (DIS '20)*. Association for Computing Machinery, New York, NY, USA, 601–613.

[35] Zhuying Li, Yan Wang, Wei Wang, Weikang Chen, Ti Hoang, Stefan Greuter, and Florian Floyd Mueller. 2019. HeatCraft: Designing Playful Experiences with Ingestible Sensors via Localized Thermal Stimuli. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12.

[36] Joseph CR Licklider. 1960. Man-computer symbiosis. *IRE transactions on human factors in electronics* 1 (1960), 4–11.

[37] Hannah Limerick, David Coyle, and James W Moore. 2014. The experience of agency in human-computer interactions: a review. *Frontiers in human neuroscience* 8 (2014), 643.

[38] Yingtong Lu, Zhuying Li, and Ding Ding. 2024. Light Up Fireflies: Towards Understanding the Design of Interpersonal Bodily Intertwinement in Bodily Play. In *Companion Proceedings of the 2024 Annual Symposium on Computer-Human Interaction in Play* (Tampere, Finland) *(CHI PLAY Companion '24)*. Association for Computing Machinery, New York, NY, USA, 169–174. https://doi.org/10.1145/3665463.3678813

[39] Yingtong Lu, Zhuying Li, Yan Wang, and Ding Ding. 2025. Light Up Fireflies: Exploring the Design of Interpersonal Bodily Intertwinement in Social Body Games. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 461, 16 pages. https://doi.org/10.1145/3706598.3713403

[40] Saifuddin Mahmud, Xiangxu Lin, and Jong-Hoon Kim. 2020. Interface for human machine interaction for assistant devices: A review. In *2020 10th Annual computing and communication workshop and conference (CCWC)*. IEEE, 0768–0773.

[41] Elena Márquez Segura, Annika Waern, Jin Moen, and Carolina Johansson. 2013. The Design Space of Body Games: Technological, Physical, and Social Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, New York, NY, USA, 3365–3374.

[42] Franck Mars, Mathieu Deroo, and Jean-Michel Hoc. 2014. Analysis of human-machine cooperation when driving with different degrees of haptic shared control. *IEEE transactions on haptics* 7, 3 (2014), 324–333.

[43] Joe Marshall, Duncan Rowland, Stefan Rennick Egglestone, Steve Benford, Brendan Walker, and Derek McAuley. 2011. Breath Control of Amusement Rides. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 73–82.

[44] Mario Martín Muñoz. 2020. *Reinforcement learning applied as a game mechanic and design element in a custom boss for World of Warcraft.* Master's thesis. Universitat de Barcelona; Universitat Rovira i Virgili.

[45] Franz Mechsner, Dirk Kerzel, GuÈnther Knoblich, and Wolfgang Prinz. 2001. Perceptual Basis of Bimanual Coordination. *Nature* 414, 6859 (2001), 69–73.

[46] Volodymyr Mnih, Koray Kavukcuoglu, David Silver, Alex Graves, Ioannis Antonoglou, Daan Wierstra, and Martin A. Riedmiller. 2013. Playing Atari with Deep Reinforcement Learning. *CoRR* abs/1312.5602 (2013). arXiv:1312.5602 http://arxiv.org/abs/1312.5602

[47] Florian Mueller, Tuomas Kari, Zhuying Li, Yan Wang, Yash Dhanpal Mehta, Josh Andres, Jonathan Marquez, and Rakesh Patibanda. 2020. Towards Designing Bodily Integrated Play. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20)*. Association for Computing Machinery, New York, NY, USA, 207–218.

[48] Florian Mueller, Pedro Lopes, Josh Andres, Richard Byrne, Nathan Semertzidis, Zhuying Li, Jarrod Knibbe, and Stefan Greuter. 2021. Towards understanding the design of bodily integration. *International Journal of Human-Computer Studies* 152 (2021), 102643.

[49] Florian Mueller, Pedro Lopes, Paul Strohmeier, Wendy Ju, Caitlyn Seim, Martin Weigel, Suranga Nanayakkara, Marianna Obrist, Zhuying Li, Joseph Delfa, Jun Nishida, Elizabeth M. Gerber, Dag Svanaes, Jonathan Grudin, Stefan Greuter, Kai Kunze, Thomas Erickson, Steven Greenspan, Masahiko Inami, Joe Marshall, Harald Reiterer, Katrin Wolf, Jochen Meyer, Thecla Schiphorst, Dakuo Wang, and Pattie Maes. 2020. Next Steps for Human-Computer Integration. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–15.

[50] Florian Mueller, Rakesh Patibanda, Richard Byrne, Zhuying Li, Yan Wang, Josh Andres, Xiang Li, Jonathan Marquez, Stefan Greuter, Jonathan Duckworth, and Joe Marshall. 2021. Limited Control Over the Body as Intriguing Play Design Resource. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 435, 16 pages.

[51] Florian Mueller, Nathan Semertzidis, Josh Andres, Martin Weigel, Suranga Nanayakkara, Rakesh Patibanda, Zhuying Li, Paul Strohmeier, Jarrod Knibbe, Stefan Greuter, Marianna Obrist, Pattie Maes, Dakuo Wang, Katrin Wolf, Liz Gerber, Joe Marshall, Kai Kunze, Jonathan Grudin, Harald Reiterer, and Richard Byrne. 2022. Human–Computer Integration: Towards Integrating the Human Body with the Computational Machine. *Foundations and Trends® in Human-Computer Interaction* 16, 1 (2022), 1–64.

[52] Florian 'Floyd' Mueller, Nathan Semertzidis, Josh Andres, Joe Marshall, Steve Benford, Xiang Li, Louise Matjeka, and Yash Mehta. 2023. Toward Understanding the Design of Intertwined Human–Computer Integrations. *ACM Trans. Comput.-Hum. Interact.* 30, 5, Article 73 (sep 2023), 45 pages.

[53] Mobeen Nazar, Muhammad Mansoor Alam, Eiad Yafi, and Mazliham Mohd Su'ud. 2021. A systematic review of human–computer interaction and explainable artificial intelligence in healthcare with artificial intelligence techniques. *IEEE Access* 9 (2021), 153316–153348.

[54] Romain Nith, Yun Ho, and Pedro Lopes. 2024. SplitBody: Reducing Mental Workload while Multitasking via Muscle Stimulation. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 81, 11 pages.

[55] Jitendra Parmar, Satyendra Chouhan, Vaskar Raychoudhury, and Santosh Rathore. 2023. Open-world machine learning: Applications, challenges, and opportunities. *ACM Comput. Surv.* 55, 10, Article 205 (Feb. 2023), 37 pages.

[56] Rakesh Patibanda, Chris Hill, Zhuying Li, Stephan Lukosch, Elise van den Hoven, and Florian 'Floyd Mueller. 2025. Homoludic Augmentation: Preliminary Reflections. *ACM Games* 3, 4, Article 23 (Nov. 2025), 12 pages. https://doi.org/10.1145/3773766

[57] Rakesh Patibanda, Nathalie Overdevest, Aryan Saini, Zhuying Li, Josh Andres, Jarrod Knibbe, Elise van den Hoven, and Florian 'Floyd' Mueller. 2024. Exploring Shared Bodily Control: Designing Augmented Human Systems for Intra- and

Inter-Corporeality. In *Proceedings of the Augmented Humans International Conference 2024* (Melbourne, VIC, Australia) *(AHs '24)*. Association for Computing Machinery, New York, NY, USA, 318–323. https://doi.org/10.1145/3652920.3653037

[58] Rakesh Patibanda, Elise Van Den Hoven, and Florian Mueller. 2022. Towards Understanding the Design of Body-Actuated Play. In *Extended Abstracts of the 2022 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '22)*. Association for Computing Machinery, New York, NY, USA, 388–391.

[59] James Pero. 2019. The eerie 'forced exoskeleton rave' where dancers' bodies are controlled by robotic suits. https://www.dailymail.co.uk/sciencetech/article-7298781/The-eerie-forced-exoskeleton-rave-dancers-bodies-controlled-ROBOTIC-SUITS.html

[60] Games Press. 2024. Auto-play RPG! Gather epic gear, solve puzzles, and unleash your team's power! https://www.gamespress.com/Auto-play-RPG-Gather-epic-gear-solve-puzzles-and-unleash-your-te-nihee

[61] Gabriel Machado Pureza. 2024. Sony Patents 'Auto-Play' Game Mode. https://gamerant.com/sony-auto-play-game-mode-patent/

[62] Roope Raisamo, Ismo Rakkolainen, Päivi Majaranta, Katri Salminen, Jussi Rantala, and Ahmed Farooq. 2019. Human augmentation: Past, present and future. *International Journal of Human-Computer Studies* 131 (2019), 131–143.

[63] Yvonne Rogers and Henk Muller. 2006. A Framework for Designing Sensor-based Interactions to Promote Exploration and Reflection in Play. *International Journal of Human-Computer Studies* 64, 1 (2006), 1–14.

[64] Robert Rosenberger and Peter-Paul Verbeek. 2015. A field guide to postphenomenology. *Postphenomenological investigations: Essays on human-technology relations* (2015), 9–41.

[65] Gery W Ryan and H Russell Bernard. 2003. Techniques to identify themes. *Field methods* 15, 1 (2003), 85–109.

[66] MHD Yamen Saraiji, Tomoya Sasaki, Kai Kunze, Kouta Minamizawa, and Masahiko Inami. 2018. MetaArms: Body Remapping Using Feet-Controlled Artificial Arms. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. Association for Computing Machinery, New York, NY, USA, 65–74.

[67] Andras Semjen, Jeffrey J Summers, and Daniel Cattaert. 1995. Hand Coordination in Bimanual Circle Drawing. *Journal of Experimental Psychology: Human Perception and Performance* 21, 5 (1995), 1139.

[68] Mirna Paula Silva, Victor do Nascimento Silva, and Luiz Chaimowicz. 2015. Dynamic Difficulty Adjustment through an Adaptive AI. In *2015 14th Brazilian Symposium on Computer Games and Digital Entertainment (SBGames)*. 173–182.

[69] William Steptoe, Anthony Steed, and Mel Slater. 2013. Human Tails: Ownership and Control of Extended Humanoid Avatars. *IEEE Transactions on Visualization and Computer Graphics* 19, 4 (2013), 583–590. https://doi.org/10.1109/TVCG.2013.32

[70] Xin Sun, Jos A. Bosch, Jan De Wit, and Emiel Krahmer. 2023. Human-in-the-Loop Interaction for Continuously Improving Generative Model in Conversational Agent for Behavioral Intervention. In *Companion Proceedings of the 28th International Conference on Intelligent User Interfaces (IUI '23 Companion)*. Association for Computing Machinery, New York, NY, USA, 99–101.

[71] Dag Svanaes and Martin Solheim. 2016. Wag Your Tail and Flap Your Ears: The Kinesthetic User Experience of Extending Your Body. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 3778–3779.

[72] Penelope Sweetser and Peta Wyeth. 2005. GameFlow: A Model for Evaluating Player Enjoyment in Games. *Comput. Entertain.* 3, 3 (jul 2005), 3.

[73] Daisuke Tajima, Jun Nishida, Pedro Lopes, and Shunichi Kasahara. 2022. Whose Touch is This?: Understanding the Agency Trade-Off Between User-Driven Touch vs. Computer-Driven Touch. *ACM Transactions on Computer-Human Interaction* 29, 3, Article 24 (Jan 2022), 27 pages.

[74] Emi Tamaki, Takashi Miyaki, and Jun Rekimoto. 2010. PossessedHand: A Hand Gesture Manipulation System Using Electrical Stimuli. In *Proceedings of the 1st Augmented Human International Conference (AH '10)*. Association for Computing Machinery, New York, NY, USA, Article 2, 5 pages.

[75] V2. 2024. Ping Body. https://v2.nl/works/ping-body/

[76] Yon Visell. 2009. Tactile sensory substitution: Models for enaction in HCI. *Interacting with Computers* 21, 1-2 (2009), 38–53.

[77] Wendell Wallach and Colin Allen. 2008. *Moral Machines: Teaching Robots Right from Wrong.* Oxford University Press.

[78] Dakuo Wang, Elizabeth Churchill, Pattie Maes, Xiangmin Fan, Ben Shneiderman, Yuanchun Shi, and Qianying Wang. 2020. From Human-Human Collaboration to Human-AI Collaboration: Designing AI Systems That Can Work Together with People. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–6.

[79] Peter Werkhoven, Leon Kester, and Mark Neerincx. 2018. Telling Autonomous Systems What to Do. In *Proceedings of the 36th European Conference on Cognitive Ergonomics (ECCE '18)*. Association for Computing Machinery, New York, NY, USA, Article 2, 8 pages.

[80] Norbert Wiener. 2019. *Cybernetics or Control and Communication in the Animal and the Machine.* MIT press.

[81] Richard Wilhelm. 2013. *The secret of the golden flower: A Chinese book of life.* Routledge.

[82] Nathan J. Wispinski, Jason P. Gallivan, and Craig S. Chapman. 2020. Models, movements, and minds: bridging the gap between decision making and action. *Annals of the New York Academy of Sciences* 1464, 1 (2020), 30–51.

[83] Wei Xu. 2020. From Automation to Autonomy and Autonomous vehicles: Challenges and Opportunities for Human-computer Interaction. *Interactions* 28, 1 (2020), 48–53.

[84] Yeonsun Yang, Ahyeon Shin, Nayoung Kim, Huidam Woo, John Joon Young Chung, and Jean Y Song. 2024. Find the Bot!: Gamifying Facial Emotion Recognition for Both Human Training and Machine Learning Data Collection. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 364, 20 pages.

[85] Deheng Ye, Zhao Liu, Mingfei Sun, Bei Shi, Peilin Zhao, Hao Wu, Hongsheng Yu, Shaojie Yang, Xipeng Wu, Qingwei Guo, Qiaobo Chen, Yinyuting Yin, Hao Zhang, Tengfei Shi, Liang Wang, Qiang Fu, Wei Yang, and Lanxiao Huang. 2020. Mastering Complex Control in MOBA Games with Deep Reinforcement Learning. *Proceedings of the AAAI Conference on Artificial Intelligence* 34, 04 (Apr. 2020), 6672–6679.

[86] Guanglu Zhang, Leah Chong, Kenneth Kotovsky, and Jonathan Cagan. 2023. Trust in an AI versus a Human teammate: The effects of teammate identity and performance on Human-AI cooperation. *Computers in Human Behavior* 139 (2023), 107536.

[87] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704

A Interview Protocol

Interviews were semi-structured and organized around five experiential domains. Below we provide representative questions used across games (Proxy Pong, DualForce Pong, SyncedWings). Interviewers did not follow this list in a fixed sequence; instead, they adapted the order and phrasing based on participant responses to encourage reflection and elaboration.

A.0.1 Overall Game and Bodily Experience.

- How was it?
- Before playing, what did you expect the interaction to feel like? In what ways did the experience differ from or match those expectations?
- What moments felt most interesting or surprising to you? Why?
- How did your feelings change over the course of the interaction?
- How did the experience influence your general understanding of your body?

A.0.2 Perceived Agency.

- How did you experience your own sense of control during the interaction?
- Can you describe moments when your sense of control changed—either increasing or diminishing?
- Did you ever want to take control back from the system? What prompted that feeling?
- How did you make sense of who (you or the system) was initiating particular movements?
- When the system succeeded or failed in the task, how did you understand your own role in the outcome?

A.0.3 Sense of Bodily Ownership.

- How aware were you of the limb controlled by the system?

- Did the system-controlled movements feel like your own actions, or like movements performed by something external? Why?
- Did your sense of ownership differ between the limb you controlled and the limb moved by the system?
- Did the system's movement change how you perceived or coordinated your other arm?

A.0.4 *Perceptions of System Autonomy.*

- How did you interpret what the system was trying to do during the interaction? Did it feel like the system had its own way of deciding what to do?
- How predictable or understandable were the system's behaviors?
- At different moments, how did you perceive the system—as a collaborator, an opponent, a helper, or something else?
- How did the patterns of movement shape your sense of the system's autonomy?

A.0.5 *Emotional or Ethical Reactions to Shared Movement.*

- How did it feel emotionally when the system moved your body?
- Were there moments that felt particularly comfortable, uncomfortable, intrusive, or surprising? What made them feel that way?
- Did the experience raise any concerns about issues like autonomy, safety, or trust?
- How did the interaction shape your understanding of humans sharing control with machines?
- How, if at all, did the experience influence your understanding of intelligent or bodily-integrated systems?

A.1 Closing Questions

- Where else can you imagine this type of bodily interaction being used?
- Is there anything you would like to improve or change about the interaction?
- Is there anything else you would like to add?