ElderPlay: Supporting Age-Inclusive Gameplay for Older Adults via Real-Time Gesture-to-Controller Translation

Ching-Wen Hung
National Taiwan University
Taipei, Taiwan
ching-wenh@sigchi.org

Che-Wei Hsu
National Taiwan University
Taipei, Taiwan
b10502005@ntu.edu.tw

Wei-Tang Hsu
National Taiwan University
Taipei, Taiwan
b11902033@csie.ntu.edu.tw

Tzu-Chin Chiu
National Taiwan University
Taipei, Taiwan
b11902105@csie.ntu.edu.tw

Li Lin
National Taiwan University of Science and Technology
Taipei, Taiwan
milktube123@gmail.com

Yao Cheng Lee
National Taiwan University
Taipei, Taiwan
r13944042@ntu.edu.tw

Ting-Wu Chang
National Taiwan University
Taipei, Taiwan
r14944031@ntu.edu.tw

Hsien-Hui Tang
National Taiwan University of Science and Technology
Taipei, Taiwan
drhhtang@mail.ntust.edu.tw

Bing-Yu Chen
National Taiwan University
Taipei, Taiwan
robin@ntu.edu.tw

Mike Y. Chen
National Taiwan University
Taipei, Taiwan
mikechen@csie.ntu.edu.tw

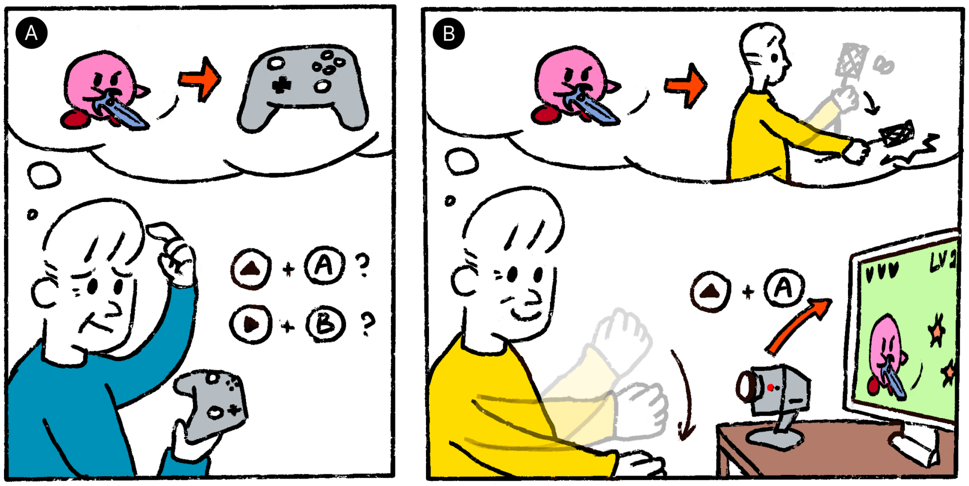

Figure 1: (A) Older adults often face difficulties with commercial games using standard controllers, as complex button mappings and fine motor demands hinder usability and engagement. (B) ElderPlay is a real-time game input translation system that enables gameplay through intuitive body movements without modifying the original game. It combines user-defined gesture input for expressive actions with conventional controls for movement, balancing accessibility and gameplay fidelity.

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Abstract

Playing video games can enhance older adults' well-being and social connections. However, most mainstream games rely on button-based controls that require fine motor skills, limiting accessibility. We present ElderPlay, a real-time game input translation system that enables older adults to play unmodified commercial games using intuitive, motion-based interaction. We first conducted a gesture elicitation study to derive user-defined gestures grounded in everyday experiences, which informed the design of a proof-of-concept system translating gestures into controller inputs. We then evaluated ElderPlay with two commercial Nintendo Switch games. Results show that gesture-based interaction improves enjoyment, perceived physical engagement, and performance. Rather than replacing controllers, our findings highlight the effectiveness of hybrid interaction, where gesture and controller inputs support different gameplay actions. We discuss implications for context-dependent and inclusive game interaction design.

CCS Concepts

• **Human-centered computing → Accessibility technologies**; **Gestural input**; **Interactive systems and tools**; **Empirical studies in HCI**.

Keywords

Older adults; Embodied interaction; Gesture-based interaction; Hybrid interaction; Inclusive game design; Game input adaptation

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1 INTRODUCTION

Playing digital video games can offer a range of cognitive, physical, and social benefits for older adults, including enhanced cognitive function, improved well-being [26, 34], and strengthened social and family connections [13, 20, 29, 36]. In this work, we use the term "older adults" broadly to refer to individuals aged 50 and above, following prior research that includes this age range when examining age-related changes in interaction and motor performance [20]. Prior reviews have further highlighted that game-based systems are widely used to support rehabilitation, physical activity, and skill training for older adults, demonstrating their potential as accessible tools for promoting active aging and overall health [26]. Despite these benefits, older adults continue to face substantial barriers when interacting with mainstream commercial video games.

Prior work has shown that traditional button-only controllers often require complex button mappings and fine motor control, which can increase learning difficulty and reduce enjoyment for older adults [48]. For example, Skalsky et al. [18] found that older players struggled with multi-button combinations and timing-based inputs, while Malone et al. [21] reported increased cognitive load and error rates when using standard game controllers. Although gesture-based controllers have been shown to be more intuitive and preferred by older players [14, 17], and are widely used in exergames and rehabilitation contexts to promote physical activity and engagement [38, 39], these systems are primarily designed for rehabilitation or training purposes rather than for engaging with mainstream commercial games. SilverBalance [9] was designed for gameplay purposes; however, it still relies on a custom-designed balancing game with simplified tasks, which restricts the range of possible actions and interactions compared to real-world gaming experiences. As a result, gesture-based interactions remain largely confined to specialized applications, while most commercial games continue to rely on button-only input schemes. This disconnect limits older adults' access to mainstream commercial games and reduces opportunities for shared or intergenerational play [32, 35].

Beyond gesture-based approaches, previous research has also explored multiple strategies to improve accessibility for older adults, including simplified interfaces [31], specially designed games [10, 26], and alternative input devices [44]. However, these approaches often require modifying original game designs or introducing non-mainstream titles, which can restrict older adults' participation in widely recognized commercial games. Moreover, most commercial adaptive controllers remain fundamentally button-based, retaining many of the limitations associated with traditional input.

To address this gap, we present ElderPlay, a real-time game input translation system that enables older adults to play mainstream, button-based games using intuitive, motion-based interaction without modifying existing game content (Figure 1). Rather than replacing conventional controllers, ElderPlay adopts a hybrid interaction design that combines gesture-based input with traditional button controls. Expressive in-game actions are mapped to bodily gestures, while button input is retained for precise character locomotion, balancing intuitiveness with control accuracy. This design reflects our observation that different input modalities may be better suited to different types of gameplay actions, motivating a hybrid approach to support diverse gameplay demands.

To ground the system design in older adults' lived experiences, we conducted a gesture elicitation study to identify intuitive, user-defined gestures, followed by a feasibility study comparing ElderPlay with traditional controllers in two commercial games. Through these studies, we examine how different input modalities support gameplay actions in practice and derive design implications for inclusive game interaction design for older adults.

The contributions of this work are as follows:

- We propose a gesture-based game input translation approach that enables older adults to interact with unmodified commercial button-based games, expanding access to mainstream gaming experiences.
- We conduct a gesture elicitation study to identify intuitive, user-defined gestures that reflect older adults' abilities, preferences, and everyday movement patterns.
- We develop a hybrid interaction system that integrates gesture-based input with conventional controller input, demonstrating how multiple modalities can be combined to support diverse gameplay actions.
- Through a feasibility study, we show that gesture-based interaction can improve older adults' enjoyment, perceived physical engagement, and performance in gameplay.

- We derive design implications that highlight the role of hybrid and context-dependent interaction in supporting inclusive game design for older adults.

2 RELATED WORK

2.1 Gameplay Challenges for Older Adults

Prior research has examined how input interfaces influence older adults' engagement with video games. Traditional button-only controllers often require complex button mappings and fine motor control, which can be challenging for older adults. For example, Marston et al. [17] found that older players experienced difficulties remembering button mappings and executing precise inputs, leading to increased cognitive load and reduced confidence during gameplay. Similarly, Palacio et al. [22] reported that older adults required longer learning periods to become familiar with controller-based interactions, which negatively affected their enjoyment. As a result, older players may experience reduced confidence and enjoyment, which in turn limits their engagement and access to the potential benefits of video games, including improved well-being [26, 34], social connection [13, 24], and family bonding [36].

Prior work has explored alternative input interfaces and their effects on older adults' performance, preferences, and usability. Pham et al. [14] compared button-based, gesture-based, and mixed-control systems, finding that gesture-based interaction was perceived as more intuitive and preferred by older adults, and in some cases supported improved performance over traditional button-only controllers, with similar observations reported in prior work [17]. These findings suggest that gesture-based interaction can reduce reliance on memorization and fine motor control, which is known barriers for older adults. However, such interaction techniques are rarely supported in mainstream commercial games, where button-based control schemes remain dominant, limiting both accessibility and real-world applicability.

To contextualize these findings in contemporary commercial games, we surveyed popular parent–child video games to examine the availability of gesture-based input (see Supplementary Table S1). The results indicate that players are required to remember numerous action–button mappings, imposing substantial cognitive load, while only a small proportion of games support gesture-based input. This gap motivates the need for alternative interaction approaches that better support older adults' engagement with mainstream video games.

2.2 Exergames for Older Adults

A growing body of research has explored gesture-based interaction and exergames as alternatives to traditional controller-based input, particularly in health and rehabilitation contexts. These systems leverage body-based movements to promote physical activity while maintaining engagement through gameplay.

Prior work has demonstrated that such systems can improve overall user experience and engagement for older adults. For example, Chang et al. [38] developed an interactive somatosensory rehabilitation game for older adults with mild cognitive impairment, showing improved willingness to use, ease of learning, and overall usability compared to traditional rehabilitation methods. Similarly, Chen et al. [39] highlighted the role of intuitive gesture interaction and culturally meaningful content in enhancing engagement and emotional connection. Other systems, such as LightSword [46] and MusicTongue [40], further explored embodied interaction for cognitive and physical training through virtual reality (VR) and novel input modalities. Together, these works suggest that gesture-based and embodied interaction can support accessible and engaging interaction experiences for older adults, particularly by leveraging familiar movements and lowering interaction barriers. However, most existing exergames are designed as standalone systems with predefined tasks and limited interaction spaces. They typically operate in controlled, task-driven environments focused on rehabilitation or cognitive training, rather than supporting open-ended gameplay.

SilverBalance [9] represents one of the closest approaches to our work, as it explores game-oriented interaction beyond pure rehabilitation. It utilizes the Wii Balance Board to enable body-based control for older adults. However, similar to many exergame systems, it relies on custom-designed mini-games with constrained mechanics (e.g., balancing and simple avoidance tasks), limiting the range of possible actions and interactions.

As a result, interaction is constrained to simplified and task-specific mechanics that differ substantially from the open-ended and dynamic nature of real-world gaming experiences. Consequently, these systems cannot be readily applied to existing commercial games. This gap highlights a fundamental disconnect between current exergame research and real-world gaming practices, motivating the need for interaction techniques that enable older adults to access and engage with unmodified commercial games.

2.3 Inclusive Gaming for Older Adults

Beyond gesture-based approaches, prior work has also explored various approaches to designing inclusive game experiences for older adults in both research and commercial contexts. Research efforts often focus on simplifying game interfaces, such as using large fonts, high-contrast visuals, and simplified menus to improve accessibility and usability [6, 31, 50]. Other works have proposed developing games specifically tailored to older adults, typically targeting cognitive [6, 15, 19, 26] and physical training [15, 19, 26], or supporting social connection [10, 15, 30, 42, 52] and mental well-being [6, 10, 12]. For instance, Gerling et al. [12] designed full-body interaction games tailored for older adults, showing that simplified interaction and physical engagement can improve participation and enjoyment. While effective for their intended purposes, these approaches often modify original game designs or introduce new titles that are not widely adopted as mainstream games, potentially limiting opportunities for co-play with younger family members, which is an important motivation for older adults' gameplay [32, 35].

Both research and industry initiatives have also investigated alternative input controls to improve accessibility. Commercial examples include adaptive controllers designed for players with disabilities [54, 55, 57, 58, 59]. Research prototypes similarly explore revised input methods [42, 44, 52], such as customizable motion-control boards for different physical abilities [44] or emerging modalities like brain–computer interfaces [45]. However, many of these solutions either target niche contexts or remain fundamentally button-based, leaving the interaction challenges of mainstream button-centric games largely unaddressed for older adults.

To address this gap, we propose *ElderPlay*, a real-time game input translation approach that enables older adults to play mainstream games originally designed for button-based controllers without modifying the underlying game input mechanisms. Unlike prior work that redesigns games or introduces specialized systems, ElderPlay enables older adults to access existing mainstream commercial games without modifying game content, bridging the gap between accessibility-focused research prototypes and real-world gaming practices.

3 GESTURE ELICITATION STUDY

3.1 Objective

The objective of this gesture elicitation study is to collaboratively explore how older adults map game actions to body-based gestures and how they conceptualize intuitive gestures for gameplay. Through a within-participants design process, we aim to capture user-defined gestures and participants' reasoning to identify gesture patterns, preferences, and design considerations that can inform the design of accessible, gesture-based game interaction for older adults.

3.2 Game Selection and Gesture Set

To evaluate how gesture-based interaction can support older adults in engaging with existing digital games, we intentionally selected mainstream commercial titles rather than games specifically designed for older adults. While prior work has explored games tailored for older adults (e.g., exergames or cognitive training games), such approaches are often limited in scope and do not reflect the complexity or social relevance of contemporary gaming experiences. In contrast, our goal is to **enable access to unmodified commercial games**, which are widely played and can better support shared and intergenerational play.

To ensure that our gesture design and evaluation cover a range of interaction demands, we selected two representative commercial games based on both their gameplay characteristics and their popularity. These games were also identified in our prior survey of popular parent–child video games (see Supplementary Table S1), reflecting game types commonly encountered in everyday and intergenerational contexts.

Animal Crossing: New Horizons is a life-simulation game featuring open-ended exploration, low time pressure, and a wide range of everyday in-game actions, such as resource collection, object manipulation, and social interaction. These characteristics make it well-suited for examining gesture-based interaction in a low-pressure and context-rich environment, where actions are familiar and socially meaningful.

In contrast, **Kirby Star Allies** is a side-scrolling action-adventure game that requires continuous joystick control, timely reactions, and coordination between multiple actions, such as movement, attacking, and ability combination. This game represents a more time-sensitive and motor-demanding interaction context, allowing us to examine how gesture-based input performs under higher temporal and coordination requirements.

Together, these two games span a spectrum of interaction demands, from relaxed, exploratory gameplay to fast-paced, action-oriented control. This enables us to systematically examine how gesture-based interaction performs across different gameplay characteristics and control complexities.

From these games, we identified and categorized 18 and 24 distinct character actions from *Animal Crossing* and *Kirby*, respectively. Actions were categorized based on their interaction characteristics, including everyday actions, movement-related actions, and game-specific ability actions. The full list of actions is provided in Supplementary Table S2. Two authors independently reviewed gameplay footage and created 42 short demonstration videos corresponding to these actions, which were provided to participants as visual references during the study. The selected actions span diverse gameplay interaction types, including familiar everyday actions (e.g., picking up, watering), movement-related actions (e.g., walking, jumping), and game-specific abilities (e.g., attacks and special skills). This diversity allows us to examine how gesture design varies across action types with different levels of familiarity, abstraction, and control requirements, and provides a basis for exploring how different gameplay actions can be translated into gesture-based input.

3.3 Study Design and Procedure

We employed a gesture elicitation methodology to explore how older adults define intuitive body-based gestures for common game actions based on the former list, building on prior work in gesture-based interaction systems [33, 41, 43].

The gesture elicitation study consisted of two main phases: a **design** phase and a **vote** phase, preceded by a brief preparatory session.

Prior to the formal study session, participants were provided with a slide deck containing short demonstration videos of all character actions. This preparatory session allowed participants to review the actions in advance and reflect on potential gesture ideas, helping to reduce design legacy bias and cognitive load during the elicitation process.

On the following day, participants took part in the **design** phase. The experimenter first introduced the study purpose and procedures, after which participants watched the demonstration videos for both games. Participants were then asked to propose body-based gestures that they felt best represented each character action and to explain the rationale behind their designs. They were encouraged to consider four criteria when proposing gestures, including *comfort*, *appropriateness*, *ease of performance*, and *intuitiveness*. To encourage exploration while minimizing design bias, participants were allowed to propose up to three gesture candidates per action; if only one gesture could be identified after careful consideration, a single response was accepted. All sessions were video recorded for subsequent analysis.

After completing the design phase, participants proceeded to the **vote** phase. In this phase, participants were asked to select their most preferred gesture for each character action from among their own proposed candidates and to justify their selections based on the same criteria. This voting process was designed to capture participants' final preferences after reflection, allowing them to evaluate multiple candidate gestures they proposed and select the most suitable one. This refinement step is commonly adopted in gesture elicitation studies to identify preferred gesture candidates and reduce ambiguity in user-defined gesture sets [41, 43]. This process resulted in a total of 378 gesture proposals (42 actions × 9 participants).

During both the design and voting phases, demonstration videos and participants' proposed gestures were displayed on a laptop connected to a large external screen, enabling participants to review the content and verbalize their thoughts throughout the study. A video camera was positioned to record participants' gesture design activities for subsequent analysis.

To mitigate order effects, the presentation order of the two games was randomized across participants. Within each game, actions were divided into two blocks to reduce cognitive load and fatigue, ensuring that participants could focus on a manageable subset of actions at a time, with block order counterbalanced.

Each study session lasted approximately 40 minutes, including a 5-minute introduction, 25 minutes for gesture design, and 10 minutes for the voting phase and post-study interview. Participants were given a 5-minute break every 20 minutes to reduce fatigue.

3.4 Participants

A total of 9 older adults participated in the study (5 self-identified as male and 4 as female), aged 52 to 88 years (M = 64.00, SD = 13.72). Participants were recruited from local community centers. While the definition of "older adults" varies across studies, prior work has included participants in their 50s to capture early age-related changes in interaction and motor performance [20]. In this study, we adopt a functional perspective, focusing on age-related characteristics relevant to gameplay interaction (e.g., reduced motor speed, coordination, and response time), rather than enforcing a strict age threshold. All participants reported normal or corrected-to-normal vision and were able to understand and follow the study procedures. Participants were also required to be capable of performing basic upper-body movements (e.g., arm gestures) safely. Four participants reported prior experience with digital games.

Although only a small number of participants reported prior gaming experience, this is consistent with our target population, as many older adults are not regular game players [17]. Rather than requiring prior gaming knowledge, our goal in the gesture elicitation study was to capture gestures grounded in participants' everyday experiences and familiar bodily actions. This approach helps ensure that the resulting gestures are intuitive and accessible to a broader population of older adults, including those with limited or no gaming background. The suitability of these gestures was subsequently examined in the feasibility study with a larger and more diverse participant group, providing further validation of their applicability in gameplay contexts.

All participants provided informed consent prior to the study, in accordance with the institutional review board (IRB) guidelines of our institution, and received USD 10 in compensation.

3.5 Results

We collected a total of 378 gestures, with representative gestures for all 42 character actions shown in Figure 2 and Figure 3. To evaluate the degrees of consensus among user-defined gestures, we calculated the agreement score A using the equation of previous works [5, 23, 33, 41]:

$$A_t = \sum_{P_i} \left(\frac{|P_i|}{|P_t|} \right)^2 \tag{1}$$

where t is one of the actions, P_t is the set of collected gestures/postures for t, and P_i is a subset of identical gesture/posture from P_t. The range for A is [0,1].

To determine gesture similarity, two authors independently grouped gestures based on movement semantics, including body parts involved, motion trajectory, and intended action meaning. Disagreements were resolved through discussion until consensus was reached. The agreement rates of gestures in the two games are shown in Figure 4. For *Animal Crossing*, the agreement rates ranged from 0.40 (high agreement, $0.300 < AR < 0.500$) to 1.0 (very high agreement, $AR > 0.500$). For *Kirby*, the agreement rates ranged from 0.19 (medium agreement, $0.100 < AR < 0.300$) to 1.0 (very high agreement, $AR > 0.500$). The mean agreement rate for *Animal Crossing* was 0.788 (SD = 0.205), while for *Kirby* it was 0.620 (SD = 0.260). Agreement scores varied across action types and games, with core movement and daily-life actions generally showing higher consensus than more abstract or ability-based actions.

3.6 Findings

To interpret these patterns, we draw on interview data and experimenters' observations to examine how differences in game context and action semantics shaped older adults' gesture design across the two games.

Familiarity and Action Semantics. Participants found it easier to design gestures for *Animal Crossing*, where many actions are grounded in familiar daily-life activities (e.g., chopping a tree, watering plants, catching fish). These actions were often described as *easy to associate*, and correspondingly showed higher agreement scores (Figure 4). In contrast, many actions in *Kirby* involve abstract or game-specific abilities (e.g., sword attack, ice attack), which lack direct real-world analogs. Participants frequently described these actions as *difficult to associate* or *lacking context*, and often resorted to mimicking character animations rather than generating novel gesture mappings. This pattern is consistent with prior work showing that motion-based interaction grounded in everyday movement can improve accessibility and engagement for older adults [27, 28]. This suggests that gesture intuitiveness is closely related to the familiarity of action semantics, particularly when grounded in everyday experiences.

Physical Effort and Feasibility. Actions requiring large body movements, such as jumping, sitting, or sliding, were perceived as physically demanding or impractical, particularly when they required participants to leave their seat or interact with the floor. In response, participants often adapted these gestures into more feasible alternatives (e.g., replacing a jump with a squat-to-stand motion), prioritizing comfort and ease of performance over strict realism. This observation is consistent with prior work [41].

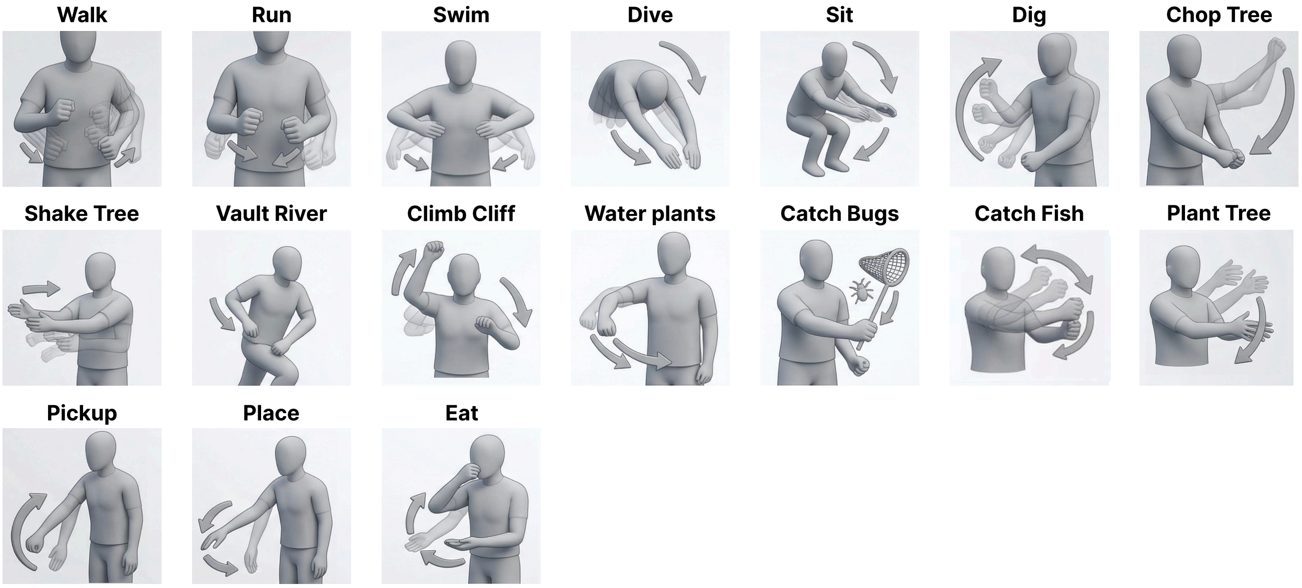

Figure 2: Representative user-defined gestures mapped to character actions in the gesture elicitation study for *Animal Crossing*.

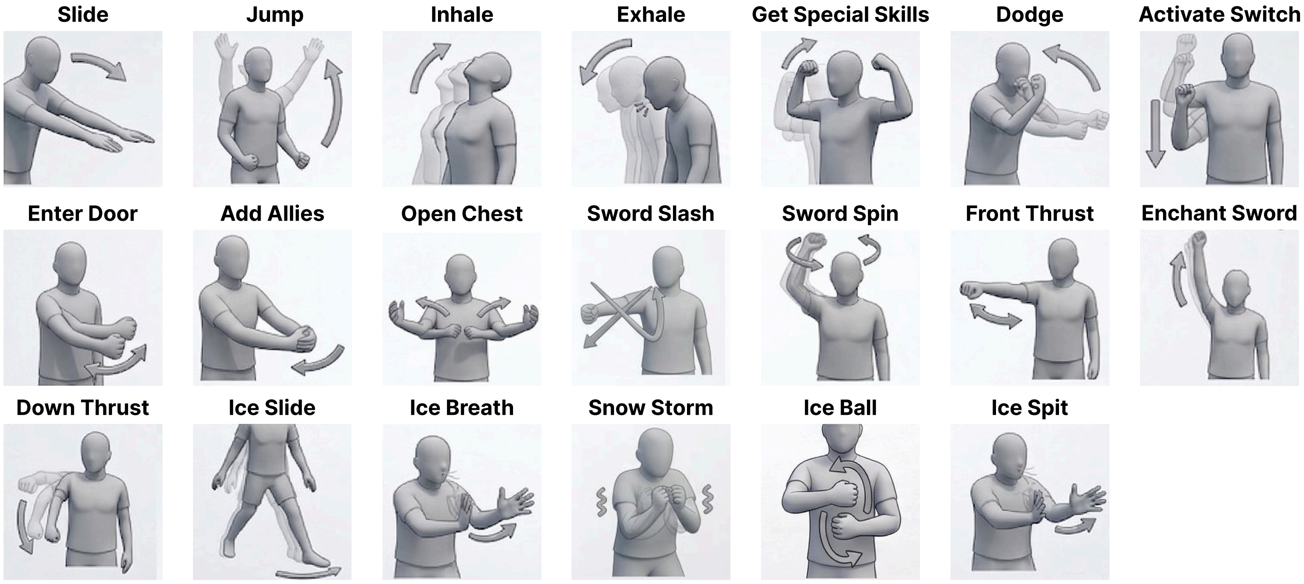

Figure 3: Representative user-defined gestures mapped to character actions in the gesture elicitation study for *Kirby*.

Differences Across Action Types. While participants were able to propose gestures for locomotion-related actions (e.g., walking, running, jumping), these gestures often required continuous or larger-scale body movements and were perceived as less practical in constrained environments. In contrast, gestures for discrete and object-related actions were generally more intuitive, easier to perform, and more consistently defined across participants. This suggests that different types of game actions may vary in their suitability for gesture-based input.

3.7 Design Considerations

Based on our findings, we identify several considerations for designing gesture-based game input for older adults.

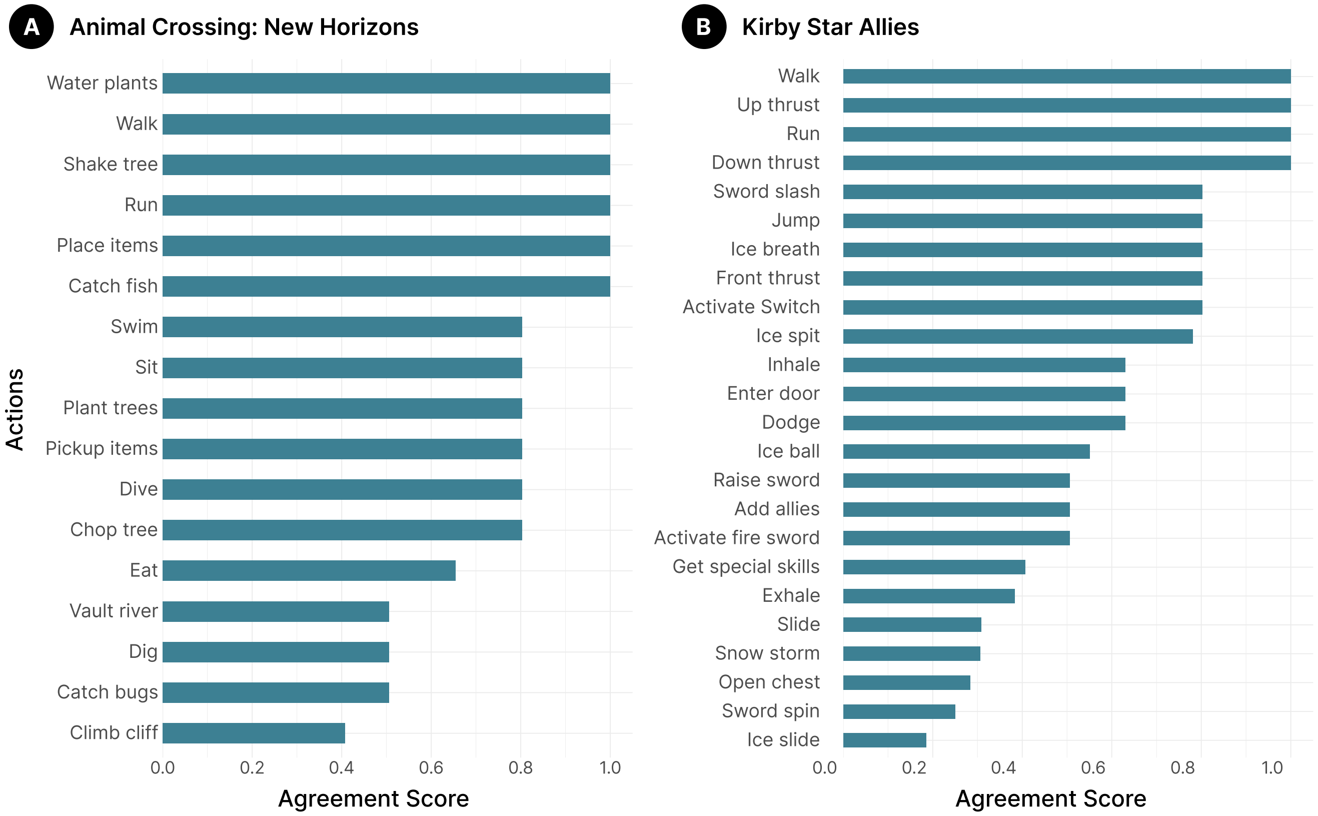

Figure 4: Agreement rates of user-defined gestures for character actions in the gesture elicitation study.

Gesture Intuitiveness and Familiarity. Our findings suggest that gesture intuitiveness is closely related to the familiarity of action semantics. Gestures grounded in everyday experiences were easier for participants to associate with in-game actions, requiring less effort to learn and recall. This highlights the importance of leveraging existing bodily knowledge when designing gesture-based interaction.

Balancing Engagement and Physical Effort. Our findings also indicate that gesture-based interaction involves a balance between engagement and physical effort. While expressive gestures can enhance immersion and enjoyment, actions that require large or continuous body movements may become physically demanding or impractical over time. This suggests that gesture design should consider both experiential engagement and long-term usability.

4 SYSTEM IMPLEMENTATION

Based on insights from the gesture elicitation study, we adopt a hybrid interaction design that combines body-based gestures with conventional controller input. Gesture-based input is used for discrete and expressive actions (e.g., object interaction, attacks, and contextual actions), while continuous locomotion (e.g., walking and navigation) is handled through a standard controller. This design is motivated by our observation that locomotion gestures require larger physical effort and space, making them less suitable for sustained gameplay, especially for older adults. In contrast, gestures are more effective for short, expressive actions that benefit from intuitive body-based mappings.

ElderPlay is a real-time game input translation system that maps users' gestures and joystick input to standard game controller signals, enabling interaction with unmodified commercial games. To lower the learning barrier for older adults, the system replaces button-based inputs with gesture-based actions derived from the elicitation study, while retaining an analog joystick for continuous control.

Figure 5 illustrates the system pipeline. The system consists of hardware and software components that detect user gestures and capture joystick input, map them to corresponding in-game actions, and generate controller signals for the game. We describe each component in detail below.

4.1 Hardware Architecture

The hardware subsystem supports gesture sensing, joystick input capture, and controller signal emulation. In the following, we describe each component in detail.

4.1.1 Gesture Capture. We choose a camera-based gesture recognition approach to enable unobtrusive and low-barrier interaction for

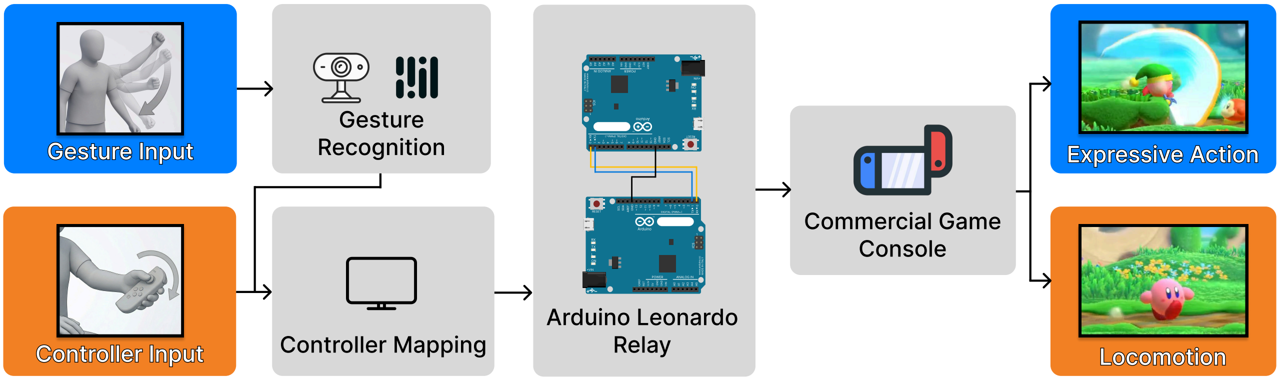

Figure 5: Control diagram of the *ElderPlay* prototype. Joystick input is received via Bluetooth, while user movements are captured through two webcams. These inputs are analyzed and integrated to determine in-game actions, which are then translated into controller signals and sent to the game via Arduino Leonardo boards.

older adults, without requiring them to wear, hold, or maintain additional devices. Compared to wearable or sensor-based alternatives (e.g., IMU or EMG), vision-based tracking reduces setup complexity and physical burden, which is particularly important for users with limited mobility or unfamiliarity with technology. Furthermore, it supports a wider range of natural, whole-body gestures that can be intuitively mapped to in-game actions. While camera-based approaches introduce practical challenges (e.g., privacy concerns and sensitivity to environmental conditions), they provide a flexible and accessible foundation for exploring gesture-based interaction with existing commercial games.

User body gestures were captured using two Logitech Brio 4K Ultra HD webcams with a horizontal field of view of 70°and a vertical field of view of 50°. One camera was mounted on a tripod positioned 1.8 m in front of the user, at a mounting height of 95 cm with an upward tilt of 8°. The second camera was placed 1.35 m to the front-left of the user at a 45°angle, with a mounting height of 120 cm and a neutral tilt. This configuration enables reliable capture of both frontal and lateral upper-body movements.

To ensure that the camera placement accommodated users with diverse body dimensions, we followed common practices in human-factors engineering [8] and consulted anthropometric data ranging from the 5th-percentile female to the 95th-percentile male for body height, standing overhead reach, waist to head and standing forward reach distance. Based on these data, the hand-to-waist height of most users falls between 116.84 cm and 148.59 cm, while the arm-span width falls between 154.21 cm and 196.03 cm. These ranges indicate that the distance between the two webcams is sufficient to capture upper-body movements with arms fully extended, both vertically and horizontally.

The webcams captured video at a resolution of 720p with a frame rate of 90 Hz. The end-to-end motion capture latency of this setup, including USB transmission and streaming buffer delays, was approximately 45 ms.

4.1.2 Joystick Capture. To enable in-game character movement via a physical joystick while using gesture input, the user holds a left-side Nintendo Joy-Con controller in their left hand, which is connected to *ElderPlay* via Bluetooth and functions solely as an analog movement input device. The open-source *PyJoyCon* library [56], integrated in *ElderPlay*, is used to read joystick input. When no gesture-triggered action is being executed, joystick signals from the Joy-Con are forwarded to the Nintendo Switch through the system with an average end-to-end latency of approximately 15 ms. When a gesture is detected and a corresponding action script involving joystick input, joystick passthrough is temporarily gated to prevent control conflicts between manual joystick input and automated gesture-triggered command.

4.1.3 Microcontroller Relay. Two Arduino Leonardo microcontrollers communicate over an RX/TX serial link to mediate control signals between *ElderPlay* and the Nintendo Switch console. One microcontroller receives processed control commands from the system, while the other emulates a Nintendo Pro Controller and injects corresponding input signals into the console. The communication pipeline operates at 40Hz and employs dual-channel checksum verification to mitigate transmission noise. The measured end-to-end input latency, including signal transmit, serial processing, and controller emulation, is approximately 25 ms on average.

4.2 Software Components

The software subsystem handles real-time gesture recognition and controller mapping, translating recognized user actions into corresponding control commands that are transmitted to the Nintendo Switch outputs. The system is built on open-source components and follows a modular architecture to enable easy customization and integration with future interaction techniques.

4.2.1 Gesture Recognition. We implemented a real-time gesture recognition pipeline based on MediaPipe keypoint detection combined with rule-based motion classification. The system leverages multimodal landmarks, including facial (mouth), torso, arm, hand, and finger joints (thumb, index, and pinky), as primary gesture features. Gesture conditions are defined using joint angles, palm orientation, and relative spatial distances between landmarks. Palm orientation is computed via the cross product of vectors from the wrist to the thumb and pinky landmarks. Certain gestures incorporate temporal constraints, requiring actions to be maintained for several seconds to be considered valid. This design choice reduces false positives and accommodates slower or more deliberate movements.

To account for variations in user height, body proportions, physical condition, and range of motion, we also designed a custom calibration system. During calibration, the system first demonstrates the predefined reference gestures. The user is then asked to perform a version of each gesture that is comfortable for them. Landmark data are captured either through experimenter control or an automatic countdown mechanism. Based on the recorded landmarks, angular thresholds are set using a lower bound of measured value $\times 0.8 - 20$ and an upper bound of measured value $\times$ 1.2 + 20. Positional thresholds are defined using measured value $\times$ 1.15 + 0.05 and measured value $\times$ 0.85 $-$ 0.05 for greater-than and less-than conditions, respectively. To ensure physically valid joint configurations, angular thresholds are further clamped to the feasible range of $[0°, 180°]$.

Some gestures are segmented into *initial*, *continuation*, and *end* phases, while others consist only of entry and exit phases. Detection rules are intentionally simplified wherever possible, provided that reliable false-activation prevention can be maintained. Inter-gesture timing constraints are adjusted based on gesture complexity, with most gestures incorporating a 3-second gap between phases to accommodate older adults' slower limb movements and longer reaction times, reducing the risk of unintended activations or physical strain.

Once a gesture is recognized, the system forwards the detection result to the controller mapping module and temporarily pauses further gesture detection at the software level until the corresponding output action has been executed. The average end-to-end latency of the gesture recognition part is approximately 17 ms measured using timestamp logging.

4.2.2 Controller Mapping. Upon gesture detection, the system triggers a predefined action script that generates a sequence of controller inputs. These inputs are transmitted to the Arduino using the *ArduinoJoystickLibrary* [49], which converts them into a communication format recognized by the Nintendo Switch. During action execution, the software temporarily suppresses joystick passthrough and resumes it once the scripted action completes. When a gesture terminates, an additional neutral input is issued to clear any residual signals and prevent the system from remaining in a previous control state.

When no gesture is detected, joystick input commands are continuously passed through to the Nintendo Switch, allowing users to retain direct control of character movement. The average latency introduced by the controller mapping module is less than 1 ms.

4.3 End-to-End Latency Summary

To evaluate the end-to-end system latency, we conducted an empirical latency measurement for each component using high-resolution timers in Python. To ensure measurement reliability and account for system jitter, each component was measured over 100 independent trials.

We report the mean latency, standard deviation (SD), and the 99th percentile (PR99) to characterize system performance and stability. The PR99 latency is particularly important as it captures high latency outliers and reflects near worst case performance, and the total latency is computed as the sum of individual component latencies, assuming sequential processing (i.e., an upper-bound estimate). The results are summarized in Table 1.

Component	Mean (ms)	SD (ms)	PR99 (ms)
Video capture	33.43	4.89	49.36
Joystick capture	15.64	1.51	16.36
Gesture recognition	30.05	1.21	34.26
Controller mapping	0.01	≈0.00	0.01
Microcontroller relay	14.83	0.16	20.14
Total Latency	**93.96**		**120.13**

Table 1: End-to-end system latency breakdown across components. Each value is computed from 100 trials, reporting mean, standard deviation (SD), and 99th percentile (PR99).

According to Dick et al. [3], the end-to-end latency of *ElderPlay* (93.96 ms) falls within the reported range of tolerable latency for casual gameplay (118.1 ms). However, the effective latency experienced during actual gameplay is likely higher, as it also includes the time required for users to physically execute or sustain gestures. While PR99 does not represent the absolute worst-case latency, it serves as a practical upper bound estimate under typical operating conditions. True worst case latency may be higher due to system-level factors such as OS scheduling, USB buffering, or frame drops. Nevertheless, the relatively low variance and tight PR99 range suggest stable system performance with limited latency spikes.

4.4 System Reliability

To evaluate the reliability of the *ElderPlay*'s gesture recognition , we analyzed a total of 2,896 action instances extracted from recorded gameplay sessions. All gameplay videos were manually reviewed and annotated to identify cases in which intended gestures were not detected (missed detections, H1) and cases in which gestures were detected without intentional user input (false activations, H2).

Across all analyzed actions, the missed detection rate (H1) was 8.80%, while the false activation rate (H2) was 4.02%. The lower false activation rate reflects the effectiveness of the temporal constraints and phase-based detection design in suppressing unintended triggers. We intentionally prioritized minimizing false activations in order to reduce disruptive or unintended in-game actions. Overall, the system demonstrates sufficient reliability for casual, gesture-augmented, and real-time gameplay interaction while maintaining robustness against accidental activations.

5 FEASIBILITY STUDY

5.1 Objective

The objective of this feasibility study is to perform an exploratory evaluation of how older adults interact with *ElderPlay* and how gesture-based input supports their gameplay experience. We collected both objective performance metrics and subjective feedback to assess usability and user experience, rather than to draw definitive comparative conclusions.

5.2 Game Selection

We used the same game titles, **Animal Crossing: New Horizons** and **Kirby Star Allies**, to ensure consistency with the gesture elicitation study while evaluating real gameplay performance. For both games, gameplay conditions were carefully controlled, including selected scenes, difficulty settings, and available character abilities, to ensure consistency across participants.

5.3 Study Design and Procedure

We conducted a feasibility study to evaluate how ElderPlay supports older adults' gameplay experiences, following procedures from prior game interactive system evaluations [53].

The feasibility study consisted of three sequential sessions: **Pre-Study**, **Gameplay**, and **Post-Study Interview**.

In the **pre-study** session, participants were first briefed on the study purpose and procedures. They then completed a demographic questionnaire and a controller skill assessment, administered with guidance from the experimenter, to characterize prior gaming experience. One participant was unable to complete the controller skill assessment due to difficulty understanding the controller operations and task instructions; this participant did not proceed to the main study but was still compensated. All sixteen participants reported in this paper successfully completed the controller skill assessment and proceeded to the gameplay session.

In the **gameplay** session, participants played two commercial games, *Animal Crossing* and *Kirby*, on a Nintendo Switch connected to a projector. Two input conditions were evaluated: (a) **Button-Only Controller**, in which participants used a standard Nintendo Switch Pro Controller; and (b) **ElderPlay System**, in which participants used the proposed gesture-based system together with a left Nintendo Joy-Con, with only the joystick enabled for character movement, while most character actions were controlled via motion input. Participants were informed that they would experience two different interaction methods for gameplay. However, we did not explicitly frame the conditions as experimental comparisons or reveal the study hypotheses. The condition labels (e.g., "Condition A/B") were not disclosed. This approach was adopted to reduce potential bias in subjective responses. Short instructional videos were presented to familiarize participants with the mechanics of each game and input condition. Each condition included a practice session to ensure participants reached a basic level of familiarity before completing the tasks and to reduce potential learning effects across input methods. Participants then completed the assigned gameplay tasks for each game (see Section 5.4 for task details). After experiencing both input conditions for a given game, participants completed a comparative questionnaire to indicate which condition they enjoyed more during gameplay (see Section 5.5.4 for questionnaire details).

Following the gameplay session, a **semi-structured interview** was conducted to collect participants' subjective feedback and to further probe their preferences, experiences, and observed behaviors during the study.

The study was conducted in a large open space, with gameplay projected onto a front-facing screen to minimize vision-related bias. The area behind participants was kept clear to reduce false detections by MediaPipe. Gameplay sessions were video-recorded for subsequent analysis, enabling the authors to label objective performance metrics, while post-study interviews were audio-recorded for further qualitative analysis.

The study employed a within-participants design. The order of input conditions was counterbalanced across participants, while the order of game presentation was fixed (*Animal Crossing* followed by *Kirby*). Each participant completed four trials in total (2 input conditions × 2 games). The study lasted approximately 160 minutes, including a 10-minute introduction, a 15-minute controller skill screening, two 30-minute gameplay sessions per game (including 10 minutes of practice per condition), and a 15-minute post-study interview. Short breaks were provided between sessions and conditions to minimize fatigue.

5.4 Game Tasks Design

Different gameplay tasks were designed for the two selected games to reflect their distinct interaction demands and in-game mechanics.

Animal Crossing: New Horizons. Participants were required to complete four structured mini-tasks that represent common everyday interactions in the game: (1) Catch a fish: take out a fishing rod, catch one fish, and put the rod away; (2) Collect and consume items: shake an apple tree to collect three apples and eat one apple from the inventory; (3) Dig a hole: select an empty location, take out a shovel, dig one hole, and put the shovel away; and (4) Water a flower: take out a watering can and water a flower in a garden area. Each mini-task was limited to two minutes. Failure was defined as not completing the task within the allotted time. Under the ElderPlay condition (Condition B), task execution during the mini-tasks was supported by a subset of seven gestures from the predefined gesture set.

Kirby Star Allies. Participants were instructed to complete two predefined stages (Stages 1–5 and 1–6). Within these stages, a total of 32 interaction-critical mini-tasks were identified, including enemy encounters and environmental obstacles that had to be addressed to progress through the level. Successfully overcoming an obstacle, either by defeating an enemy or safely bypassing it, was counted as task completion. Failure was defined as either losing all health points or not defeating the stage boss within the time limit. When using the ElderPlay system (Condition B), a subset of five gestures from the predefined gesture set was used to support gameplay actions required in the selected stages.

The task design was informed by the abilities of older adults, balancing operational complexity and cognitive demands across both games. Tasks were designed to reflect typical gameplay scenarios while remaining achievable within a limited session duration, allowing participants to quickly familiarize themselves with gameplay mechanics while maintaining sufficient challenge to support engagement and perceived control. This balance was intended to facilitate gameplay experiences aligned with the game flow framework [4].

These mini-tasks were annotated in advance by one of the authors based on gameplay progression and reviewed by the research team to ensure consistency.

The selected gesture subsets were chosen based on their relevance to task requirements, as well as their high agreement and perceived usability observed in the gesture elicitation study, ensuring that commonly preferred and representative gestures were used in the evaluation.

5.5 Measures

5.5.1 Demographics. Prior to gameplay, participants completed a demographic questionnaire to capture background information. The questionnaire collected data on age, prior familiarity with traditional game controllers and motion-based input systems, physical activity level, gaming engagement, and self-assessed gaming ability. All items, except age, were assessed using a 6-point Likert-type scale (0 = very negative, 5 = very positive).

5.5.2 Background Controller Skills. To characterize participants' baseline proficiency with traditional game controllers, we administered a controller skill assessment adapted from prior literature [1, 16, 25, 37, 53]. The assessment consisted of six fundamental controller interaction primitives: *reaction time*, *four-choice response*, *rapid tapping*, *temporal prediction*, *thumbstick target selection*, and *thumbstick path following*. These measures were used as background variables to contextualize participants' gameplay behaviors and to explore potential relationships between controller proficiency and input preferences. Detailed participant-level results are provided in Supplementary Figure S1 and Figure S2.

5.5.3 In-Game Performance (Objective). Across both games, we logged in-game telemetry to compute objective performance metrics aligned with each mini-game's goals for each input condition (*Controller* vs. *ElderPlay*), focusing on task performance and input reliability.

> **Task Completion:** Whether participants successfully completed the game tasks.
> **Task Completion Time:** The time required to complete the game tasks.
> **Mini-task Success Count:** The number of predefined mini-tasks successfully completed.
> **Number of Successful Actions:** The number of actions that directly resulted in positive outcomes contributing to the successful completion of a mini-task (e.g., defeating an enemy in *Kirby Star Allies* or shaking a tree in *Animal Crossing: New Horizons*).
> **Number of Failed Actions:** The number of actions that resulted in explicit negative outcomes and directly caused a mini-task to fail (e.g., being hit by an enemy instead of defeating it in *Kirby Star Allies*, or performing an incorrect action such as digging instead of shaking a tree in *Animal Crossing: New Horizons*).
> **Redundant Actions:** The number of additional or repeated actions performed toward a mini-task that were unnecessary and did not affect task success (e.g., continuing to swing the weapon after an enemy has already been defeated in *Kirby Star Allies*).
> **Death Count in *Kirby*:** The number of times participants' characters died during gameplay. This metric was recorded only for *Kirby Star Allies*, as player death occurs when in-game health reaches zero.
> **Control Loss Events:** The number of instances in which the input system failed to correctly recognize participants' intended actions.
> **Unintended Actions:** The number of instances in which the input system triggered actions without participants' intention.

Two authors independently annotated the gameplay recordings using a predefined coding scheme for action-level events. The coding scheme was defined prior to analysis based on task definitions and action outcomes, specifying criteria for categorizing actions as successful, failed, redundant, or unintended. Inter-rater disagreements were resolved through discussion until consensus was reached before aggregating the final counts for analysis.

5.5.4 Subjective Experience. After experiencing both input conditions in each game, participants completed a comparative questionnaire to report their subjective experience. For each item, participants indicated their preference using a 10-point difference scale ranging from −5 (the *Controller* condition much better) to +5 (the *ElderPlay* condition much better). This comparative rating approach follows a forced-choice format with strength-of-preference ratings commonly used in prior HCI work [47, 51]. An additional overall preference question was administered only after participants completed all gameplay.

The questionnaire assessed the following aspects:

> **Enjoyment:** Which condition was more fun?
> **Engagement:** Which condition made you feel more engaged during gameplay?
> **Ease of learning:** Which condition felt more intuitive and easier to learn (i.e., required less mental effort to understand and remember)?
> **Ease of use:** Which condition was easier to use during gameplay?
> **Perceived physical effort:** Which condition required less physical effort to use?
> **Physical well-being:** Which condition better supported your physical well-being (i.e., felt like healthy movement and was comfortable for your body)?
> **Overall input preference:** Overall, which input condition did you prefer across the entire gameplay experience?

5.5.5 User Interview. After completing all tasks, we conducted semi-structured interviews to elicit participants' qualitative feedback on their gameplay experiences. The interviews explored participants' *perceptions of control and breakdowns*, *enjoyment and frustration*, *gesture naturalness and learnability*, *perceived physical effort and engagement*, *perceived physical well-being enhancement*, as well as *potential family or intergenerational play scenarios.* Participants were encouraged to elaborate on their experiences and to reflect on moments they found particularly meaningful.

5.6 Data Analysis

5.6.1 Background Measures. Background measures, including demographics and controller skill assessments, were summarized using descriptive statistics to characterize participants. These measures were not treated as primary outcome variables. To account for potential differences in prior gaming experience, we assessed participants' baseline controller skills before gameplay and conducted exploratory correlation analyses to examine their relationship with both performance and subjective outcomes. These analyses were intended to evaluate whether prior interaction ability systematically influenced the observed results.

5.6.2 Objective Performance Analysis. Objective in-game performance outcomes were analyzed using mixed-effects models to account for the within-participants study design, with input condition (*Controller* vs. *ElderPlay*) and game treated as fixed effects, with participant included as a random intercept.

Task Completion. Binary task completion (completed vs. not completed) was analyzed using mixed-effects logistic regression models.

Task Completion Time. Task completion time was analyzed using linear mixed-effects models. Completion times were log-transformed when necessary to address skewed distributions, and analyses included only successfully completed trials.

Mini-task Success Count. Mini-task success count was analyzed using mixed-effects binomial regression models, with the number of successfully completed mini-tasks modeled relative to the fixed total number of mini-tasks per game.

Count-based Error and Reliability Measures. Count-based measures, including failed actions, redundant actions, death count in *Kirby*, control loss events, and unintended actions, were analyzed using Poisson mixed-effects models and refit with negative binomial models when overdispersion was observed.

5.6.3 Subjective Ratings Analysis. Subjective comparative ratings were analyzed using Wilcoxon signed-rank tests to examine within-participants differences between the *Controller* and *ElderPlay* conditions. Although Likert-type scales are often analyzed using parametric methods due to their robustness to violations of normality, we employed a non-parametric test as a conservative choice, given the ordinal nature of the comparative rating scale and the relatively small sample size. Effect sizes were reported using r.

5.7 Participants

A total of 16 older adults participated in the study (9 self-identified as female and 7 as male), ranging in age from 60 to 75 years (M = 67.63, SD = 4.11). Participants were recruited through local community postings, both online and offline.

Inclusion criteria required participants to be aged 60 years or older, have normal or corrected-to-normal vision, and possess sufficient cognitive ability to understand the study procedures and in-game instructions, as assessed through communication during recruitment and onboarding, as well as a pre-study controller skill task used to ensure participants could follow basic instructions and complete simple interaction tasks. Participants were also required to have adequate physical capability to safely perform the required motion-based interactions, including standing and arm movements, without severe upper-limb impairments.

Participants exhibited diverse gaming backgrounds. Seven participants reported no prior gaming experience, one reported less than one year, one reported 1–3 years, two reported 3–5 years, and five reported more than five years of gaming experience. Participants reported using a variety of gaming platforms, with mobile devices (e.g., smartphones and tablets) being the most common. More experienced players additionally reported using personal computers and home consoles (e.g., Nintendo Switch, PlayStation, or Xbox), while several participants with no prior gaming experience reported not regularly using any gaming devices. Regarding daily activity levels, twelve participants reported engaging in physical activities almost every day, while the remaining participants reported lower activity frequencies. Participants reported generally low familiarity with both traditional controllers and motion-based input systems. Familiarity with traditional game controllers (e.g., Nintendo Switch controllers; 0–5 scale, where 0 indicates not at all familiar and 5 indicates very familiar) was low overall (M = 0.88, SD = 1.02), with 13 out of 16 participants rating their familiarity as 0 or 1. Similarly, familiarity with motion-based input systems (e.g., Wii or Kinect; 0–5 scale) was also limited (M = 1.06, SD = 1.44), with 11 participants reporting ratings of 0 or 1.

Overall, participants exhibited limited prior gaming experience and low familiarity with both traditional controllers and motion-based systems, suggesting that the sample largely represents novice or low-experience players. This reduces the likelihood that prior gaming experience systematically biased the observed results.

All participants provided informed consent prior to the study, in accordance with the institutional review board (IRB) guidelines of our institution, and received USD 20 in compensation upon completing the study.

5.8 Results

5.8.1 ***Objective In-Game Performance.*** Objective in-game performance results are reported based on the mixed-effects analyses described in the Data Analysis section and are summarized in Figure 6.

Animal Crossing: New Horizons. All participants successfully completed the Animal Crossing task in both the Controller and ElderPlay conditions, yielding a 100% task completion rate. Because no variance was observed, no inferential analysis was conducted for *task completion.*

Task completion time showed no significant difference between ElderPlay and the Controller (β = -0.153, SE = 0.128, t = -1.19, p = .242).

Mini-task success counts did not differ significantly between input conditions (β = 1.152, SE = 0.833, z = 1.38, p = .167).

Figure 6A illustrates these differences in action-level outcomes. Analysis revealed a higher rate of *successful actions* when using ElderPlay (β = 0.150, SE = 0.0717, p = .037), while *failed actions* did not differ significantly between conditions.

Participants using ElderPlay exhibited substantially fewer *redundant actions* (β = -2.150, SE = 0.492, p < .001) and fewer *control loss events* (β = -1.309, SE = 0.223, p < .001). No significant difference was observed for *unintended actions.*

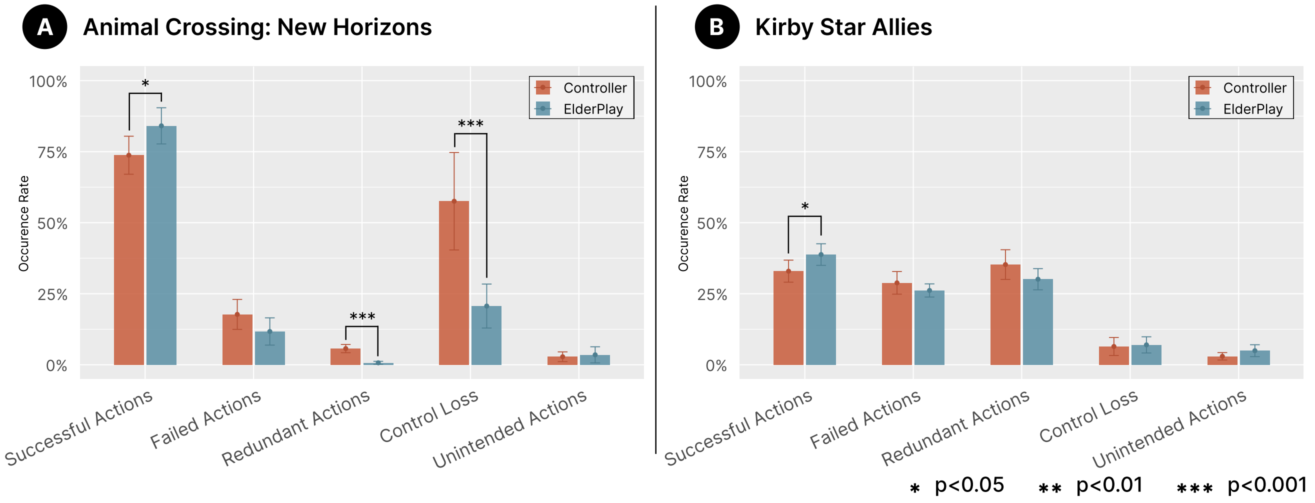

Figure 6: Action occurrence rates comparing *Controller* and *ElderPlay* for two games (*Animal Crossing: New Horizons* and *Kirby Star Allies*) across five action categories: Successful Actions, Failed Actions, Redundant Actions, Control Loss, and Unintended Actions. Bars show mean occurrence rates with 95% confidence intervals (CI); asterisks indicate statistical significance (* p<0.05, ** p<0.01, *** p<0.001). Occurrence rates are computed relative to the total number of valid action attempts per participant, with Control Loss and Unintended Actions reported as the proportion of trials in which such events occurred.

Kirby Star Allies. All participants successfully completed the Kirby task in both the Controller and ElderPlay conditions, yielding a 100% task completion rate. Because no variance was observed, no inferential analysis was conducted for *task completion.*

Task completion time differed significantly between input conditions ($\beta = 0.471$, SE = 0.106, t = 4.43, p < .001), with longer completion times observed when using ElderPlay compared to the Controller.

Mini-task success counts showed a significant condition effect, with higher modeled success rates in the ElderPlay condition. However, as most participants achieved near-ceiling performance (i.e., completing almost all mini-tasks), this effect should be interpreted cautiously and likely reflects limited variability rather than a substantive performance difference.

As shown in Figure 6B, fewer action-level differences were observed for *Kirby Star Allies* compared to *Animal Crossing: New Horizons.* Analysis of *action-level outcomes* revealed a higher number of *successful actions* when using ElderPlay ($\beta = 0.265$, SE = 0.104, p = .011), while *failed actions* did not differ significantly between conditions.

No significant differences were observed between input conditions for *redundant actions*, *control loss events*, or *unintended actions* (all p > .25), suggesting comparable action efficiency and input robustness across conditions.

For *Kirby Star Allies*, *death count* was additionally analyzed as a game-specific outcome. A significant condition effect was observed, with more death events occurring in the ElderPlay condition; however, death events were relatively infrequent overall.

In addition, exploratory Spearman’s rank correlation analyses were conducted to examine associations between baseline control skills and in-game performance metrics. While some weak to moderate correlations were observed for specific metrics, no single control skill consistently predicted in-game performance across games or input conditions. These results suggest that prior interaction ability did not systematically influence performance outcomes. Detailed analyses are reported in the supplementary materials.

5.8.2 ***Subjective Experience and Perception.***

Figure 7 presents the comparative strength-of-preference ratings from 16 participants across two games, contrasting the *Controller* and *ElderPlay* input methods.

Animal Crossing: New Horizons. Participants showed mixed subjective responses across dimensions (Figure 7A). Ratings for physical well-being were significantly higher when using ElderPlay compared to the controller ($p < .001$). In contrast, the controller was rated as requiring significantly less physical effort than ElderPlay ($p < .05$).

Interview responses provide further insight into these findings. Participants consistently associated ElderPlay with increased bodily movement and reduced sedentary behavior, often describing it as a form of light physical activity integrated into gameplay. For example, one participant noted:

> “Using gestures allows me to get up and move instead of sitting still. It feels like combining physical activity with gaming, which is healthier.” — P4 (female, 70)

While enjoyment and ease of learning showed a tendency toward ElderPlay, engagement and ease of use did not exhibit a clear preference between the two input methods. Despite the lack of strong statistical differences, interview data suggested that gesture-based

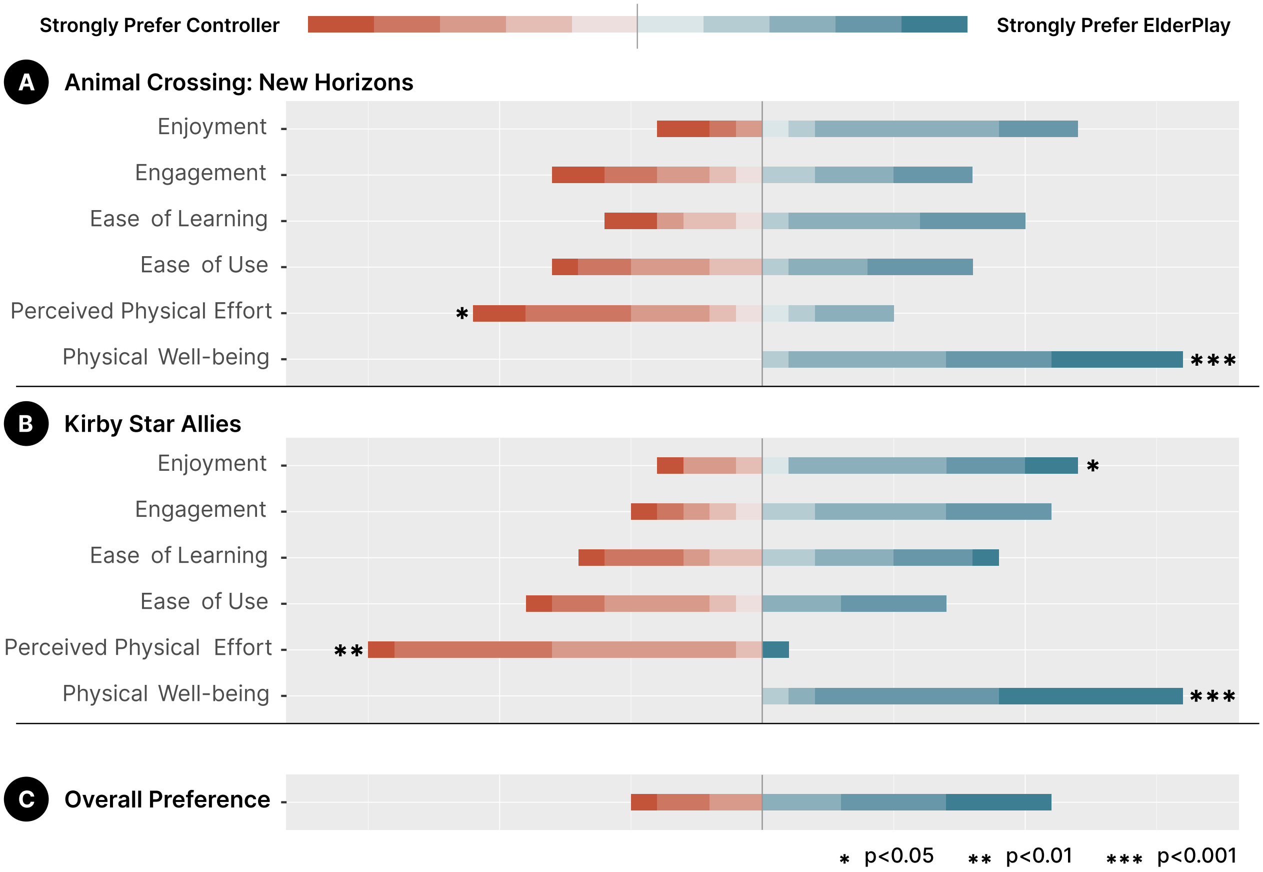

Figure 7: 10-point strength-of-preference ratings comparing the *Controller* and *ElderPlay* input methods across seven dimensions: Enjoyment, Engagement, Ease of Learning, Ease of Use, Perceived Physical Effort, Physical Well-being, and Overall Preference. Ratings were collected after participants experienced two commercial games (*Animal Crossing: New Horizons* and *Kirby Star Allies*). For the Perceived Physical Effort dimension, higher values indicate a stronger preference for the condition requiring less physical effort.

interaction was often perceived as more engaging due to its embodied nature. Participants described that performing everyday-like actions, such as fishing or interacting with objects, made gameplay feel more connected to real-world experiences and increased their sense of involvement.

Kirby Star Allies. A similar pattern was observed in *Kirby Star Allies* (Figure 7B). Participants reported significantly higher enjoyment with ElderPlay than with the controller ($p < .05$), alongside a markedly higher rating for physical well-being ($p < .001$). In contrast, the controller was rated as requiring significantly less physical effort than ElderPlay ($p < .01$).

The increased enjoyment associated with ElderPlay was frequently attributed to the embodied and expressive nature of gesture-based interaction. Participants described that using body movements made gameplay more immersive, engaging, and rewarding. For example:

> "Using body movements to attack felt really fun." — P10

Others emphasized a stronger sense of accomplishment when performing actions through gestures:

> "Using gestures gave me a greater sense of accomplishment. Pressing buttons felt disconnected, but defeating enemies or jumping with body movements felt much more rewarding." — P14 (male, 66)

Although ElderPlay required greater physical effort, participants did not necessarily perceive this as a disadvantage. Instead, many framed the additional effort as beneficial, associating it with active movement and physical engagement:

> "Using body movements feels more physically demanding, but I don't think that effort is a bad thing. It encourages active movement rather than the kind of fatigue that comes from sitting still." — P12 (male, 65)

Engagement showed a weak trend favoring ElderPlay ($p < .1$). Interview responses suggest that this increased engagement was related to heightened physical involvement, sustained attention, and a stronger sense of presence in the game. Participants noted that larger and faster body movements required continuous focus and made gameplay more stimulating.

Overall Preference. Overall preference ratings suggested a marginal tendency toward ElderPlay over the controller across both games (Figure 7C), although individual differences were observed ($p < .1$).

Interview data indicates that this preference was often driven by a combination of increased engagement, enjoyment, and perceived physical benefits. Participants frequently described ElderPlay as a more active and immersive way to experience gameplay, even when it required more effort. At the same time, some participants preferred the controller in situations requiring speed, precision, or reduced physical demand, highlighting a trade-off between efficiency and embodied engagement.

Control Skills and Subjective Experience. Exploratory Spearman's rank correlation analyses were conducted to examine associations between baseline control skills and subjective preference ratings (see Supplementary Figure S1). While some weak to moderate correlations were observed for specific dimensions, no single control skill consistently predicted subjective experiences or overall preferences across games. These findings suggest that participants' perceptions of gesture-based interaction were not strongly determined by prior controller proficiency. Detailed results are provided in the supplementary materials.

5.8.3 Additional Qualitative Insights.

Perceptions of Control and Breakdowns. Participants reported distinct sources of control and breakdown across the two input methods. Several participants described **a stronger sense of control with ElderPlay**, attributing this to the direct mapping between body movements and in-game actions, which enabled more intuitive, moment-to-moment interaction. For example, one participant noted:

> "When playing *Kirby* with gestures, I felt a higher level of control and more intuitive reactions, similar to responding naturally in sports." — P15 (male, 67)

However, control breakdowns were observed in both conditions. For ElderPlay, breakdowns were primarily associated with gesture recognition inconsistencies or difficulty maintaining stable tracking during continuous movements. In contrast, breakdowns in the controller condition were commonly attributed to fine motor demands and difficulties recalling button mappings. Across both input methods, tasks requiring precise timing or coordination (e.g., flying or jumping) remained challenging, suggesting that certain gameplay mechanics may be inherently difficult regardless of input modality.

Gesture Naturalness and Learnability. Most participants described the gesture-based interaction in **ElderPlay as natural, intuitive, and easy to learn**. Gestures were often perceived as closely aligned with everyday movements, requiring minimal effort to understand or remember. Participants highlighted that actions such as attacking, jumping, or fishing felt immediately understandable due to their resemblance to familiar real-world behaviors. For example:

> "All of the gestures were easy to learn. The movements felt like they were supposed to be done this way, as they resembled familiar everyday actions." — P15 (male, 67)

Nevertheless, a few participants noted that certain gestures required initial adjustment, particularly when system recognition did not fully align with their expectations. Despite this, participants generally attributed interaction difficulties with traditional controllers to the need to remember button mappings rather than to the interaction itself. In contrast, gesture-based input allowed actions to be performed through direct bodily movements, reducing reliance on abstract memorization and supporting a more intuitive and continuous learning process.

Intergenerational and Social Play Potential. Although the study focused on individual gameplay, many participants described scenarios in which they would be interested in playing together with family members. Participants particularly highlighted the **visibility of body-based actions** as a key factor enabling social interaction. Unlike controller input, gestures made players' actions observable to others, supporting discussion and shared understanding during gameplay. One participant noted:

> "Using gestures to play together feels more interactive. You can see what others are doing and discuss strategies, which creates more interaction between people." — P15 (male, 67)

Beyond interaction, gesture-based input also appeared to **lower psychological barriers to participation**. Several participants reported increased willingness to engage in family gameplay after using ElderPlay, even if they previously felt hesitant. For example:

> "I wasn't familiar with how to play before, and I felt that I would need someone to teach me step by step. I used to worry that children wouldn't have the patience, so I would just give up trying. But now I feel that I could try playing with my family." — P6 (female, 69)

At the same time, some participants noted that controller input may still be preferred in fast-paced or precision-critical scenarios, indicating a trade-off between efficiency and social engagement.

5.9 Findings

We synthesize results from objective performance metrics, subjective ratings, and qualitative feedback to examine how older adults experienced gameplay using ElderPlay.

Enhanced Engagement and Participation. Across both games, participants' experiences suggest that ElderPlay supported a more engaging and participatory form of gameplay. While objective performance metrics showed comparable task completion across input conditions, ElderPlay was associated with higher levels of successful actions and fewer control-related errors in certain contexts.

Subjective ratings and interview responses further indicate that participants often found gesture-based interaction more engaging and enjoyable. Many participants described that performing actions through body movements increased their sense of involvement and connection with the game. Rather than relying on abstract button mappings, gestures enabled more direct and intuitive interaction, which participants reported as easier to follow and more meaningful during gameplay.

Perceived Physical Well-being and Bodily Engagement. Participants consistently associated ElderPlay with increased bodily movement and perceived physical well-being. Compared to controller-based input, gesture-based interaction was often described as encouraging active movement and reducing sedentary behavior.

Although ElderPlay required more physical effort, this effort was not always perceived negatively. Many participants framed bodily movement as beneficial, describing gameplay as similar to light physical activity or exercise. These responses suggest that physical engagement can play a meaningful role in shaping gameplay experiences for older adults.

Differences in Effort and Interaction Preference. Participants expressed differing preferences between controller-based and gesture-based interaction. The controller was generally perceived as requiring less physical effort and was preferred in scenarios that demanded precision, speed, or prolonged use.

In contrast, gesture-based interaction in ElderPlay was often preferred for its intuitive and expressive interaction style, particularly in actions that involved direct bodily mapping. Participants described gesture-based interaction as more immersive and engaging, even when it required greater effort.

These findings highlight a fundamental trade-off between efficiency and embodied engagement across input modalities, indicating that the effectiveness and preference of gesture- and controller-based interaction depend on gameplay context, task demands, and users' physical conditions.

Control Perception and Breakdown Sources. Participants reported distinct sources of control and breakdown across input methods. With ElderPlay, control was often associated with the direct mapping between body movements and in-game actions, which supported intuitive reactions during gameplay. However, breakdowns occasionally occurred due to gesture recognition inconsistencies or difficulties maintaining stable tracking.

In contrast, breakdowns in the controller condition were more commonly attributed to difficulties with button mappings and fine motor control. Across both input methods, tasks requiring precise timing or coordination remained challenging, indicating that certain gameplay demands may be inherently difficult regardless of input modality.

Social and Intergenerational Play Potential. Participants' responses suggest that gesture-based interaction may influence how gameplay is experienced in social contexts. Unlike traditional controller input, body-based gestures externalize players' actions, making them visible and interpretable to others in the environment. This visibility can support shared understanding and coordination during gameplay, as co-players are able to observe actions directly rather than relying on abstract button inputs. Such characteristics may reduce the need for explicit instruction and facilitate more natural communication, particularly in intergenerational settings where familiarity with game controllers may differ. Beyond coordination, prior work has shown that body movement can also serve as a medium for expression and communication in gameplay, contributing to more engaging and socially rich experiences [7]. This suggests that gesture-based interaction may not only support task execution but also enable more expressive and socially meaningful forms of play. These two aspects, coordination and expression, further illustrate how embodied interaction can support richer social dynamics in gameplay.

5.10 Design Considerations

Based on our findings, we identify several considerations for designing inclusive game interaction for older adults.

Gesture Intuitiveness and Familiarity. Our findings reinforce that gesture-based interaction is more intuitive when grounded in familiar, everyday actions. Participants were able to leverage their lived experiences to interpret and perform gestures, suggesting that familiarity plays an important role in reducing cognitive effort and supporting learnability.

Balancing Physical Effort and Engagement. Our results indicate that physical effort in gesture-based interaction is not inherently negative. While excessive effort can reduce usability, moderate bodily movement was often associated with increased engagement and perceived enjoyment. This highlights a tension between minimizing effort and maintaining meaningful bodily involvement.

Context-Dependent Input Preferences. Participants' preferences for gesture-based and controller-based interaction varied depending on gameplay context, task demands, and individual physical conditions. This suggests that no single input modality is universally optimal, and that interaction effectiveness depends on how well input methods align with specific gameplay situations.

Flexible Play Contexts. While our findings highlight the social potential of gesture-based interaction, they also suggest the importance of supporting flexible play contexts. Participants expressed interest in both independent and shared gameplay experiences, indicating that interaction design should accommodate a range of play scenarios.

6 GENERAL DISCUSSION

Across both studies, ElderPlay showed strong potential to encourage older adults' participation in gameplay. Building on this, we discuss how these findings contribute to broader perspectives on game interaction design.

6.1 Bridging Exergames and Commercial Games

Our findings highlight a fundamental gap between existing exergame systems and mainstream commercial gaming. Prior work has shown that gesture-based interaction can improve engagement, accessibility, and physical activity for older adults, particularly in rehabilitation and training contexts [38, 39]. However, these systems are typically designed as standalone applications with predefined tasks and limited interaction spaces [9].

Our results extend this line of work by demonstrating that gesture-based interaction can be applied to unmodified commercial games through real-time input translation. Participants were able to engage with existing games using body-based interaction while maintaining functional task performance to traditional controllers. This suggests that gesture-based approaches can move beyond specialized applications and support more open-ended, real-world gaming experiences.

6.2 Trade-offs Between Gesture and Controller Input

Across both studies, we observe a consistent tension between gesture-based and controller-based interaction. Gesture input was often perceived as more intuitive, engaging, and expressive, particularly for discrete and action-oriented tasks. Participants reported that bodily movements increased their sense of involvement and made gameplay more meaningful. However, gesture-based interaction also introduced challenges related to physical effort, precision, and system recognition [9]. Tasks requiring continuous control, rapid input, or fine-grained coordination were often better supported by traditional controllers. These observations align with prior work on embodied interaction, which highlights both the benefits of physical engagement and the constraints introduced by bodily input [9, 11].

Rather than viewing gesture-based and controller-based input as competing paradigms, our findings suggest that they offer complementary strengths. Gesture-based interaction is better suited for discrete and expressive actions, whereas controller input supports continuous control and precision. This distinction suggests that gesture-based and controller-based input naturally support different types of gameplay actions.

6.3 Designing for Accessibility Through Embodied Interaction

Building on our findings from the gesture elicitation and feasibility studies, our results suggest that gesture-based interaction can support accessibility by leveraging users' existing bodily knowledge. Rather than requiring users to learn and recall abstract button mappings, gesture-based input enables users to perform actions through direct movement. This shift from symbolic input to embodied action may reduce the need for explicit memorization and support more immediately interpretable interaction [2], particularly for older adults who may experience difficulties with memory, coordination, or unfamiliar control schemes. As a result, gameplay interaction can become easier to understand and less reliant on memorization, supporting more sustained engagement over time.

Our findings also contribute to a broader understanding of accessibility in game interaction. Traditional approaches often focus on simplifying interfaces or adapting controller configurations [31, 44], aiming to reduce interaction complexity within existing input paradigms. Prior work on exergames has demonstrated the benefits of embodied input for accessibility and engagement [9], but these systems are often developed as standalone applications with limited interaction scopes and restricted gameplay scenarios. In contrast, gesture-based interaction in our work enables access to unmodified mainstream games by translating bodily movements into standard controller inputs. This points to an alternative approach to accessibility: one that not only aligns interaction with users' existing bodily skills and experiences, but also expands access to a broader range of existing game content, without requiring the creation of specialized applications.

At the same time, our results indicate that accessibility is not achieved simply by replacing one input modality with another. Prior work on exertion-based interaction frames physical effort as a design dimension that can both support and constrain user experience [11]. Extending this perspective, our findings show that physical constraints, fatigue, and recognition reliability all influence usability in gesture-based interaction. Designing accessible systems therefore requires balancing intuitiveness, physical effort, and control, rather than optimizing a single dimension.

6.4 Context-Dependent Interaction

Taken together, our quantitative results and qualitative feedback suggest that the effectiveness of game interaction is inherently context-dependent, shaped by task characteristics, gameplay dynamics, and individual user abilities and preferences. Rather than viewing gesture-based interaction as a universal replacement for traditional controllers, our findings highlight that different input modalities afford distinct strengths across gameplay situations. Gesture-based interaction is particularly advantageous for expressive, discrete, and action-oriented tasks, especially in cases where users experience difficulty with fine-grained button input, whereas controller-based input remains more suitable for tasks requiring continuous control, precision, and sustained navigation. These findings highlight the importance of aligning interaction modalities with gameplay demands rather than relying on a single input paradigm.

6.5 Implications for Inclusive Game Interaction Design

Together, our findings suggest four key design implications for inclusive game interaction systems for older adults.

First, **design interaction techniques that support compatibility with existing commercial games**, rather than requiring the creation of specialized content. Approaches that adapt or translate user input to existing control schemes can enable access to mainstream titles, thereby expanding opportunities for participation and social play [32, 35].

Second, **adopt hybrid interaction approaches that combine multiple input modalities to accommodate diverse user needs and gameplay contexts**. Our findings indicate that different types of actions are better supported by different forms of input, such as gesture-based interaction for discrete and expressive actions, and controller-based input for continuous navigation and precise control [14].

Third, **leverage embodied interaction to enhance engagement and social visibility in gameplay**. By aligning bodily actions with in-game effects, gesture-based interaction can foster a stronger sense of connection to the digital experience, contributing to enhanced emotional engagement and immersion [7].

Finally, **balance physical engagement with usability when designing interaction**. While increased movement can enhance enjoyment and perceived well-being, excessive physical effort or unreliable recognition may reduce accessibility. Designing for older adults therefore requires careful calibration of physical demand and interaction fidelity [9, 11].

7 LIMITATION AND FUTURE WORK

While our feasibility study demonstrates the potential of ElderPlay to enable older adults to engage with mainstream commercial games, several limitations highlight important directions for future work.

Generalizability Across Games and Interaction Contexts. Our evaluation focused on two commercial games, which limits the generalizability of our findings across the full range of game genres and control schemes. However, our goal is not to exhaustively evaluate all game types, but to demonstrate the feasibility of enabling access to mainstream games through gesture-to-controller translation. The selected games were intentionally chosen to represent contrasting interaction demands, allowing us to examine how gesture-based input performs across different gameplay contexts. Our findings suggest that the effectiveness of interaction techniques is context-dependent, particularly across different types of gameplay actions (e.g., discrete vs. continuous). Thus, rather than generalizing to specific games, this work contributes interaction-level design insights for aligning input modalities with gameplay characteristics. Future work should extend this approach to a broader range of genres and interaction contexts.

Intergenerational and Social Play Contexts. First, our feasibility study focused on older adults playing independently, without examining co-located or intergenerational gameplay settings. While participants described potential interest in playing with family members, the current study does not provide empirical evidence on how gesture-based interaction functions in shared play contexts. As a result, it remains unclear how such interaction would influence communication patterns, coordination strategies, or social dynamics during gameplay. Future work should investigate dyadic or group play scenarios (e.g., older adults playing with children or grandchildren) to better understand how gesture-based interaction supports collaborative and socially embedded gameplay experiences.

Gesture Recognition and System Scalability. Second, the current ElderPlay system relies on a predefined gesture set and rule-based recognition pipeline. This approach was intentionally chosen to ensure interpretability, stability, and feasibility for a small-sample user study with older adults. Nevertheless, rule-based systems inherently limit scalability and adaptability to a wider variety of gestures, body types, and play contexts. Future work could explore integrating machine learning or large language model–based approaches to support more flexible and personalized gesture recognition. Such approaches may enable broader gesture vocabularies and adaptive mappings but also introduce trade-offs related to training data requirements, computational cost, and system transparency. Investigating these trade-offs will be an important step toward deploying gesture-based game interaction systems in real-world, long-term settings.

Accessibility for Diverse Physical Abilities. Third, our studies primarily recruited older adults with relatively intact mobility and the ability to perform upper-body gestures in a standing posture. As a result, the current findings may not generalize to users with more diverse physical conditions, such as wheelchair users or those with limited range of motion. The current gesture design also implicitly assumes standing interaction and sufficient upper-body mobility, which may not be suitable for seated or mobility-constrained users. Future work should explore more inclusive interaction designs, such as seated-friendly gestures, reduced-range movements, or adaptive mappings that can be personalized to users' physical capabilities. Expanding the participant population to include users with varying mobility conditions would further enable a more comprehensive evaluation of accessibility and inclusiveness, and help inform the design of more universally accessible gameplay interaction systems.

Camera-Based Interaction in Real-World Settings. In addition, the current system relies on camera-based gesture recognition, which introduces several practical considerations for real-world deployment. For example, the use of cameras may raise privacy concerns, particularly in domestic or care environments where continuous visual monitoring may be perceived as intrusive. In addition, recognition performance may be affected by environmental factors such as lighting conditions, occlusion, and background complexity. While our controlled study setting ensured stable performance, these factors may impact robustness in everyday contexts. Future work could explore alternative sensing approaches (e.g., wearable or depth-based sensing), as well as privacy-preserving techniques and more robust recognition models to support deployment in diverse real-world environments.

Application to Physically Engaging Game Genres. While our current study focused on general commercial games, future work could explore applying the proposed approach to physically engaging game genres, such as sports or activity-based games. Such genres may further encourage light physical movement and support mobility and well-being among older adults. Importantly, our real-time game input translation approach enables these experiences without requiring the development of specialized games, thereby extending accessibility to a broader range of existing titles.

8 CONCLUSION

In this paper, we presented ElderPlay, a real-time game input translation approach that enables older adults to play mainstream, button-based games through intuitive, motion-based interaction without modifying existing game content. By layering embodied interaction onto commercial games, ElderPlay expands access to existing gaming experiences while preserving their original design. Grounded in older adults' lived experiences, this work combines a co-designed gesture elicitation study with a feasibility evaluation to examine how body-based input can lower interaction barriers and reshape gameplay experiences. Importantly, our findings suggest that gesture-based interaction should not be treated as a replacement for traditional controllers, but rather as a complementary modality that supports different types of gameplay actions. Overall, this research highlights the importance of hybrid and context-dependent interaction design for inclusive gameplay. By showing how different input modalities can be aligned with gameplay demands, we contribute empirical insights and design perspectives for supporting meaningful and accessible gaming experiences among aging populations. We hope this work inspires future research to further explore embodied, co-designed, and multimodal approaches to inclusive game interaction.

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