Makeshift: An Evaluation of Cross-Display Ecologies for Multiplayer Role-Playing Games

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Abstract

Cross-display ecologies are ad-hoc arrangements of synchronised devices that emulate a larger screen, offering unique possibilities for co-located multiplayer gaming. This study investigates cross-display ecologies in the context of multiplayer role-playing games, addressing the limited understanding of their impact compared to traditional co-located gaming, focusing on overall player experience, social presence, and control intuitiveness.

We developed the *Makeshift* framework using the Godot game engine to enable the development of games designed for mobile cross-display ecologies. A demonstration game was created using the framework, supporting being played on both a shared cross-display ecology and on individual handheld devices to allow for a comparison between the two modes. A trial was run with 22 participants in groups of 2-3, with each group playing both game variants. Participants completed surveys assessing factors of player experience and social presence and provided open-ended feedback.

Qualitative feedback showed that players responded positively to the cross-display ecology. Statistical analysis of the quantitative data revealed significant increases in behavioural involvement - the measurement of how much players paid attention to each other's actions - and autonomy - the game's measure of providing interesting choices and possibilities. Players perceived game controls to be intuitive across both game modes. Other factors - psychological involvement, competence, relatedness, immersion, and control intuitiveness - did not show statistically significant changes.

The findings suggest that cross-display ecologies can enhance specific aspects of player experience, particularly in promoting player interdependence. This research highlights the potential of cross-display ecologies to enrich player interaction in co-located multiplayer games and provides insights for future work on co-located gaming.

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Chapter 1

Introduction

1.1 Cross-Device Computing

In his influential work, *The Computer for the 21st Century*, Mark Weiser (1991) envisioned a world where computing devices would disappear from the user's awareness, becoming integrated into the environment to allow users to focus on their tasks rather than on the technology itself. Weiser's vision of *"ubiquitous computing"* proposed a seamless integration of devices that work together to provide natural and intuitive interactions without the user needing to be aware of their underlying complexity.

Cross-device computing builds upon Weiser's vision, focusing on the software and hardware platforms that enable multiple devices to interact and synchronise to provide these intuitive user experiences. It aims to allow devices to share data, resources, and tasks in a flexible, dynamic manner not confined to any particular use case. When co-located devices are aware of one another and collaborate to support the user's goals, they form an *ecology*, a term borrowed from the natural sciences, likening the network of devices to the complex, symbiotic relationships between organisms within an environment. One of the most prominent examples of cross-device computing is Apple's Continuity software, which enables users to transition tasks, including document editing and web browsing, between their Apple devices, including phones, tablets, and computers without disruption.

A key concept in cross-device computing is the idea of proxemic interactions. *Proxemics*, a term coined by Edward Hall (1966), traditionally refers to the study of how people perceive and use physical space in social interactions. In the context of computing, proxemic interactions extend this idea to describe how users and devices interact based on their physical proximity to one another. In the study of proxemic interactions, devices within a defined spatial range can detect each other's presence, location, and capabilities, taking advantage of this information to best serve the user's needs (Ballendat et al.,

(a) Illustration of a cross-display ecology in a regular configuration.
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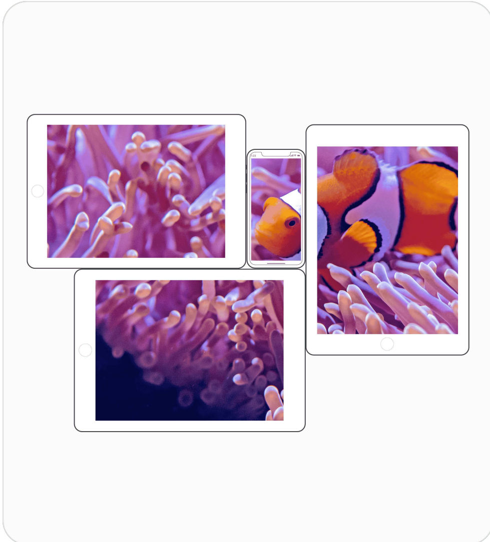


(b) Illustration of a cross-display ecology in an irregular configuration.
Photo by David Clode, used under Unsplash license.

Figure 1.1: Examples of cross-display ecologies displaying a photo distributed across multiple mobile devices.

2010). This method enables more natural user interactions, as the ability for devices to interact relies on proximity instead of abstract network configurations, aligning proxemic interactions closely with Weiser's vision of seamless, ubiquitous computing.

An area of study within cross-device computing is the concept of *cross-display ecologies*, also known as multi-display environments (Brudy et al., 2019), representing a shift away from the tight coupling between devices and their individual screens. A cross-device ecology involves forming an aggregate display using the screens of multiple devices, orchestrating them to allow content to span across the screens as though they were one. For instance, a series of mobile phones or tablets could be arranged to create a cross-device ecology showing a video or a photo at a higher resolution, with each device contributing a portion of the image being shown (see Figure 1.1).

1.2 Gaming Venues

In the context of video games, there is often focus placed on the devices on which games are played - for instance, consoles, PCs, mobile devices, and handhelds - but less attention is given to the physical venues that influence how games are experienced. One such venue is the "gaming table", an environment traditionally associated with board games, card games, and tabletop role-playing games (Schell, 2020). A gaming table provides an intimate social setting where players gather around a shared surface, facilitating face-to-face interaction and communal play. Despite the popularity of this type of play in physical games, the gaming table has seen limited use in the context of video games.

Interactive tabletop displays, which appear to be a natural fit for adapting the gaming table venue to video games, have not reached widespread adoption due to their high costs and heavy, immobile hardware requiring a permanent installation (Brudy and Marquardt, 2017). While research has explored the potential of tabletop touch displays for gaming (Antle et al., 2010; Piper et al., 2006; Chaboissier et al., 2011), tabletop video games remain uncommon due to the platform's barriers to adoption.

1.3 Social gaming

Throughout history, play has been inherently social, with games serving as a means for interaction, cooperation, and competition. From ancient board games to physical sports, games have acted as a way to bring people together from different backgrounds. The rise of video games continued this tradition, initially through arcades, where gaming was a public and social experience, with players gathering around machines to compete and cheer each other on. As gaming moved into homes, the social aspect persisted, with early consoles fostering shared experiences in living rooms. In more recent years, online multiplayer gaming has expanded the boundaries of these social connections, allowing players to engage with other players around the world.

Just as the term "ubiquitous" applies to Weiser's vision of omnipresent but invisible computing in daily life, it equally describes the nature of modern online multiplayer gaming. With nearly everyone carrying a smartphone capable of playing with players from anywhere around the world at a moment's notice, online gaming has become a constant and accessible form of social interaction. This accessibility has made it easier to join online gaming communities that are distributed across the world. Moreover, the rise of technologies like virtual reality and augmented reality has further enhanced these experiences, providing increasingly more immersive and lifelike interactions with other online players in virtual worlds.

While online gaming provides increased opportunities for social interactions, questions remain about the depth and quality of these social relationships compared to co-located play. Online gaming does contribute to social well-being, with many players forming meaningful friendships that extend into real life (Trepte et al., 2012; Uz and Cagiltay, 2015; ESA, 2024). However, studies suggest that online interactions may lack the same level of emotional and physical engagement found in face-to-face gaming (De Kort et al., 2007). Online gaming often has more limited communication mediums, and the resulting interactions may sometimes fall short of the rich and complex social engagement associated with physical proximity, raising concerns about the long-term impact on players' social well-being and support networks.

Social presence refers to the measure of how co-players experience and respond to one another psychologically and behaviourally (Biocca et al., 2003; De Kort et al., 2007). In recent years, a growing body of research has focused on how to enhance social engagement and presence in gaming (Gonçalves et al., 2023), both in online and co-located settings, exploring mechanics like cooperative or interdependent play (Depping and Mandryk, 2017; Depping et al., 2018), synchronised physiological behaviour (Robinson et al., 2020) and asymmetric roles (Harris and Hancock, 2018).

1.4 Gaming on Cross-Display Ecologies

The concept of gaming on cross-display ecologies brings together the ideas of cross-device computing, tabletop gaming, and social gaming, offering a largely unexplored form of co-located multiplayer gaming. Users can connect tablets and phones to form a flexible, ad-hoc *gaming table* venue. This approach retains the benefits of mobile gaming, such as portability and the ability to play in various environments, even outdoors, while providing the larger, more social environment provided by tabletop displays.

Research on gaming with cross-display ecologies has so far been limited, primarily focusing on a small range of genres, particularly casual puzzle games, and collaborative games (Barendregt et al., 2017; Eriksson et al., 2022; Huang et al., 2012; Ohta and Tanaka, 2012). While these genres naturally lend themselves to co-located play, many popular genres, such as adventure, shooters, and other role-playing games, remain unexplored. Cross-device ecologies show promise for these video game genres, but there are research and user experience challenges that need to be addressed.

1.5 Research Questions

From the gaps identified in the literature, the following research questions for this thesis are outlined:

1. Does the use of cross-display ecologies increase players' sense of social presence compared to using individual devices in co-located multiplayer role-playing games?

2. What is the effect of cross-display ecologies on overall player experience compared to using individual devices co-located multiplayer role-playing games?

3. How do cross-display ecologies affect players' perceptions of control intuitiveness, and what user experience challenges are associated with their use for multiplayer role-playing games?

1.6 Contributions

As outlined in the research questions, the goal of this thesis was to investigate the impact of cross-display ecologies on player experience, social presence, and control intuitiveness in co-located multiplayer role-playing games. To achieve this, we developed the *Makeshift* framework, a library for the popular Godot game engine that allows games to be developed supporting being played on cross-device ecologies, with a focus on role-playing games. A demonstration game was designed using the framework, allowing a direct comparison between playing on a cross-device ecology versus using individual devices.

We conducted a user study with 22 participants, collecting quantitative and qualitative data on the players' experiences of the two game modes. We analysed the quantitative data to reveal statistically significant trends and performed thematic analysis on the qualitative data to identify common feedback themes.

Chapter 2

Related Work

2.1 Social Engagement in Games

Social gaming has been shown to have numerous positive benefits on psychological well-being (Halbrook et al., 2019). Research has shown that social gaming is positively correlated with both online and offline emotional support, fostering connections that can enhance strong social capital (Trepte et al., 2012). Studies and surveys indicate that half of gamers have formed friendships through online video gaming, with many of these relationships transitioning into in-person interactions (Uz and Cagiltay, 2015; ESA, 2024). Accordingly, there has been extensive research into identifying what aspects of gaming can best promote social engagement, especially as social gaming increasingly takes place online rather than in-person.

In order to measure the complex dynamics of social interactions in games, the concept of *social presence* is often used. Biocca et al. (2003) define social presence based on the ideas of copresence, psychological engagement, and behavioural engagement. Drawing from theories of the social psychologist Erving Goffman, they outline how *copresence* is distinct from *spatial presence*, involving not just being physically nearby but also involving sensory awareness of one another. Building on this idea, they define two forms of awareness, with psychological engagement referring to the understanding of each other's mental state and agency, and behavioural engagement referring to the attention to each other's physical actions and cues. This theory has been extended to gaming, where social presence is often used as a way to measure the quality of interactions between game participants (Gonçalves et al., 2023). De Kort et al. (2007) found that physical proximity plays an important role in the experience of social presence, with co-located interactions naturally facilitating non-verbal communication like eye contact and body language. However, in line with Biocca et al.'s theory of social presence, they found that physical proximity alone isn't a sufficient factor, with aspects of the environment and the game's content and interface also needing to be considered in a game's potential to promote social presence.

In-person gaming interactions involve subtle social cues that are challenging to replicate in online environments. Phenomena like the *chameleon effect*, the unconscious mimicking of other people's expressions, postures, and other physical behaviours, help to create a sense of empathy and understanding between individuals (Chartrand and Bargh, 1999). In attempting to create a virtual reality experience resembling co-located gaming, with player avatars sitting side by side playing on a virtual screen, Sykownik et al. (2023) found several factors that made it difficult to replicate the full depth of in-person social presence. They found that the lack of facial animations, limited body language, and a limited field of view inhibited facets of the social experience, resulting in reduced mutual awareness and emotional comprehension. These natural dynamics are often missing in online games, even when using mediated environments that attempt to recreate the richness of face-to-face interactions. Robinson et al. (2020), developed *"In The Same Boat"*, an online game designed to synchronise players' physiological activities, with the goal of promoting cooperation, concentration, and engagement among players. In the game, two remote players were tasked with coordinating their breathing and facial expressions to control a virtual boat and overcome obstacles. They compared playing with physiological inputs against playing with traditional keyboard controls, through a self-reported scale and through evaluating before and after photos based on perceived happiness and closeness, finding that participants assigned to the physiological controls appeared happier and closer despite not performing as well in the game, and enjoyed the gameplay despite perceiving the controls as less intuitive.

Cooperation is often a central focus of studies on social gaming as a means to promote social engagement (Gonçalves et al., 2023). However, Depping et al. (2017) identified *interdependence*, the degree to which players must rely on one another, as a more important factor than cooperation. They outlined how a competitive game high in interdependence can still promote greater player connection. Their findings demonstrated that cooperation and interdependence are additive in promoting social closeness, supporting a focus on interdependent cooperation in social gaming. One means to promote interdependence in cooperative games is through asymmetric player roles, where players have different game abilities, goals or information. Harris et al. (2018; 2019) compared several forms of symmetric and asymmetric play, finding that asymmetry reliably promotes social presence and perceptions of connectedness. Additionally, they pointed out that asymmetric games can connect together players with different preferences and personalities, by offering different experiences to each participant.

The potential for social games to facilitate the forming of connections extends beyond entertainment, with research demonstrating their use as alternatives to traditional social ice-breakers, additionally having the benefit of being well-suited to online environments such as remote workplaces. Depping et al. (2016) showed that social games can be effective in connecting distributed teams, through simulating risk and interdependence as means to promote trust between unacquainted players. They found that social games were more effective and reliable than traditional ice-breakers, promoting trust between participants regardless of their demographics, inherent propensity to trust, enjoyment of the game, or agreeableness. Social gaming can therefore be used as a way to both facilitate the formation of new relationships (Garcia et al., 2022) as well as to strengthen existing relationships (Trepte et al., 2012).

2.2 Tabletop Gaming

Interactive tabletops are large, digital surfaces that support touch inputs from multiple users simultaneously, making them inherently social and collaborative. They are most commonly employed in public settings, like museums and galleries, where they provide information in an interactive and engaging manner (Coppola et al., 2020); schools, where they promote teamwork between students through educational software (Antle et al., 2010; Piper et al., 2006); and business settings, where they can be used for collaborative work between employees (Zagermann et al., 2016).

Additionally, there has been research investigating interactive tabletops' use as gaming platforms, both as a way to enhance traditional tabletop board games and role playing games (Mandryk and Maranan, 2002; Chaboissier et al., 2011), as well as to explore the novel gameplay mechanics made possible by the displays (Dang and André, 2013).

Although interactive tabletops can promote social engagement, care still needs to be taken in designing collaborative tabletop software and games to achieve this goal. Zagermann et al. (2016) found that when using larger tabletop sizes, there was a reduction in eye contact between users, as participants tended to focus more on the shared display, even when it was not displaying relevant information. This shift in attention away from face-to-face interaction suggests that larger tabletops may inadvertently diminish the social interaction that they aim to support, highlighting the need for careful design choices to maintain user engagement and collaboration.

2.2.1 Orientation Independence

Orientation independence refers to the ability for users to interact with a shared display from any angle. This feature promotes social interaction and behavioural engagement by allowing players to gather around the display, facilitating opportunities for eye contact and non-verbal communication. For games, it contrasts setups where all the players are using individual devices or are positioned in parallel facing a single screen, which can limit opportunities for direct interaction, even when players are physically close (Magerkurth et al., 2004a; De Kort et al., 2007).

One approach to achieving orientation independence in games is through the use of fully symmetrical game objects and a perpendicular top-down perspective (Mandryk and Maranan, 2002). While this method ensures consistent gameplay for players seated at different angles, it can impose limitations on both visual design and gameplay complexity. Text, in particular, presents a challenge, as it must either be avoided or displayed in multiple orientations to be accessible to all players (Reda et al., 2014). This principle should not only be applied to graphical content but should also be extended to game logic, ensuring that game mechanics function consistently from all angles. If a game implements gravity, for example, it must be carefully designed to avoid confusion for players viewing from different angles.

Another approach is applied in turn-based games, where content, or even the whole board, is rotated to face the user whose turn it is, or even increasing the size of game windows relative to the distance to the player whose turn it is, and hiding or increasing the transparency of windows that are not relevant to the current user (Magerkurth et al., 2004b, 2005). Games may also use a combination of these two approaches, with a small area directly in front of each user displaying controls or text from that player's perspective, with the rest of the game being symmetrical. Orientation can also be used as a means to indicate a game object's ownership (Nacenta et al., 2007).

2.2.2 Territoriality

Territoriality refers to how users perceive the different parts of the tabletop while interacting with other users. Scott et al. (2004) examined the use of territoriality in a variety of tabletop settings, including both gaming and collaborative work, and identified three types of tabletop territories: personal, group, and storage. Personal territories refer to areas of the displays where individuals kept virtual items they were actively using, group territories are areas for communal interaction, and storage territories are areas where virtual items were temporarily placed until they were needed.

Territories can be explicitly defined by the user interface, or they can form organically in a manner analogous to Hall's concept of proxemics, which describes how people intuitively think about physical space in the context of social interactions (Hall, 1966). Additionally, the physical layout of tabletops, such as the inability to easily reach across the table, also influences how territorial boundaries are formed. Territoriality can be both an advantage and a challenge in the design of tabletop interfaces. Games can take advantage of territoriality to provide each user with individual controls or to naturally guide users towards specific behaviour (Piper et al., 2006), and territories can help maintain a balance between individual participation and group collaboration. At the same time, territoriality can interfere with the goal of promoting interdependent activities (Xambó et al., 2013). One way to prevent the formation of the natural territories formed by proximity is through the use of remote manipulation, enabling users to control game objects outside their nearby screen area through, for example, a minimap in front of them (Nacenta et al., 2007).

Related to the idea of territories is the distinction between public and private information on interactive tabletops. When the playing area is fully shared, there is little opportunity for asymmetric or secret information. Asymmetric information is an important factor in many games and can be used to promote both cooperative (Pais et al., 2024) and competitive gameplay (Magerkurth et al., 2004b). To address these challenges, some game designs have taken the approach of combining the use of tabletop displays with personal devices, with the tabletop game sending secret information to the users via their personal devices (Magerkurth et al., 2004b; Zagermann et al., 2016; Brudy et al., 2018), helping to keep the shared tabletop display a neutral area.

2.2.3 Multi-User Input

Multi-touch interactive screens provide the ability to detect multiple simultaneous touch events, but when multiple users are using the display, game designers may additionally need to associate touch inputs with specific users. One of the most common solutions is to design games in a way that does not require distinguishing between users. This can be achieved by embracing territoriality, where players' controls and personal game items are placed directly in front of them, and using distance as a natural way to prevent disallowed interactions. Similarly, turn-based games can assume that touch inputs are coming from the current active user, and leave it up to the players to socially enforce this.

Software approaches include analysing the touch "blobs" to infer the orientation of the finger and thus which user is performing the touch event (Wang et al., 2009). This has the advantage of not needing any specialised hardware but may lack precision during the fast-paced interactions that often occur in video games.

There are several approaches that require additional components or specialised tabletop hardware. Fiberio (Holz and Baudisch, 2013) demonstrated an interactive tabletop system featuring full-screen fingerprint recognition by constructing the display with a large fiber optic plate, able to identify the fingerprints in a frame in 21ms. The DiamondTouch interactive tabletop (Dietz and Leigh, 2001) involves placing a receiver pad on each participant's chair; when the users touch the screen, a circuit is completed from the receiver pad to the display, allowing it to associate the input with the user. Piper et al. (2006) employed this feature to enforce game rules and manage ownership in a collaborative game for children, ensuring that players could only move their own game pieces and could only perform actions in their turn. Other solutions rely on overhead cameras to track users' hand positions and associate them with the more precise capacitive touch inputs (Döweling et al., 2016).

2.3 Cross-Device Computing

Cross-device computing refers to the interaction between multiple co-located devices to accomplish tasks that would traditionally be confined to individual devices, forming a device *ecology*. Forms of cross-device computing vary widely in characteristics, including the following identified by Brudy et al. (2019) and Garcia-Sanjuan et al. (2016):

- ***Temporality***, being either synchronous (e.g. using two devices side-by-side) or asynchronous (e.g. starting a document on a computer and then transitioning to a tablet)

- ***People-to-device relationships***, varying from one user using multiple devices ($1..n$), multiple users all using the same set of shared devices ($m..n$), or multiple users each using one or more devices ($[1..n]^m$), including a mix of individual devices and shared devices.
- ***Scale***, the physical dimension of the interactions, relating to Hall's (1966) scale of social interactions (near, social, personal, and public), and the dimensions of the devices, often categorised using Weiser's (1991) scale of *inch*, *foot*, and *yard*. Ecologies will usually be of the next size up from the devices it is made up of, extending into the imperial measurements *perch* and *chain* as suggested by Terrenghi et al. (2009).
- ***Dynamics*** *or* ***Mobility***, being made up of ad-hoc devices (usually mobile phones and tablets) or fixed setups (e.g. large-scale wall displays or tabletops)

Devices in a cross-device ecology often need to determine the relative positions of one another in order to offer intuitive proximity-based interactions or to synchronise displays or content spatially. To achieve this, there are three main approaches for determining relative positions: outside-in tracking, passive inside-out tracking, and interactive inside-out tracking.

2.3.1 Outside-In Device Tracking

Outside-in tracking relies on external infrastructure or sensors to track the relative positions of devices. A common approach in this category makes use of an overhead RGB or depth camera to track devices, either on a table surface (Rädle et al., 2018) or in a room (Marquardt et al., 2012). Optical tracking can offer high-precision tracking and can track devices over time. However, they are generally limited to fixed setups and suffer from limitations due to visual occlusion. Rädle et al. (2014) developed *HuddleLamp* to address optical tracking's limited mobility, designing a compact unit that replaces the lightbulb in a desk lamp, allowing desks or tables to easily be turned into a tracked environment to support cross-device interactions.

Other outside-in approaches include using sensors or markers attached to the edges of devices, allowing them to detect when any two devices are side-by-side. Connectables demonstrated this through built-in sensors along the edges of the custom appliances (Tandler et al., 2001), and MagMobile extended this idea to mobile devices by creating a phone case containing magnets and magnetic field sensors. Like overhead cameras, this approach makes use of specialised hardware, which can limit its practicality in developing applications for a general audience.

2.3.2 Passive Inside-Out Device Tracking

Passive inside-out tracking, in contrast, refers to devices using their own sensors, including built-in cameras, accelerometers, or radio signals, to determine the relative position of nearby devices. Passive inside-out tracking is especially well suited to improvised and mobile setups, not requiring any external hardware beyond the devices being used, and often supporting continuous tracking over time.

Jin et al. (2015b) presented *Corona*, which takes advantage of Bluetooth Low Energy (BLE) signals to estimate the relative positioning devices by examining the RSSI distribution created by the devices' BLE antennas. *Corona* additionally uses built-in accelerometers as an additional data source to resolve ambiguity, enabling devices to determine relative positions with 50% accuracy within a 2cm range.

Several systems have demonstrated the use of audio signals to track the relative positions of mobile devices, relying on the timing and volume differences between devices, with accuracy ranging from 2cm to 6.5cm in close proximity up to 15cm at distances of several meters (Jin et al., 2015a; Qiu et al., 2011; Zhang et al., 2012). Zhang et al. (2012) showcased how acoustic positioning can be used to create real-time movement-based games, emulating sword fighting with each player's phone acting as their sword. By accounting for low background noise and Doppler shifts, they were able to achieve 2cm accuracy, although the system tracked relative distances rather than positions. Jin et al. (2015a) developed *Tracko*, which uses inaudible sounds in contrast to prior work and is able to track 3D relative positions without requiring any prior calibration. Despite various approaches to account for noise, all of these systems have limitations when it comes to noisy environments, which would be typical in a gaming context.

Another approach to inside-out tracking in cross-device ecologies involves the use of built-in cameras. Li et al. (2012) developed a system that used the front-facing cameras of devices to track a marker placed on the ceiling, allowing the devices to be positioned on a flat surface in order to create a larger tiled display. In contrast, Dearman et al. (2012) used devices' rear-facing cameras to track common visual features such as the users' shoes, as a means to determine the positions of hand-held devices. This latter context, being more mobile, can tolerate a larger margin of error, but demonstrates that Li et al.'s work could potentially be adapted to not require a dedicated marker on the ceiling, instead identifying common visual features such as ceiling textures, lighting variations or light fixtures.

2.3.3 Interactive Inside-Out Device Tracking

Interactive inside-out tracking requires the users to perform some kind of action in order for the relative positions to be determined. It often involves detecting the same or synchronous user input from separate devices and inferring the intention to link them together, for example detecting two devices being bumped together (Hinckley, 2003).

SurfaceLink, by Goel et al. (2014), is a framework that allows users to transform a table into a multi-touch input surface by simply placing mobile devices on it, being able to detect and identify complex gestures on the table through the devices' accelerometers and microphones. It additionally uses these gestures as a way to calculate the relative arrangements of the devices, by comparing the different peaks in the vibrations generated by the gestures, using acoustic tones to resolve symmetric configurations. It also uses the devices' vibration motors as a way to trigger vibrations directly, turning the table surface into a shared communication medium between the devices. This provides the ecology with an intuitive boundary, with devices only being part of it if they are on the same surface. SurfaceLink is able to determine relative arrangements with 89.4% accuracy but does not attempt to calculate distances between devices.

One of the most common forms of interactive inside-out tracking is through detecting touch inputs spanning across different touch screens, first explored by Hinckley et al. (2004) in the context of stylus gestures, or *"stitches"*, across personal digital assistants and tablets. It involves detecting when a user starts a swipe gesture on one screen, moves across the bezels of the devices, and finishes the gesture on a second screen, or, in a similar manner, by detecting *"pinches"* between the two devices (Ohta and Tanaka, 2012; Nielsen et al., 2014; Jensen et al., 2016). The relative positions of the two devices can then be determined based on the path of the swipe, approximating the distance between the two devices from the gesture velocity and duration. Such an input can be used to create a temporary connection between two devices, for example to transfer an image between them, or can be used as a way to input the relative positions of multiple devices for extended use, for example for *cross-display ecologies*.

2.3.4 Cross-Display Ecologies

Cross-display ecologies, also referred to as *multi-display environments* (MDEs) (Brudy et al., 2019), *multi-surface environments* (MSEs) (Garcia-Sanjuan et al., 2016), or *multi-display compositions* (MDCs) (Lyons et al., 2009), refer to synchronising the screens of multiple devices in order to form a larger display. A common use case for cross-device ecologies is to display photos or videos on the distributed display, taking advantage of its larger size or unusual shape (Lucero et al., 2011; Ohta and Tanaka, 2012; Jun, 2012; Nielsen et al., 2014; Ohta and Tanaka, 2015). We refer to them as cross-display ecologies because the term *multi-display environments* can refer more generally to displays that are synchronised without necessarily being adjacent.

Garcia-Sanjuan et al.'s (2016) taxonomy differentiates cross-display ecologies based on these additional factors:

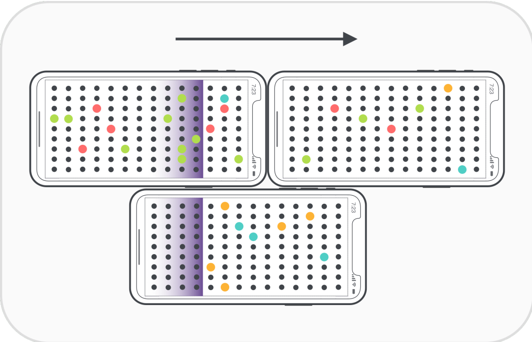
- ***Homogeneity of surfaces***, referring to whether the devices all have similar features and sizes (e.g. all touch devices) or are mixed (e.g. combining phones with tabletops)
- ***Spatial Form***, whether the devices are positioned on a 2D plane (*planar*) or in 3D space (*volumetric*).
- ***Shape regularity***, based on whether the devices are always synchronised in the same arrangement (*regular*, for instance a tiled wall displays) or can be rearranged differently between sessions (*irregular*).
- ***Scalabilty***, being either *unbounded* or *bounded* depending on whether devices can be added during a session or only during an initial setup phase, respectively.

Figure 2.1: Illustrations based on the *VISTILES* framework demonstrating cross-device visualisations: (A) Two tablets combined to extend a chart across a larger display, (B) Two tablets aligned to synchronise axes for easier data comparison, (C) A phone sliding along a tablet to display a zoomed version of the data, (D) A chart on a tablet, with controls moved to a separate phone screen.

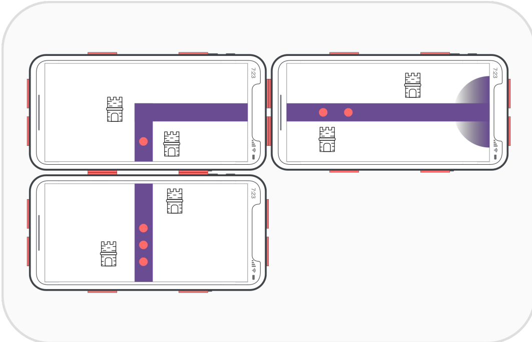
Data visualisation is another common use case for cross-device ecologies (Gryphon et al., 2023; Langner et al., 2018b). Langner et al. (2018b) developed *VISTILES*, a framework that allows users to distribute and coordinate different views of data across multiple mobile devices. For example, users can arrange devices side-by-side to create a larger display, can place two charts side-by-side to align their axes or to combine their data, or can slide a phone across the bottom of a tablet to show a zoomed-in version of the data, illustrated in Figure 2.1. They also allow moving chart controls to a separate device in order to reduce visual clutter. *VISTILES* initially was demonstrated using a top-down camera to track devices, enabling fluent and intuitive interactions. They have also developed an inside-out implementation requiring users to swipe between devices, allowing the system to be used in more contexts but adding an additional step for each device interaction (Langner et al., 2018a).

Up until now, implementations of cross-display ecologies have largely used either outside-in tracking, requiring additional hardware components, for instance AirConstellations (Marquardt et al., 2021) and MagMobile (Huang et al., 2012), or interactive inside-out tracking, requiring users to swipe or pinch between devices to configure their locations. While passive inside-out tracking can allow for fast-paced dynamic interactions without the need for external hardware, they are currently limited to centimetre-level accuracy, one order of magnitude above the millimetre-level precision required to seamlessly synchronise displays without noticeable misalignments. Passive tracking techniques may be able to achieve the required accuracy in the future, but there is also potential for passive and interactive tracking to be combined together to achieve more intuitive user experiences.

There have been several works that have contributed general-purpose cross-device computing frameworks that support forming cross-display ecologies as one of their features among their full set of capabilities (Schreiner et al., 2015; Bateman et al., 2023; Mar-



(a) Illustration based on *Tuneblock*, a musical game built with *Pinch* where phones can be placed in sequence to prolong a song, or in parallel to create multiple melodies.



(b) Illustration based on *MagMobile*'s Tower Defence game, where players have to keep re-organising phones to prevent enemies from reaching the end of the line.

Figure 2.2: Illustrations of games that have been implemented to demonstrate cross-device ecology frameworks

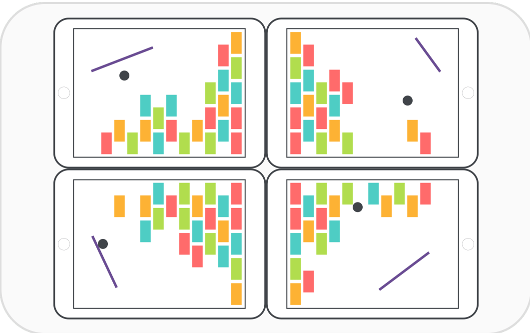
quardt et al., 2021). In this context, cross-display ecologies are just one of many ways devices can be linked together, allowing users to see a device's screen as a distinct tool separate from its computing capabilities, helping to bring about the vision of *ubiquitous computing* where the computer as an isolated entity fades into the background.

2.4 Video Games on Cross-display Ecologies

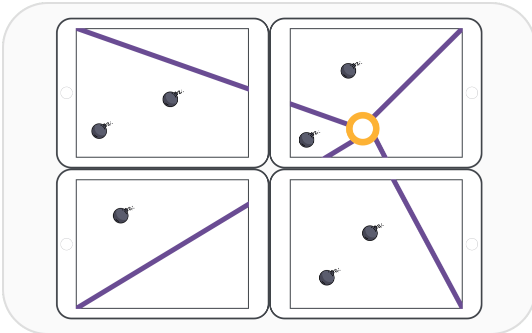
Commercial games have occasionally featured elements of cross-device computing that extend beyond simple LAN multiplayer modes. For example, Scrabble was adapted for the iPad featuring the ability to use iPhones as each player's tile rack (Rashid, 2012). However, there has been limited work, academic or commericial, making use of cross-display ecologies for enhancing the playing experience of video games.

Several general-purpose cross-display frameworks have used simple games as a means to demonstrate their capabilities. Ohta and Tanaka (2012), for instance, used the *Pinch* framework to implement a musical composition game where players can create longer songs by connecting phones in sequence, or can have multiple melodies playing simultaneously by arranging one phone under another (see Figure 2.2a). *MagMobile*, which uses magnets along the edges of phones to determine relative locations, was used to implement a tower defence game where players have to continuously re-organise the phones to prevent the enemies from reaching the end of the line (see Figure 2.2b), as well as an adaptation of the arcade game *Snake* (Huang et al., 2012). These games demonstrate how MagMobile's outside-in tracking enables novel interactions by requiring players to physically move and rearrange their phones during gameplay.

The *4in1* concept is a cross-display gaming setup where 2 or 4 tablets are arranged



(a) Illustration based on Quadropong, where players collaborate to clear bricks by controlling a paddle on their quadrant.



(b) Illustration based on StringForce, requiring players to collaborate to move a shared cursor by pulling on the string joined to their quadrant's corner/

Figure 2.3: Illustrations of games developed using the *4in1* concept

in a grid to form a larger rectangular surface. During the setup, the system instructs players where to position each device, and each player is typically associated with one of the devices, controlling their designated quadrant of the grid. The concept has been used in the implementation of 16 different collaborative puzzle and arcade games, for instance an adapted version of the classic Breakout game (see Figure 2.3a). *4in1* is not a single framework, but instead a design concept that has been implemented on multiple platforms, including the Unity game engine. It primarily uses the cross-display mechanic as a way to create a bigger screen, but also uses the territorial quadrants to promote collaboration, requiring each player to participate equally. In *StringForce*, for example, players collaborate to move a cursor by pulling on a string that leads from each quadrant to the cursor (see Figure 2.3b) (Barendregt et al., 2017; Eriksson et al., 2021, 2022).

Kim et al. (2017) explored how cross-device ecologies can be used to form more dynamic game layouts, arranging phones into different configurations, including bars, radials, rings, and rectangles (see Figure 2.4), and investigating how the different physical layouts inspired gaming styles and interactions. For each configuration, they implemented a different casual-style collaborative game, where each player controls the game from their own phone and is able to interact with the other players by swiping game elements toward their phones. Their work highlights the flexibility enabled by cross-display ecologies, which aren't confined to the right angles and rectangular views that restrict standard gaming experiences.

One example of a commercial cross-display game was *Racer*, a simple slot car game developed by Google to promote the Chrome browser for mobile devices (Google, 2013). *Racer* allowed players to line up up to five phones or tablets to create a racetrack spanning across their screens in a line (see Figure 2.5a). It assigned each device a number, requiring players to arrange the devices in the correct order and align them vertically to line up a racetrack. Players controlled their slot cars by pressing down on

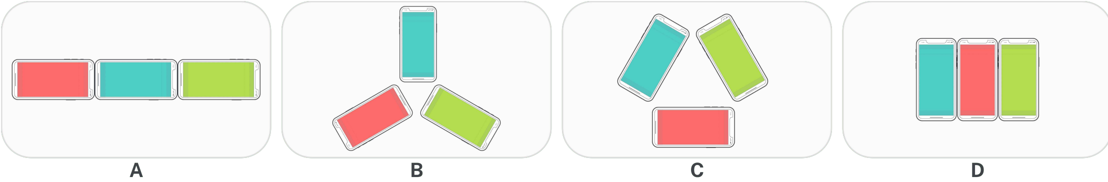


Figure 2.4: Different smartphone configurations explored by Kim et al.: (A) Bar, (B) Radial, (C) Ring, and (D) Rectangle.

(a) Racer played on mobile devices arranged in a line

(b) Racer on a tabletop display with phones used as controllers

Figure 2.5: Photos of Racer, a slot-car game played across multiple mobile devices.

Screenshots of video by Hush Studios, available at https://vimeo.com/68912865.
Licensed under CC BY-ND.

their own phones to accelerate and then releasing to brake. Although intended as a simple demo, Racer was an example of a well-polished cross-display game advertised to the public, even featuring a soundtrack by famed composer Giovanni Giorgio. It was additionally extended to make use of a tabletop surface, allowing players to control a slot car by placing their touch device over the top of the track (see Figure 2.5b). The design of this latter setup appears to be primarily for technical demonstration purposes, as the user experience of covering the track with their phone, which then mirrors the obscured screen area below, is likely not as intuitive as phones being simply held by users to act as throttles.

Cross-device ecologies can be used as a way to promote greater social engagement (Eriksson et al., 2021), but they may also show benefits for single-player games. Thompson et al. (2012) investigated what impact the size of touch screens have on the experience of immersion in video games, and found that players reported higher levels of immersion with larger touch screens.

2.5 Summary

To summarise, there is extensive research investigating the technical capabilities enabled by cross-device computing, contributing various ways to position phones relative to one another, establishing a solid foundation for building cross-display ecologies.

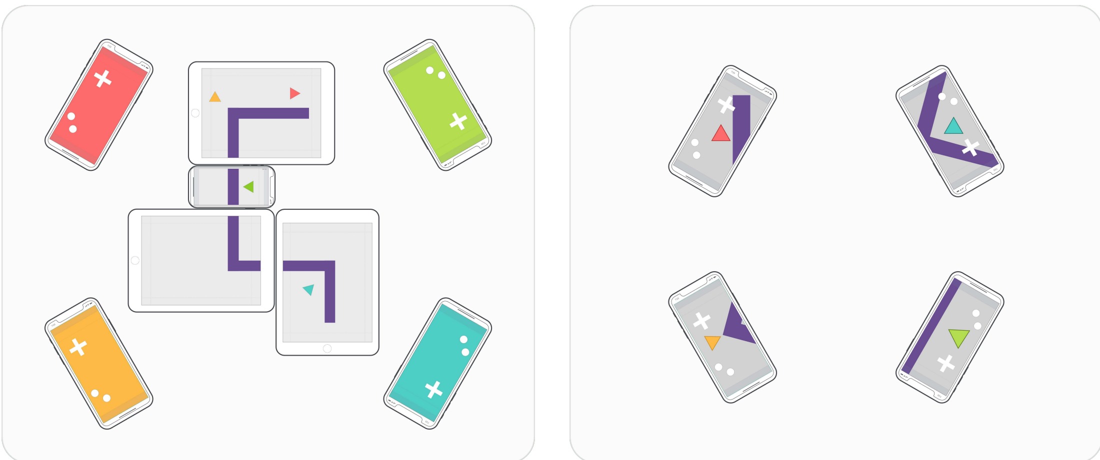
However, there is limited work applying these ideas specifically to entertainment and gaming. While some projects have begun to explore the potential novel gameplay experiences enabled by cross-device ecologies, the area is still largely unexplored, with most of the examples being limited to the short casual-style game genre that is popular among busy phone users today. There has not yet been an attempt to re-create the more serious *gaming table* venue, which is associated with the longer playing sessions required for most board games and role-playing games. Additionally, most examples of games designed for cross-display ecologies have maintained a strong association between each player and their individual device, restricting the playing area and the styles of games that can be implemented.

There is an opportunity for additional research exploring how games developed for cross-device ecologies can learn from the standard practices developed for interactive tabletop surfaces, bringing the interactions enabled by these larger displays to the more ad-hoc environments enabled by mobile devices. Games developed for such systems can potentially be used as a way to promote greater social presence between players, without the need for uncommon and expensive hardware.

Chapter 3

System Design

This chapter outlines the design and implementation of *Makeshift*, a prototype framework developed to enable the use of ad-hoc cross-display ecologies for multiplayer role-playing games with minimal setup. The goal of *Makeshift* is to allow touch-enabled mobile devices to be connected together to form a larger synchronised display, in addition to supporting individual handheld devices acting as controllers for players. The framework addresses the challenges of synchronizing relative device positions and orientations, both for the shared display tiles and the individual player controllers.



(a) An illustration of a game using *Makeshift*, with four devices acting as display tiles, and four controllers used by four players.

(b) *Makeshift* also supports playing on individual devices to allow the two game modes to be compared.

Figure 3.1: Illustration of a game using the *Makeshift* framework.

The *Makeshift* framework was built on top of the Godot game engine. The decision to use Godot was primarily influenced by its open-source and permissive license, ensuring unrestricted access and making it especially well-suited for academic research. Additionally, Godot is actively developed and used by a growing community of users and developers, leading in the rate of new projects added weekly on independent game distribution platforms (itch.io, 2024). Godot supports deploying to a variety of platforms, including both iOS and Android devices.

Makeshift employs a local server model, a common approach in co-located multiplayer games. In this setup, one device serves as the host server, broadcasting its presence to other devices on the same network. This central device is responsible for handling game logic and physics processing, subsequently distributing game state updates to the other connected devices. This architecture simplifies the overall implementation and ensures the game state remains consistent across the tile devices. Device communication occurs over a local Wi-Fi network, requiring all devices to be connected to the same network to participate in a game.

In contrast, an alternative approach would be for each tile device to manage the game entities displayed on its own screen, with responsibility for entities being handed off as they transition between tiles. This decentralised method would allow the game to scale to a greater number of tile devices and reduce latency on each screen, as each device would process its local entities independently. Moreover, this model would mitigate the risk of a single point of failure - the game could handle any single tile device disconnecting, avoiding the risk of a central server device crashing and halting the game. However, such an approach would increase the complexity of a game's implementation, requiring careful synchronization between devices to ensure continuity and consistency as entities move across tiles. Consequently, while the local server model in *Makeshift* may limit scalability, it simplifies development and ensures consistent handling of game logic and entity management. It also simplifies handling game state that occurs outside the domain of any single tile, such as off-screen entities.

3.1 Tiles and Controllers

In a *Makeshift* device ecology, devices are categorised into two types:

- **Tiles:** Devices arranged together to form a larger synchronised screen, presenting a view of the game world. They are intended to be shared by all players.
- **Controllers:** Individual devices held by players, used to control in-game avatars. These devices display touch controls and may also present personal game information.

This logical division between tiles and controllers contrasts with prior research in cross-display games (Eriksson et al., 2021; Ohta and Tanaka, 2012; Huang et al., 2012), although using phones as dedicated controllers in other contexts has been investigated extensively (Baldauf et al., 2015). The division is motivated by several factors.

Firstly, employing individual smartphones as controllers plays a critical role in maintaining the neutrality of the shared display, which avoids territoriality and fosters a balanced user experience. The decision draws from Hall's theory of *proxemics* (Hall, 1966), which describes how personal spaces are managed in face-to-face interactions. By assigning each player their own device, the setup ensures that no particular section of the shared display is dominated by any individual player, thereby creating a neutral interaction zone, with each player's personal device acting as an interface to the shared display. In this context, the personal controllers occupy Hall's *Near* and *Personal* distances, while the shared display ecology resides in the third level, the *Social* distance. If the ecology is situated within each player's *Personal* distances, such as when the game requires touch inputs directly on the shared display, players may naturally associate different parts of the display as their own responsibility. This division can reduce opportunities for co-dependent gameplay, even if cooperative or competitive play is still maintained. By positioning the shared display within the *Social* distance, the design encourages players to engage more collectively with the entire game world.

Furthermore, ensuring that the shared display remains neutral enhances accessibility for spectators. If the ecology were within the players' personal spaces, spectators would need to intrude into those spaces to observe the game. By situating the shared display in the *Social* distance, spectators can comfortably transition into the social space without encroaching on personal boundaries. This arrangement is similar to console gaming on a large TV, which allows individuals in the *Public* distance to spectate.

The use of individual controllers additionally facilitates comparisons between cross-display ecologies and standard gaming setups. Since the controls on the personal devices can be kept consistent across different configurations, games can easily be designed to support both cross-device and traditional gaming environments, allowing for the differences in player experience to be measured more accurately.

Providing each player with a personal device also enables the display of private information, such as private inventories or secret objectives, which would not be possible if all displays were shared. Asymmetric information can be used to promote both cooperative (Pais et al., 2024) and competitive gameplay (Magerkurth et al., 2004b) and is an important factor in allowing for games to be easily adapted to be played on a cross-device ecology.

Using dedicated controllers eliminates the need to associate touch inputs on the shared display with specific users, which can introduce design challenges. As discussed, dedicating distinct areas of the shared screen for each player (Eriksson et al., 2021) reinforces the notion of "personal territory" on the shared display. Alternatively, systems can analyse touch "blobs" to infer user identity (Döweling et al., 2016), though this method may lack precision during fast-paced interactions. More advanced setups, like fingerprint recognition (Holz and Baudisch, 2013), electric circuits passing through the user (Dietz and Leigh, 2001), or overhead cameras (Döweling et al., 2016), offer greater accuracy but rely on specialised hardware, which is incompatible with the goal of *Makeshift* to provide an ad-hoc, low-setup system.

Makeshift also aims to facilitate building orientation independent games. Orientation independence, the concept that the game should be playable viewed from all angles without favouring any particular point of view, allows players to sit in a circle around the shared display, allowing for opportunities for eye contact and non-verbal communication. It contrasts with setups where all the players are using individual devices or are positioned in parallel facing a single screen, which can limit opportunities for direct interaction, even when players are physically close (Magerkurth et al., 2004a; De Kort et al., 2007). The framework promotes this feature by handling the tracking of controller orientations, enabling the players' controls to work intuitively regardless of where the players are sitting, and by providing tools for managing symmetrical game content like multi-directional text labels. However, games built on top of *Makeshift* aren't required to adopt orientation independence and may instead opt for playing configurations where all players view the game from the same side of the screen.

3.2 Tile Setup

In order to synchronise the game view across the cross-display ecology, the relative positions and orientations of the *tile* devices need to be known. There is extensive literature providing numerous ways to achieve this, each with varying trade-offs. To minimise the setup complexity and reduce barriers to entry for players, an inside-out tracking method is preferred, as it eliminates the need for external sensors or complex environmental setups. Inside-out localisation can be either interactive, requiring explicit user input to define device positions, or passive, where the system automatically determines positions using built-in sensors. However, the primary challenge with passive inside-out tracking is achieving the required precision. For the displays to align seamlessly, millimetre-level accuracy is essential, as even small deviations in position or orientation can result in noticeable misalignment, disrupting the continuity of the game world across devices.

Based on these considerations, *Makeshift* requires users to configure the positions of tiles before playing the game by swiping between sets of adjacent screens to establish their relative positions and orientations. *Makeshift* supports various touch input methods, in order to make this process as intuitive as possible. Users can swipe between each shared border, they can make a single continuous swipe event across multiple sets of borders in succession or can replace swipe events with *pinching* between two devices instead, as is used in previous work on cross-display ecologies (Ohta and Tanaka, 2012; Nielsen et al., 2014).

One limitation with using touch inputs is the requirement for swipe events to occur in successive order - simultaneous swipes on different parts of the collection of devices, for example from two different users both trying to configure the tile locations, can result in the swipe events being paired up incorrectly. This is especially relevant when a larger number of tiles are being used, where multiple users would be involved in the setup. A hybrid system could be used to account for this, with a less precise sensor-based method being used initially to approximate the devices' positions. User swipes can then be used to provide higher accuracy, and simultaneous swipe events can easily be differentiated.

Makeshift does not attempt to infer connections between two tiles even if there's enough information to do so based on other connections, to allow users to decide which adjacent tiles can be navigated between in-game.

When a device joins a *Makeshift* server, the user indicates whether it will be used as a tile device. Once all the devices have joined, the tiles then enter a setup screen, with a signifier on each screen indicating to the user that the tile needs to be connected by swiping between devices. The location of the server tile is used as the base coordinate, falling back to the first tile to be connected if the server device is acting as a controller - referred to here as the *base tile*. When a screen's position is known relative to this reference point, its screen's background colour is changed to green to indicate that it has been configured correctly. If a user swipes between two devices that have both not yet been positioned, the swipe information will only be used once either of the devices' positions is known, and then both devices will be considered to be connected (see Figure 3.2). Once all tiles are positioned, a button is revealed on the base tile allowing the users to start playing. The orientations of the tiles are inferred based on the edges on which the swipes were made. These steps are analogous to the the four-step approach described by the *Pinch* framework (Ohta and Tanaka, 2012; Nielsen et al., 2014). Throughout this setup, a mini-map is shown on the base tile rendering a preview of the devices and their positions, allowing the users to visually validate that the tile positions are correctly configured.

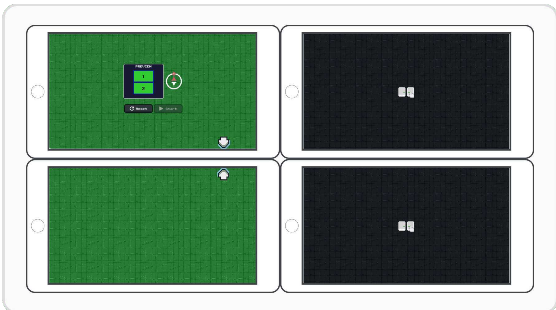


Figure 3.2: Screenshots of the setup process, with the two left devices being already positioned, while the two right devices still need to be positioned. The arrows indicate where the two devices were joined, allowing the user to visually confirm they are lined up correctly. Additionally, the minimap on the base tile shows the relative positions of the positioned devices, dynamically zooming out as additional devices are positioned. Devices that haven't been positioned show an animated icon demonstrating the swiping process.

The bezels of the tiles are accounted for by considering the timing between the two components of a swipe event, one on each of the two devices being joined. In order to approximate the distance between the two devices, the velocity is calculated on either side of the bezel and averaged, and the time difference. *Makeshift* assumes that the devices' clocks are synchronised, as modern operating systems typically manage clock synchronization automatically to within a suitable margin of error. An alternative would be to keep a reference table of known device frame sizes, which could be combined with the time-based estimate to provide a more accurate measurement. Games built on the *Makeshift* framework can additionally choose to disregard the bezel space, allowing game objects to instead jump across the gap as though there was no space between the screens, as illustrated in Figure 3.3.

(a) Maintain the physical gap, with game entities moving through a blind spot.

(b) Ignore the physical gap, with game entities jumping across the gap.

Figure 3.3: Different ways to handle the gap between devices.

The framework currently has limitations in how it resolves conflicts in tile positioning. For example, if a tile is connected to two different adjacent tiles that are both already positioned within the ecology, its position is determined by the first swipe input, without attempting to reconcile the two expected positions by averaging them or determining the most likely of the two.

In order to handle the variations in resolutions across different devices, *Makeshift* adapts all of the tiles to use the same virtual resolution, configurable by the game implementation but limited to the lowest resolution across the tiles. This ensures that as a game entity moves across borders, its size remains constant on both screens. Additionally, the framework handles setting the display orientation of the tiles to all be consistent, so that the game does not have to take this into consideration.

There are other screen factors that aren't currently accounted for, such as brightness and colour profiles. Brightness could normalised by programmatically setting it to a common value, but differences in device models would still be evident. Similarly, variations in colour profiles between devices could lead to inconsistencies in colour display across the tiled display. Future work could explore solutions such as applying colour correction techniques during runtime to ensure a more consistent visual experience across all devices.

The framework also provides utilities for handling the irregular playing areas that can arise in cross-display ecologies, for example calculating the playing area polygon and creating boundaries to prevent game entities from moving off-screen. This is especially relevant when the display tiles have been set up in a ring, resulting in a multiply-connected playing polygon. Allowing for these scenarios enables the creation of more complex and interesting game environments, where players can interact with non-standard layouts (Figure 3.4). This flexibility helps promote emergent gameplay by encouraging players to explore unconventional strategies and use the irregular play spaces to their advantage, leading to more dynamic and unpredictable game experiences.

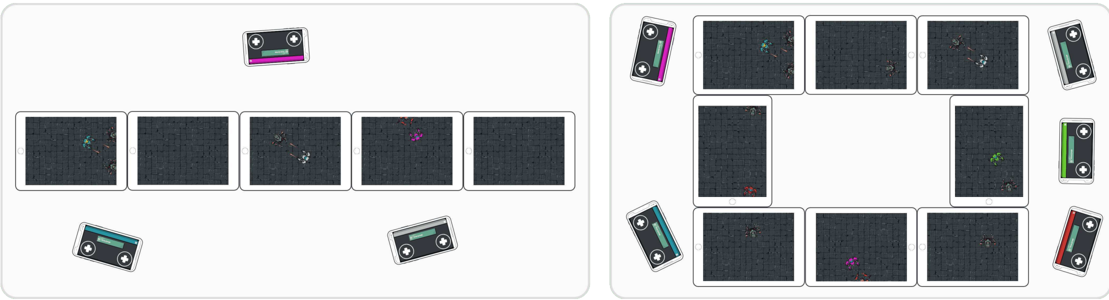


Figure 3.4: Different types of device layouts, including a ring-shaped layout where the game boundary is a multiply-connected polygon, meaning it has a hole inside of it.

3.3 Controller Calibration

As mentioned in Section 2.2.1 **(Orientation Independence)**, accurately tracking the controller's orientation is crucial for correctly aligning player inputs with the shared display (see Figure 3.5). However, devices' built-in magnetometers can be unreliable, necessitating calibration before use (Poulose et al., 2019). To account for this, a compass is displayed on controller screens during the tile setup described above, allowing players to calibrate their device's orientation relative to a compass displayed on the base tile. Users can rotate the compass on their device to align with the reference tile.

In the testing of the framework, this step proved to be unintuitive to users not familiar with the process. One alternative would be to instead require users to line up their controller next to a tile from the display ecology and drag their character over to the tile, analogous to the steps above for linking up two tiles. Since the orientation of the tiles are all inferred during the setup process, the orientation of the controller device can then be synchronised during this temporary alignment. As a secondary benefit, the player's character is then positioned directly in front of the user,

When a user's input is orientation-based, for example a joystick for moving or rotating the character, the input is shifted by the difference in rotation between the controller

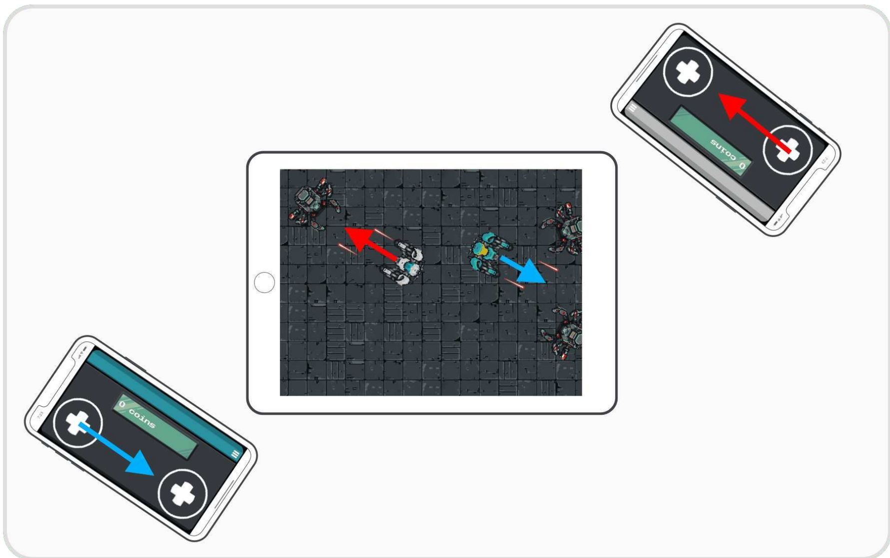


Figure 3.5: Both players are moving their virtual joystick to the right, but the game interprets this differently based on their controller's orientation.

and the base tile, before being passed on to the game logic, ensuring that the game implementation does not need to account for this.

In addition to individual devices acting as controllers during gameplay, games can utilise these devices to maintain continuity between playing sessions, allowing persistent game elements, such as character progression, customisation, or other relevant activities. By extending these interactions beyond active play sessions, games can enable ongoing engagement players to perceive their devices as physical representations of their in-game characters, analogous to a player's deck of cards in collectible card games.

3.4 Framework Limitations

Several limitations of the *Makeshift* framework have already been discussed in previous sections, but additional considerations are presented below:

Localised Audio: Currently, all game audio is played through the speakers of the base tile. While this setup may be sufficient for smaller configurations, it could disrupt immersion in larger setups, where game events occurring on one side of the display might have their sound emitted from a speaker on the opposite side. A simple improvement would involve playing sound effects through the speakers of the tile where the event occurs. A more advanced solution could involve synchronizing audio across multiple tiles, adjusting the volume based on the proximity of the sound source to each tile, allowing for more precise positional audio. From the game developer's perspective, the only adjustment required would be to associate sounds with specific coordinates in the game world.

Dynamic Tile Reconfiguration: The current system does not support changing the configuration of tiles during gameplay. Allowing players to dynamically reconfigure the arrangement of devices during a session could promote novel and emergent gameplay mechanics.

Adding Devices Mid-Game: Similarly, all devices must be added before the game starts. Allowing new devices, including controllers, to be introduced during gameplay could be used to promote social engagement, enabling spontaneous participation and encouraging a more inclusive gaming experience.

3D Positioning: The current setup assumes a 2D plane for tile placement. An interesting extension would be to allow tiles to be positioned at different angles, opening up new gameplay possibilities such as creating ramps or vertical structures, expanding the potential for novel gameplay.

Device Shape Assumptions: The system currently assumes that all devices have rectangular screens. However, newer devices are breaking away from this convention, featuring rounded screen corners, notches, side displays, and foldable screens.

Chapter 4

Evaluation

To test the hypotheses regarding the impact of cross-display ecologies on player experience, a game was developed using the *Makeshift* framework, and a study was conducted with 22 participants who played both cross-display and individual device setups, followed by feedback collection and surveys to assess overall player experience, social presence, and control intuitiveness.

4.1 Game design

A custom game was developed specifically for this study (see Figures 4.1 and 4.2), using the *Makeshift* framework to allow participants to play either using the cross-display ecology or on individual screens, allowing for a direct comparison between the two configurations. In the game, each player takes on the role of a mech robot operator, tasked with combating waves of incoming enemy robots. As the game progresses, the waves of enemy robots increase in difficulty and number. The game uses a top-down perspective to support orientation independence, which, as discussed in Section 2.2.1 **(Orientation Independence)**, ensures players can interact with the shared display from any angle. Each player controlled their character using two virtual joysticks on their personal devices, with one joystick controlling the player's character movement, while the other controlling the direction in which the player's character was facing and shooting.

Although the *Makeshift* framework has been designed to support a variety of genres where the player controls a virtual avatar, for instance racing, sports, or fighting, the focus of this study is primarily on role-playing games. The game was developed to emulate the gameplay and combat mechanics of an RPG but, due to its simplicity, lacks other features typically associated with the genre, such as complex narrative and dialogue. Additionally, while the framework is ambivalent to the game being turn-based

Figure 4.1: Screenshot of the game developed to evaluate *Makeshift*.

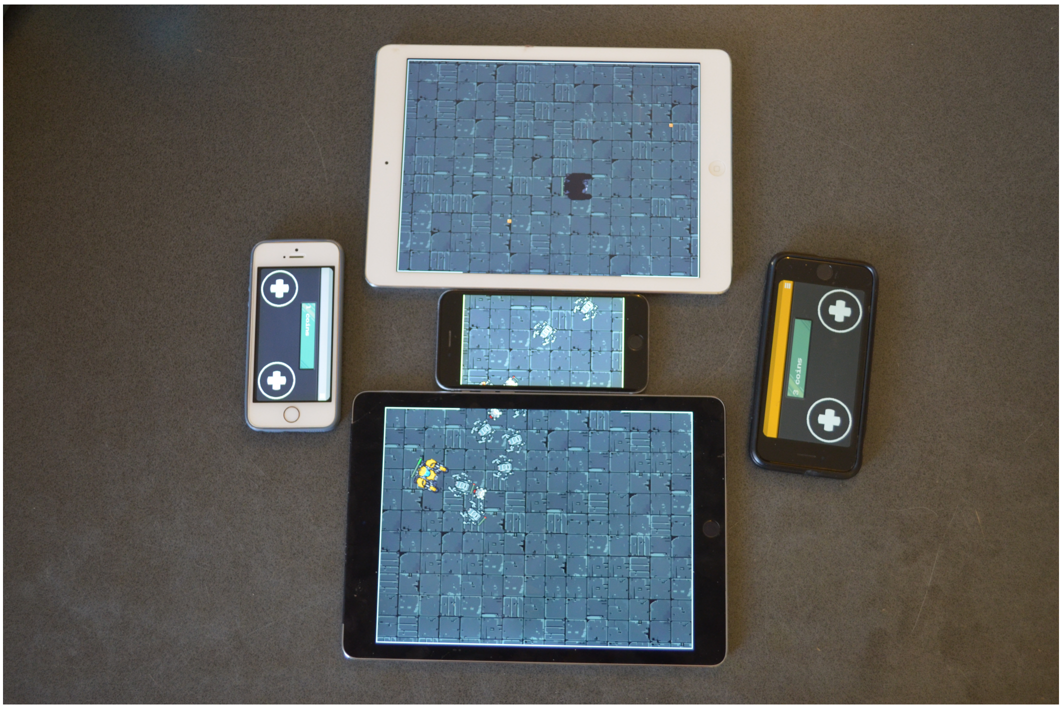


Figure 4.2: Photo of the game running on mobile devices.

or real-time based, we chose to use a faster-paced real-time game in order to more fully showcase the capabilities of the system.

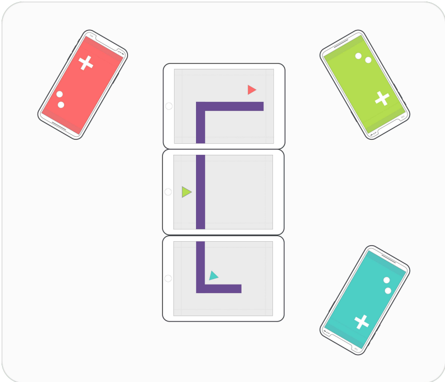
The game was divided into distinct waves, with each wave progressively increasing in difficulty. If a player died during a round, the game would end at the conclusion of that round, ensuring that individual players weren't excluded from play for extended periods. The game was designed to feature elements of both cooperative and competitive play, with players working together to survive each wave, but ultimately competing to win the most points at the end. This combination of cooperative and competitive mechanics allowed us to assess how the cross-display ecology affects both types of gameplay. After each wave, players were given the opportunity to choose a skill to upgrade, as a way to provide variety and interest to the game and further promoting interdependence by allowing players to upgrade complementary skills.

Additionally, two modes were implemented to handle the screen bezels between devices. In one mode, the bezels created a hidden area where game entities could momentarily disappear in a blind spot as they transitioned between screens. In the other mode, entities would seamlessly jump between screens, disregarding the physical gap between the devices. This feature was included to gather user feedback on which mode provided a more favourable gameplay experience.

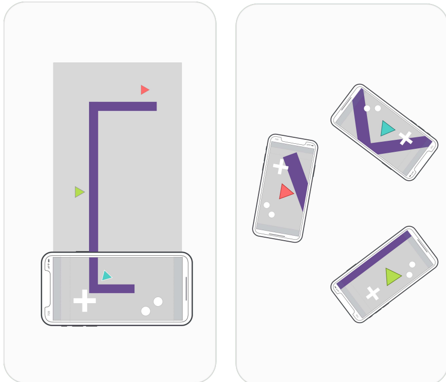
4.2 Study Design

The study employed a within-subject design to evaluate player experience in cross-display ecologies for role-playing games. A total of 22 participants, grouped into teams of 2 to 3, participated in sessions lasting 40-60 minutes. The participants were co-located and seated around a table, simulating a natural multiplayer gaming environment. They were recruited using the local university's Psychology Research Participation Scheme (SONA) and though advertising posters displayed on the university campus.

Before the gaming session, participants completed a gaming habits questionnaire, which gathered information on how often they played games, what platforms they used, their preferred genres, who they played with most often, and their motivations for gaming (see Appendix A **(Demographics Survey)**). Players were then given an informal tutorial going through the game objectives and controls, before moving on to each game variation and corresponding set of questionnaires. Each variation of the game was played twice to allow participants to become familiar with the gameplay, and then after each variation participants completed surveys measuring players' self-reported sense of social presence and overall player experience, discussed in Section 4.3 **(Measures)**. The order in which the two game modes were played was randomised between the studies. An open-ended feedback discussion was then conducted to collect qualitative data on players' experiences. While guiding questions were used as prompts (see Appendix B **(Guiding Questions for Feedback Interview)**), participants were allowed to direct the discussion toward any topic they wanted to provide feedback on.



(a) In the cross-display ecology session, the players' individual devices only displayed controls, with the game world and characters being displayed on a shared cross-display ecology.



(b) In the individual devices session (right), each participant had their own device displaying their character and touch controls, with the view following the character's movement across the game world.

Figure 4.3: The two game modes compared in the studies.

Although the *Makeshift* framework supports cross-platform play, the study was conducted exclusively on iOS devices, ranging from models released between 2013 and 2020. Since *Makeshift* is designed to make use of spare or older devices to create a larger playing area, including older devices in the study ensured that the game performance could be evaluated across a variety of hardware configurations during real gameplay.

After completing the two game mode sessions and surveys, some of the groups were also asked to test both bezel handling modes (gap with blind spot vs. seamless transition) and provide feedback on their preference and experience with each style.

4.3 Measures

As discussed in Section 1.5 **(Research Questions)**, this study has three primary concerns, relating to players' social presence, overall player experience, and perception of control intuitiveness.

We measure social presence, introduced in Section 1.3 **(Social Gaming)**, using the Social Presence in Gaming Questionnaire (SPGQ). The SPGQ survey was designed by De Kort et al. (2007) based on the measures of social presence developed by Biocca et al. (Biocca et al., 2001), and measures three subscales. Two subscales - Empathy and Negative Feelings - measure psychological involvement as positively and negatively toned emotions towards co-players. The third subscale, Behavioural Involvement, measures the degree to which players feel their actions are dependent on the actions of other players. SPGQ is commonly used as a standalone survey to measure social presence in games

(Gonçalves et al., 2023), but it also forms part of the more general Game Experience Questionnaire (GEQ) (IJsselsteijn et al., 2013).

De Kort et al. found the Negative Feelings subscale to be generally very low between players, but identified a positive correlation between it and the Empathy subscale, with participants who reported more positive feelings towards other players also feeling greater negative feelings, suggesting that being socially present involves experiencing both of these sets of emotions (De Kort et al., 2007).

The second concern of this study, overall player experience, is measured using the Player Experience of Need Satisfaction (PENS) scale. The PENS survey, developed by Ryan et al. (2006), is based on *Self-Determination Theory* (SDT), which asserts that human motivation is driven by the fulfilment of three psychological needs - *competence*, *autonomy*, and *relatedness*. The ability of social contexts to meet these three needs has been found to be linked to greater motivation, performance, and well-being (Deci and Ryan, 2000). PENS includes self-reported questions to measure the satisfaction of these three needs, and additionally aims to measure players' sense of *immersion* and perception of *control intuitiveness*:

- *Competence* relates to the psychological need for challenge and the feeling of being able to overcome challenges.

- *Autonomy* relates to players' experience of choice and freedom in the game.

- *Relatedness* relates to a player's need to feel connected to the other players.

- *Immersion*, also called *presence*, relates to players' sense of physical, emotional, and narrative presence in the game.

- *Intuitive Controls* assesses how players experience a game's interfaces and controls.

Self-determination theory and the PENS survey provide a more comprehensive understanding of player motivation and the fulfilment of psychological needs. While it doesn't attempt to quantify overall game enjoyment as a single empirical measurement, Ryan et al. (2006) found that the fulfilment of the needs of autonomy, competence, and relatedness independently predict enjoyment and players' preference for future play.

There is likely a strong correlation between *Relatedness* as measured by PENS, and social presence as measured by SPGQ. However, because this connection has not been formally identified, *Relatedness* is only used as a subscale contributing to the measurement of overall experience and is not used to address the research question addressing social presence. Nevertheless, it can still contribute to the understanding of how cross-device ecologies impact the more general concept of social connectedness.

4.4 Hypotheses

For each research question outlined in Section 1.5 (**Research Questions**), null and alternative hypotheses have been formulated.

4.4.1 Research Question 1

Research question: *Does the use of cross-display ecologies increase players' sense of social presence compared to using individual devices in co-located multiplayer role-playing games?*

Based on the literature review, there is reason to hypothesise that cross-device ecologies can positively impact players' experience of social presence. For this reason, this hypothesis is one-directional, allowing for greater sensitivity to statistical significance.

Null Hypothesis ($H1_{NULL}$): There is no significant increase in players' social presence using cross-display ecologies compared to individual devices in co-located multiplayer role-playing games.

Alternative Hypothesis ($H1$): Players' social presence is significantly higher using cross-display ecologies compared to individual individual devices in co-located multiplayer role-playing games.

Social presence is measured using the Psychological Involvement - Empathy, Psychological Involvement - Negative Feelings, and Behavioural Involvement sub-scales from the SPGQ survey.

4.4.2 Research Question 2

Research question: *What is the effect of cross-display ecologies on overall player experience compared to using individual devices co-located multiplayer role-playing games?*

Null Hypothesis ($H2_{NULL}$): Cross-display ecologies do not significantly affect overall player experience compared to individual devices in co-located multiplayer role-playing games.

Alternative Hypothesis ($H2$): Cross-display ecologies significantly affect overall player experience compared to individual devices in co-located multiplayer role-playing games.

Overall player experience is measured using the five subscales in the PENS survey.

4.4.3 Research Question 3

Research question: *How do cross-display ecologies affect players' perceptions of control intuitiveness, and what user experience challenges are associated with their use for multiplayer role-playing games?*

Only the first part of this research question is relevant to the quantitative results.

Null Hypothesis ($H3_{NULL}$): Cross-display ecologies do not significantly affect players' perceptions of control intuitiveness compared to individual devices.

Alternative Hypothesis ($H3$): Cross-display ecologies significantly affect players' perceptions of control intuitiveness compared to individual devices.

Players' perception of control intuitiveness is measured via the intuitive controls sub-scales from the PENS survey.

Chapter 5

Results

The results from the study detailed in Chapter 4 **(Evaluation)** are provided and statistically analysed. The demographics section provides a brief overview of the study population, and the quantitative survey data provides an overview of the results from the PENS and SPGQ surveys. A thematic analysis is performed on the qualitative feedback provided by participants during the studies.

The study was run with 22 participants across 8 groups, with each group having 2 or 3 participants (two groups of 2, six groups of 3). The experiment for one group with three participants had to be adapted in response to networking issues, and as a result the survey responses from these participants have been excluded from the statistical analysis. This resulted in a total of 19 participants being included in the analysis.

5.1 Demographics

Due to the limited sample size of 19 participants, the statistical relevance of the data could potentially be greater if the population studied is found to be more homogeneous,

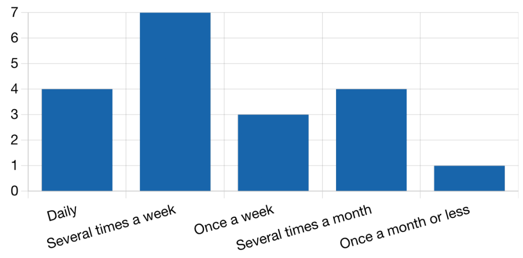


Figure 5.1: (Q1) How often do you play video games?

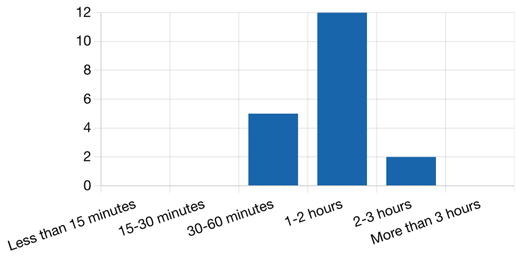


Figure 5.2: (Q2) How long is your typical gaming session?

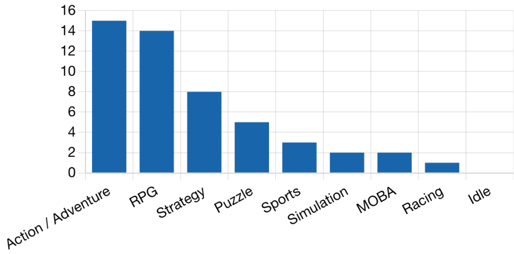


Figure 5.3: (Q3) What types of games do you play most often? (multiple choice)

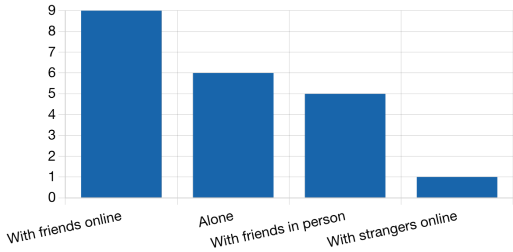


Figure 5.4: (Q4) Do you usually play games alone or with others?

having less variability. However, the analysis would then be constrained by the smaller demographic, limiting the broader applicability of the findings.

The recruited participants were all university students at the undergraduate and masters level, and were a mix of psychology students and computing students, with a majority of them being enrolled in a game development course. Most participants were unfamiliar with each other, with only one group having signed up to participate together.

Figures 5.1 and 5.2 reveal that the majority of participants were frequent gamers, with 58% playing either daily or several times a week, and all participants typically playing between 30 minutes and 3 hours each session. Additionally, a majority reported playing Action / Adventure or RPG, followed by Strategy, whereas more casual genres like Puzzle games were less frequently played (Figure 5.3).

Most participants reported usually playing with friends, either online (47%) or in person (25%), while only one respondent reported playing with strangers online, with the rest usually playing alone.

Almost all players agreed or strongly agreed that entertainment was a motivation for gaming, which follows common wisdom, and acts as a baseline to compare the other motivations against. The next most common motivations were for the immersive stories and worlds, followed by as means to relax. Only half of the partipants agreed or strongly agreed that socializing with friends or playing for the challenge / sense of achievement were motivations (Figure 5.5).

5.2 Quantitative Survey Data

Participants completed the Player Experience of Need Satisfaction (PENS) questionnaire and the Social Presence in Gaming Questionnaire (SPGQ) after playing the game in each setup. The difference scores, measuring each participant's subscale score for the cross-display ecology setup minus their score for the traditional setup, were calculated for each subscale for analysis.

To decide between conducting Student's paired t-tests or Wilcoxon signed-rank test, the normality of the set of difference scores was assessed for the subscales using the

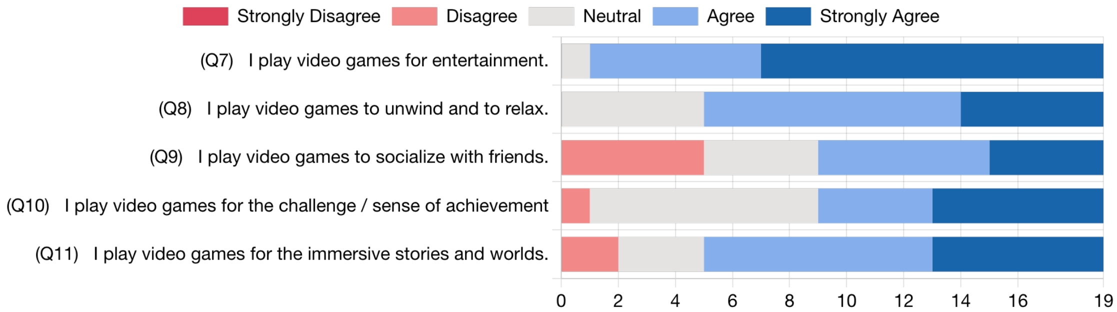


Figure 5.5: (Q7-11) Motivation for Gaming

Shapiro-Wilk test. Normality was met for most subscales ($p > 0.05$), except for PENS Competence and PENS Intuitive Controls, which showed significant deviations from normality ($p = 0.012$ and $p = 0.005$, respectively). For this reason, Wilcoxon signed-rank tests were used to evaluate the statistical significance of the difference scores.

Tables 5.1 and 5.2 summarise the results of the one-tailed paired t-tests on the differences for each subscale between the two game variants.

Table 5.1: SPGQ Results Summary

Subscale	Mean Difference	S.D.	One-Tailed P-Value
Psychological Involvement			
- Empathy	+0.0526	0.4716	0.3966
- Negative	+0.0421	0.4970	0.1952
Behavioural Involvement	+0.3860	0.8222	0.0378

Table 5.2: PENS Results Summary

Subscale	Mean Difference	S.D.	Two-Tailed P-Value
Competence	+0.2456	0.8077	0.1234
Autonomy	+0.4561	0.9572	0.0403
Relatedness	+0.1930	0.8264	0.4367
Immersion	+0.1988	0.8970	0.4202
Intuitive Controls	+0.0702	0.4789	0.3653

Overall, every subscale experienced a positive increase in the mean difference, meaning that on average, participants scored each subscale higher for the cross-display ecology game variant. However, not all of these differences were statistically significant.

5.2.1 Research Question 1: Social Presence

For the first research question, addressing social presence, the measures analysed were the three SPGQ subscales, namely the two Psychological Involvement components of Empathy and Negative Feelings, and the Behavioural Involvement component.

For the two Psychological Involvement components, the mean differences were not statistically significant ($p > 0.05$), so we fail to reject $H1_{NULL}$.

The increase in SPGQ Behavioural Involvement scores was statistically significant ($p < 0.05$), indicating that cross-device ecologies had a meaningful impact on participants' behavioural involvement with other participants. Therefore, we reject $H1_{NULL}$ for this measure and accept the alternative hypothesis $H1$ for behavioural involvement.

It is important to acknowledge that the first hypothesis was one-tailed, meaning it was designed to detect increases in social presence measures, and not decreases. As a result, we cannot definitively rule out that psychological involvement could have decreased.

5.2.2 Research Question 2: Overall Player Experience

The measures analysed for the second research question, evaluating overall player experience, were the five PENS subscales - Competence, Autonomy, Relatedness, Immersion, and Intuitive Controls. For Competence, Relatedness, Immersion, and Intuitive Controls, the mean differences were not statistically significant ($p > 0.05$), so they fail to reject $H2_{NULL}$. The increase in PENS Autonomy scores for the cross-display ecology was statistically significant ($p < 0.05$), so we reject the null hypothesis $H2_{NULL}$ for this measure and accept the alternative.

5.2.3 Research Question 3: Control Intuitiveness

We also use the PENS Intuitive Controls subscale to address how players perceived their control intuitiveness. As mentioned, this result was not statistically significant, so we fail to reject $H3_{NULL}$.

5.2.4 Result Charts

Figures 5.6 through 5.13 provide a detailed breakdown of the change in each participant's score for the relevant subscales across both game conditions, sorted and colour-coded based on the net change. Using the scores for the individual device survey results as the reference point, each row is coloured red to indicate a decrease in the participant's score for the cross-device ecology survey, and green for an increase, with unchanged scores in between.

This detailed data visualisation provides additional insights into the results, hinting at whether several of the changes in subscales were not statistically significant due to a balance between participants' scores both increasing and decreasing or due to a large number of participants experiencing no change. For example, the PENS subscale of

Intuitive Controls chart reveals that a majority of players experienced no change between the two game variants, with a large number of participants scoring the maximum possible score for both. The Empathy chart, on the other hand, shows a balanced distribution of increasing and decreasing scores, with nine participants experiencing a decrease and nine an increase. However, these statements are observational only, and additional statistical techniques would be required to confirm their significance.

Note: In the charts red represents a decrease in scores and blue represents an increase, instead of a more standard red/green colour palette, to cater for common colour vision deficiencies.

Figure 5.6: Effect on Competence (PENS)

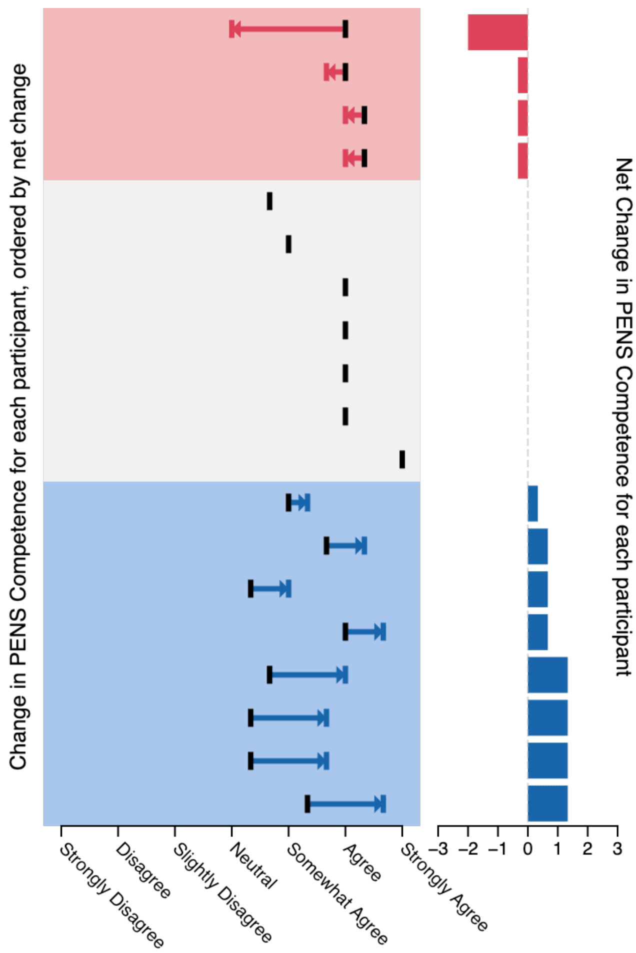


Figure 5.7: Effect on Autonomy (PENS)

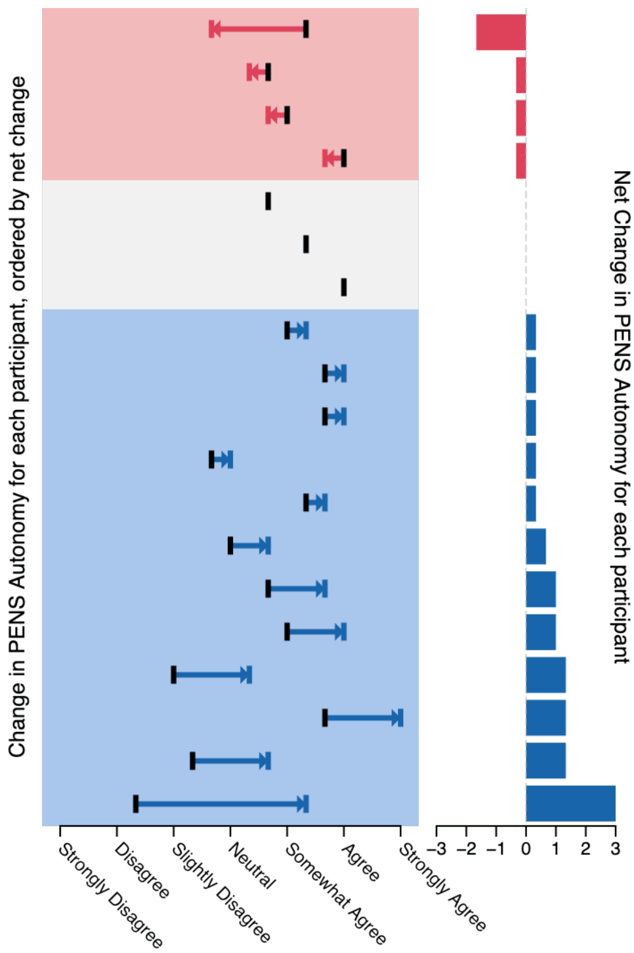


Figure 5.8: Effect on Relatedness (PENS)

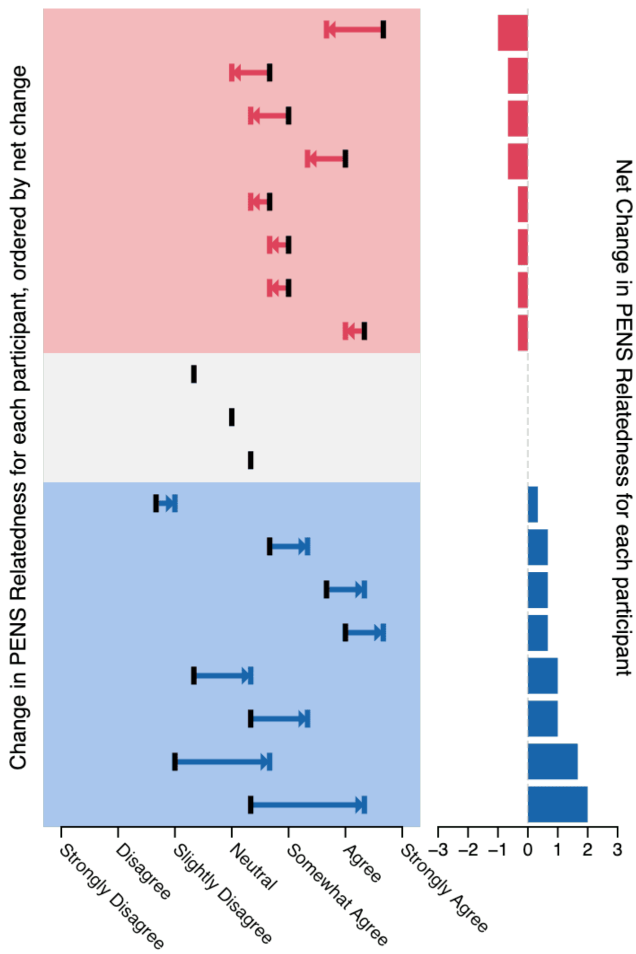


Figure 5.9: Effect on Immersion (PENS)

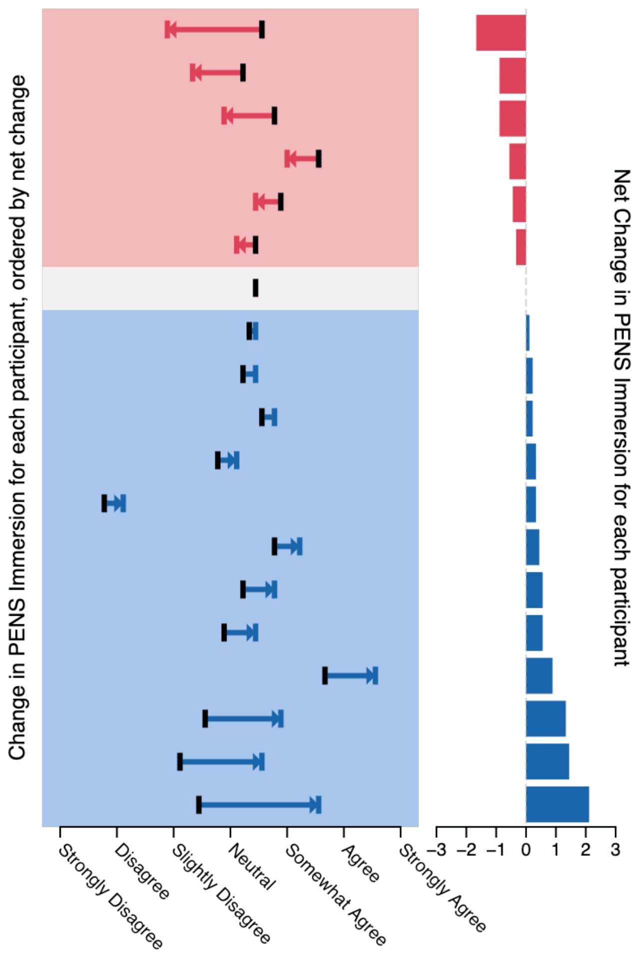


Figure 5.10: Effect on Intuitive Controls (PENS)

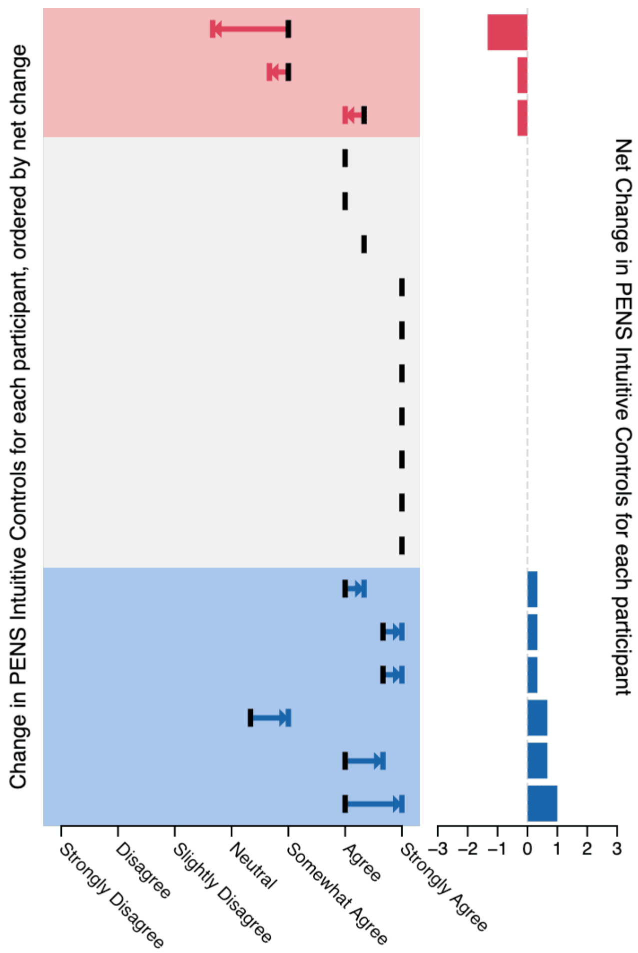


Figure 5.11: Effect on Empathy (SPGQ)

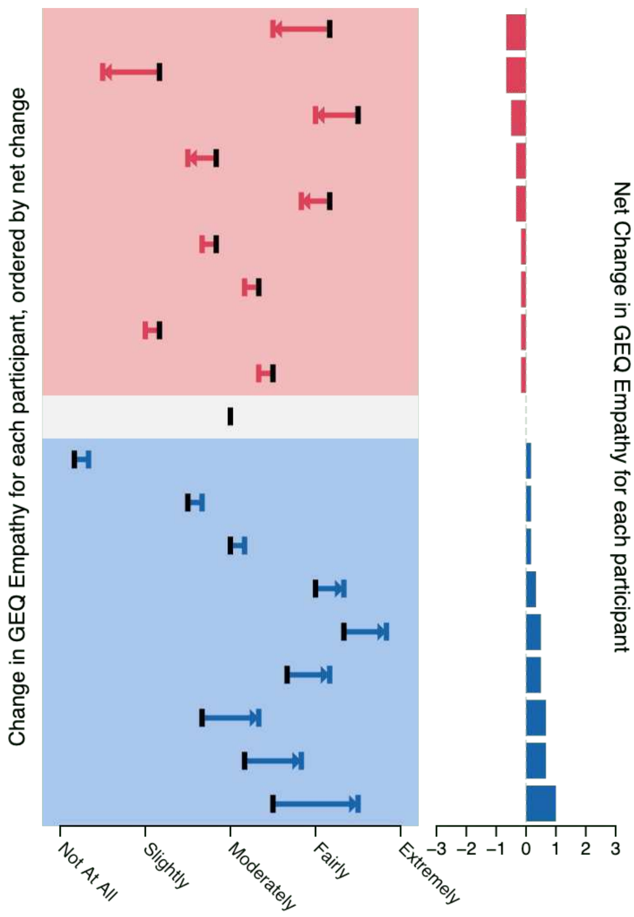


Figure 5.12: Effect on Negative Feelings (SPGQ)

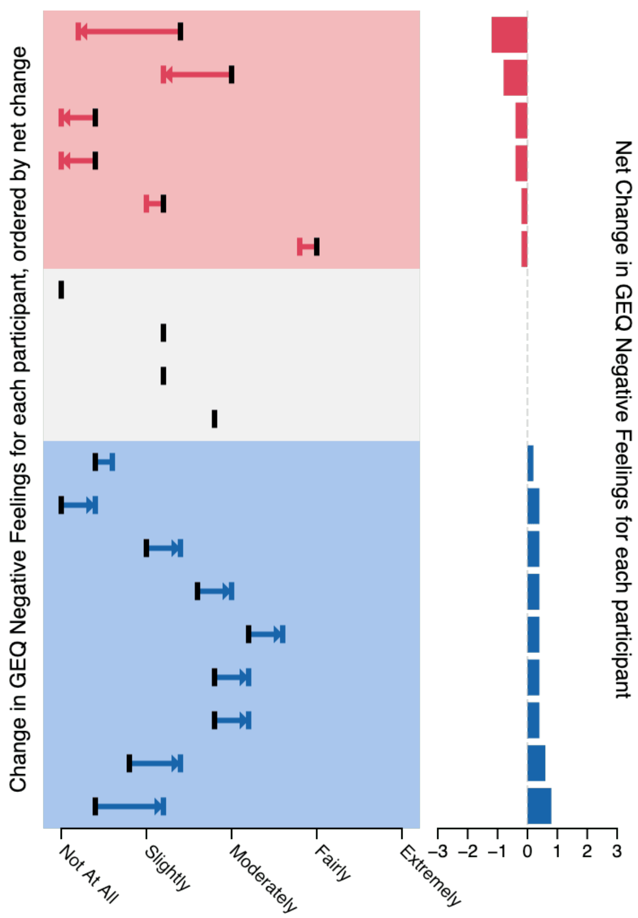
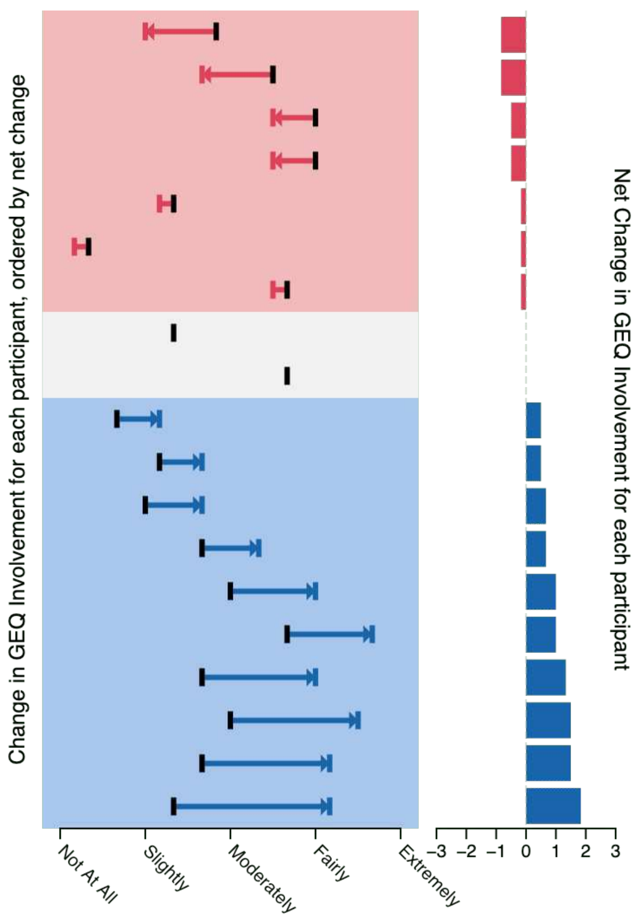


Figure 5.13: Effect on Involvement (SPGQ)



5.3 Thematic Analysis of Qualitative Feedback

We conducted a thematic analysis of the qualitative feedback provided by participants in the open-ended feedback section after they had played both game variants - using a cross-display ecology and on individual devices. Throughout the study, cross-display ecologies were referred to as a "tiled display", or simply "tiles", which is used in this section as well. Participant feedback was not directly recorded verbatim, instead being noted down in forms such as "Participant X said that" or "Participant X preferred". It's important to note that this transcription step may have introduced additional bias, and also may have limited some of the more nuanced feedback. Additionally, for some statements, the other participants were asked whether they agreed or disagreed, and agreements have been grouped into a single line to reflect that they weren't independent statements.

The analysis revealed six main themes:

- Theme 1: Preference for Tiled Display or for Individual Devices
- Theme 2: Collaboration and Social Interaction
- Theme 3: Visibility and Spatial Awareness
- Theme 4: Gap Between Devices
- Theme 5: Relevant Gaming Genres and Platforms

5.3.1 Theme 1: Preference for Tiled Display or for Individual Devices

For the most part, participants said that they preferred playing on the tiled display, with participant P7.3 explicitly stating that playing on the tiled displays was fun while using individual phones was boring. Several participants pointed out the novelty of playing on the tiled displays, with P1.1 referring to it as a unique mechanic and P5.1 and P5.2 agreeing that the setup was clever.

Two participants, on the other hand, expressed preference for playing on individual devices, with participant P6.1 stating that they felt that using the phones was more immersive.

Participants P6.1 and P5.2 both made comments about using phones as separate controllers, with P6.1 finding the controls more intuitive when using individual devices, and P5.2 suggesting that using console controllers would be better and that the phone controllers didn't work well for them. During the study, we observed that when players were using the phones as controllers, they would occasionally not notice that their thumbs had slid away from the virtual joysticks, as their focus was on the tiled displays instead. Some players also experienced issues with perspiration affecting the phone touch screens after extended play, which especially affected the tiled display sessions for the same reason.

Table 5.3: Codes for Theme 1: Preference for Tiled Display or for Individual Devices

Codes	Participant Statements
Preferred playing on tiled display	• P4.1 said that they preferred playing on the tiled display • P4.3 said that they preferred playing on the tiled display • P5.1, P5.2 and P5.3 agreed that they preferred playing on the tiled display • P6.2 and P6.3 preferred playing on the tiles • P7.3 said that playing on the tiled display was fun, and that playing on phones was boring
Preferred playing on individual devices	• P4.2 said that they preferred playing on the individual phones • P6.1 preferred playing on the phones, which felt more immersive
Tiled display novelty	• P1.1 said that it was a unique mechanic, referring to the tiled display • P5.1 and P5.2 agreed that the tiled display setup was clever
Didn't like phones as controllers	• P6.1 said that the controls were more intuitive when playing with individual phones • P5.2 said that it would be better with a real console controller, they felt that the phone controls didn't work very well for them

5.3.2 Theme 2: Collaboration and Social Interaction

Several participants made comments about more co-player interaction when using the tiled displays. Several players stated that it was easier to collaborate, with P2.1 and P8.3 explaining that being able to see the other players was the reason for this. P7.3 said that when using the shared tiled displays, it felt like all the players had a common goal. P6.2, on the other hand, stated that *competing* with the other players was easier with the tiled displays because they were able to see the whole map, suggesting that being able to monitor the other players outweighed the fact that their own movements were also public. With the game including elements of both competition and collaboration, we observed different groups tending more toward one or the other behaviour.

Two participants, P1.1 and P4.1, provided feedback about the player interaction for the game in general, with P1.1 saying that they didn't feel the need to collaborate and P4.1 saying that the game didn't promote enough competition. This could affect the studies' ability to effectively compare the two game variants for each of these social aspects.

Table 5.4: Codes for Theme 2: Collaboration and Social Interaction

Codes	Participant Statements
More player interaction with tiled display	• P2.1 said it was easier to collaborate when using tiled displays because they could see other players. • P6.2 and P6.3 said that collaborating was easier with the tiles • P7.3 said that collaborating was easier on the tiled display, and that it felt like they had a common goal • P8.3 said that the tiled display made it easier to collaborate because they could see all the other players • P6.2 said that competing is easier with the tiled display because you can see the whole map • P8.3 said that playing on the phones felt more individual
Insufficient player interaction overall	• P4.1 said that there wasn't enough competition • P1.1 said that it had potential, but wasn't driven to have to collaborate
Interest in group performance	• P6.3 was interested in how their group went compared to other groups

5.3.3 Theme 3: Visibility and Spatial Awareness

Players had different experiences relating to how they focused on the game, with P6.1, P6.2, and P6.3 agreeing that they were able to pay attention to enemies that were on other tiles beyond the one their character was currently on, while P4.2 and P1.2 said that having a smaller visible playing area with individual devices made it easier to focus on the game. Relating to controllers in particular, P1.2 said that there wasn't sufficient notice when they were required to switch their focus from the shared display to their individual controller, which for example happened when players all had to select a skill upgrade before a new enemy wave could begin. This matched our experience observing the studies, where players would often not notice the audio alert, suggesting the need for more intrusive methods, for instance visual signals on the shared display or continuous sounds. While haptic feedback was programmed into the framework, it was later found that disabling notifications for the purposes of the study also disabled vibrations on two of the phones. Players who failed to notice would eventually be reminded by their co-players, as the game was unable to progress.

While P4.1 and 4.3 said that they preferred being able to see the whole game world with the tiled displays, P1.1 stated that seeing all the enemies at once resulted in greater tension. This could be an advantage or a disadvantage depending on the goal of the game.

Several players (P5.1, 5.2, 5.3, and P7.2) said that the game map felt bigger when playing on the tiled displays, despite the fact that the game world had the same virtual size across the two variants. While this could be explained by the game interface being scaled up linearly to fit on the tablets, it could also be affected by the player's ability to see the entire map at once on the shared displays.

P1.2 and P2.2 both shared ways the game could incentivise or require players to use the whole playing area. P1.2 suggested that players could be sectioned off specifically as a way to require collaboration, in relation to P1.1's statement that there wasn't enough need for players to collaborate. P2.2's statement, on the other hand, related to the fact that their group spent most of the time huddled in the centre of the middle tile with limited movement when playing with a shared display, especially later into the game sessions when the number of enemies increased exponentially. As they suggested, the game design could do a better job of requiring players to move about. This may have also been a factor in players' different perceptions of collaboration between the two game variants, as having a visual centre point on the tiled displays could cause players to naturally gravitate towards it, thereby making it more likely that the players would be near one another.

Table 5.5: Codes for Theme 3: Visibility and Spatial Awareness

Codes	**Participant Statements**
Able to focus across tiled displays	• P6.1, P6.2 and P6.3 agreed that they were able to pay attention to the enemies even on other screens
Tiles' negative affect on focus	• P4.2 said that playing on their phone made it easier to focus • P8.3 said that having a smaller area of play is important, to not have to track what's going on • P1.2 said that they needed to be told to look at their phone
Effect of seeing whole map	• P4.1 and P4.3 agreed that they preferred seeing all the information with the tiled display • P1.1 said that there was more tension with the tiled devices because they could see all the enemies at once
Map felt larger on tiled display	• P5.1, P5.2, and P5.3 agreed that the map felt bigger with the tiles • P7.2 said that the map felt bigger with the tiles
Need reason to use whole map	• P1.2 suggested that having players confined to different sections could promote better collaboration • P2.2 said that skills should be dropped throughout the game as a way to make full use of the space

5.3.4 Theme 4: Gap Between Devices

The fourth theme related to the gap that was present between devices, with some of the feedback describing players' experience of it during gameplay, while some groups were additionally asked to try a demonstration mode across the three tablets that had a blind spot across the border of two tablets, and a seamless jump across the other border, with no enemies being spawned in this mode.

All of the players who were able to directly compare the two modes said that the blind spot felt more intuitive, while one participant who didn't try the demonstration mode, P4.1, conjectured that they would prefer not having a blind spot.

Two participants, P7.2 and P8.1, noted that they occasionally got surprised by enemies in the blind spot, possibly either referring to enemies emerging from the blind spot, or the players moving into the blind spot and colliding with them. This suggests a need to have some kind of indicator on either side of the gap when a game entity is fully or partially obscured as it moves between devices. Additionally, game entities can be designed to be larger so that they are less likely to be fully hidden.

As devices feature increasingly thinner bezels, this issue will become increasingly irrelevant, with both modes of dealing with the gap between screens becoming less problematic.

Table 5.6: Codes for Theme 4: Gap Between Devices

Codes	**Participant Statements**
Having gap between devices is intuitive	• P5.1 and P5.2 said that moving across with the blind spot felt intuitive • P6.1, P6.2 and P6.3 agreed that the blind spot was intuitive • P7.1, P7.2, and P7.3 all agreed that jumping across was less intuitive • P7.2 said that moving across the blind spot was intuitive • P8.1, P8.2 and P8.3 agreed that they all preferred moving across the gap • P8.3 said that the gap was intuitive and that they didn't notice it too much
Having *no* gap between devices is more intuitive	• P4.1 thought the game would be more intuitive without a blind spot between devices
Surprised by enemies in blind spot	• P7.2 said that they got surprised occasionally by an enemy in the blind spot • P8.1 said that enemies did surprise them in the blind spot occasionally

5.3.5 Theme 5: Relevant Gaming Genres and Platforms

Several participants made the connection between playing on the tiled display to the Nintendo Switch gaming console, which features two detachable controllers that can be used by different players to play local multiplayer games, either connected to a TV or using the console's built-in 7-inch display. P5.2 pointed out that Switch games could work well with the tiled display, which provides a potential area for future work.

When asked what game genres could work well on a tiled display, P5.3 suggested racing games, which would be well suited to the perpendicular top-down view required to maintain orientation independence. A racing game could make full use of the dynamic tile layout made possible by cross-display ecologies, allowing players to arrange the tiles and then draw a racetrack spanning all the tiles, which would additionally configure the device locations in the same step. P6.2 suggested that tabletop games would work well, in line with the genre of games that have been commonly implemented for interactive tabletop displays.

Table 5.7: Codes for Theme 5: Relevant Gaming Genres and Platforms

Codes	**Participant Statements**
Comparison to nintendo switch	• P4.1 likened the tiled displays to playing on a Switch console • P5.2 said that Switch games would work well with the tiled display • P6.1 likened the tiled display to a Switch console
Genre suggestion	• P5.3 suggested that racing games would work well • P6.2 said that tabletop games would work well on the tiles

Chapter 6

Discussion

The purpose of this study was to investigate the impact cross-display ecologies have on multiplayer role-playing games, focusing on overall player experience, social presence, and control intuitiveness. In order to evaluate the study's hypotheses, we conducted a within-subject study comparing a game being played on both cross-display ecologies and on individual devices, evaluating the difference through quantitative surveys and qualitative feedback.

6.1 Social Presence

A key finding from the study was the statistically significant increase in *behavioural involvement*, the extent to which players' actions depended on and influenced each other. Participants reported greater mutual dependence and attentiveness to others while using cross-display ecologies, reflected in survey prompts such as "I paid close attention to the other(s)" and "My actions depended on the other(s) actions". This finding is of particular note when compared to the research of De Kort et al. (2007) who found that increasing physical proximity in gaming setups often leads to higher psychological engagement but not necessarily higher behavioural engagement. In fact, many co-located gaming setups can limit behavioural involvement between players by not offering opportunities for face-to-face engagement during play, with players facing away from each towards a screen.

However, no statistically significant increases were found for the other social presence measures, namely the two psychological engagement measures - Empathy and Negative Feelings. De Kort et al. found feelings of empathy were positively correlated with longer play duration, ranging from less than 30 minutes to more than 3 hours. Given the short play duration in the trials for this study of around 10 minutes, it's possible that the participants didn't play together for long enough to experience these feelings. Empathy was also found to be higher for co-located gaming versus online play. With behavioural involvement increasing without an associated increase in psychological involvement, our observations suggest that empathy may be less dependent on the playing medium itself and more related to the game design and the co-location of players. Kort et al. additionally found limited variation in Negative Feelings across different forms of play, so it's not surprising that we did not observe any statistically significant increases either.

6.2 Overall Game Experience

In terms of overall game experience, as measured by Deci and Ryan's (2000) Self-Determination Theory, the only statistically significant improvement was in the measure of *autonomy*, which refers to the player's sense of freedom and availability of interesting choices in the game. This increase is consistent with the feedback from participants, several of whom agreed that playing on the cross-display ecologies was interesting. However, in order to fully measure this subscale, players would have to spend more time playing on a cross-device ecology, to reduce the impact of initial experience of novelty. Additionally, in order to directly compare the two game modes, a consistent rectangular game map was used for all studies, preventing participants from experiencing the more novel device layouts possible with cross-device ecologies.

Since the game design and mechanics were consistent across both variations, it is not surprising that there was no statistically significant change in competence, which measured how players felt the game's difficulty matched their ability.

The third relevant measure, immersion, also showed no statistically significant change. This contrasts findings by Thompson et al. (2012), who found a positive correlation between screen size and immersion. One factor that may have affected this is how the game handled displaying the game world, with the individual devices' view displaying only a section of the world and following the player's character, while the shared cross-display ecology displayed the entire game world. Users may have experienced the shared display as a less personal, more detached view. One potential way to mitigate this could be to have a hybrid game mode where players can view the game on both their phone, with overlaying controls, as well as on a shared display, allowing players to choose what mode works best for them, giving them both a larger game overview as well as a more zoomed in view.

We also did not see a change in the Relatedness subscale. This suggests that it may be more closely related to psychological involvement, which also observed no increase, compared to behavioural involvement. Relatedness refers to players' need for connection and the feelings of belonging and care from others, which is more in line with the emotional experience measured by the SPGQ's psychological involvement subscales.

Ryan et al. (2006) found that autonomy was one of the factors that predict greater game enjoyment. With the other factors not showing a statistically significant decrease, the greater sense of autonomy supports the feedback provided by the study participants, the majority of whom expressed a preference for playing on the shared display.

6.3 Controls and User Experience

The analysis of the PENS control intuitiveness measure did not show any significant differences between the two setups, with players finding the controls largely intuitive in both conditions. This is a positive outcome, particularly considering that it was likely the first time many players had interacted with a cross-display ecology. The fact that the cross-display setup did not impact the players' ability to interact effectively with the game suggests that the controls translated well across both formats. However, it is worth noting that the initial setup of the cross-display ecology was handled by the experimenter during the study, being out of scope for the comparison trial due to it having no equivalent in the individual devices setup.

In the qualitative feedback, users were asked to address several points relating to their experience playing on cross-device ecologies. One of the themes that arose was around visibility and spatial awareness, with players offering different opinions on whether using multiple displays affected their awareness of the game. Some participants expressed no issues with the larger game view provided by the shared display, while others brought up that they failed to notice game enemies moving towards them in a blind spot, indicating they weren't fully paying attention across the screens while the enemies were still visible. Future research could measure this empirically, comparing whether users' focus is impacted by screen boundaries (see Figure 6.1).

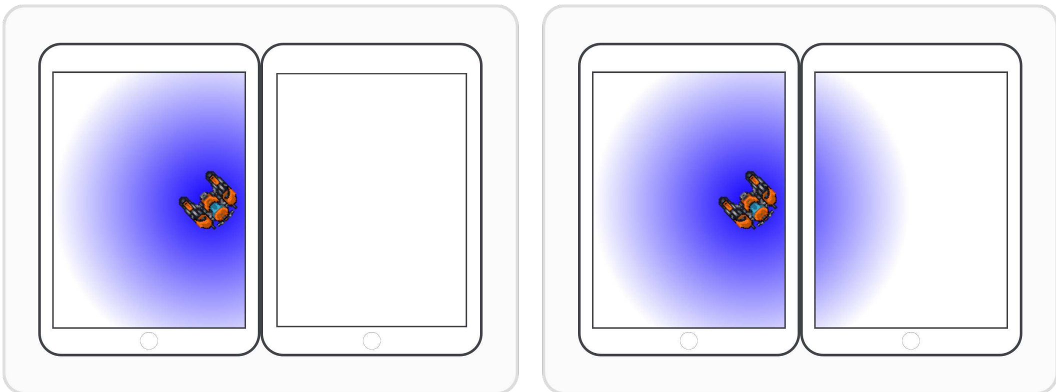


Figure 6.1: Users' focus, represented by the fading blue circle, being affected by screen boundaries (left) or crossing screen boundaries (right)

Players also provided feedback relating to the cross-device ecologies' effect on collaboration and competition, expressing that being able to see the other players made it easier to collaborate. However, one participant related this to competition as well, saying that seeing the whole map made it easier to compete with the other players. Although participants' use of the term "easier" could be interpreted multiple ways, it suggests that players experienced greater interdependence when playing on cross-device ecologies, regardless of whether they viewed collaborating or competing with the other players as being more important. As Depping et al. (2017) outlined, interdependence is relevant for both collaborative and competitive games in promoting social connection.

6.4 Limitations

As addressed in Section 5.3 **(Thematic Analysis of Qualitative Feedback)**, participant feedback was transcribed during the trials, instead of being recorded verbatim. This step could have introduced bias by the researcher, and this limitation should be considered throughout the thematic analysis and discussion of this thesis. Additionally, it likely limited the level of detail of the feedback, preventing more nuanced thoughts from being recorded.

The second major limitation of this study was the design of the game used for the study. Although it included characteristics typical of role-playing games, it lacked the same level of detail and narrative associated with more immersive games. Combined with the short playing sessions in the trials, it's likely that the game failed to promote a strong sense of connectedness across either of the game modes, making a comparison between the two more difficult. A more reliable approach would be to repurpose an existing game instead of designing one from scratch. This would also be a good way to evaluate the programming interface of the *Makeshift* framework.

The game also featured aspects of both collaboration and competition, with all the players needing to survive each round, while also having individual scores compared on a leaderboard. However, by trying to include both types of social interaction, it's likely the game didn't promote a strong sense of either, as expressed by two players in their feedback. This also may have limited players' experience of social presence across both game variants. There is extensive research on how to promote collaboration through game design, which could be used to design or adapt a game to more effectively evaluate cross-device ecologies' effect on social presence. Collaboration could also be measured empirically by measuring the players' performance in a collaborative game across the two game modes.

The study conducted was also limited in scope and number of participants, being a within-subject study with a small number of participants. A larger study would help identify more subtle statistical trends, and a between-subject study would help control against factors that may have impacted our findings. We also did not include additional relevant playing modes, such as being able to see the game world on both individual devices as well as on the shared display, as well as using a single large tablet as the shared display instead of a cross-device ecology.

6.5 Future Work

As addressed in the limitations, the game used to evaluate our research aims was limited in scope. Additionally, in order to support a direct comparison between playing on cross-device ecologies, the game was not able to make use of the novel dynamics enabled by having a modular display. Designing or adapting a game specifically to make use of the game mechanics enabled by cross-device ecologies would allow for a more in-depth evaluation of their effect on player experience, including features not currently implemented in the framework. For instance, allowing users to dynamically re-position tile displays would allow for new gameplay possibilities, such as role-playing games featuring shifting game worlds or challenges requiring physical rearrangement.

Additionally, the *Makeshift* framework is a limited prototype, implementing only the features required for the study conducted. Each of the framework limitations described in Section 3.4 **(Framework Limitations)** poses interesting future work, including investigating the use of localised audio to create a more immersive experience, as well as implementing 3D positioning using device accelerometers to allow tiles to be arranged at different angles. Each of these potential features could be used as a way to design novel game mechanics, increasing the potential for emergent gameplay.

The open-ended feedback also revealed additional game genres that participants felt were relevant to cross-device ecologies. Future work could investigate how cross-device ecologies could be relevant to the popular Nintendo Switch gaming console, or explore additional genres such as racing or tabletop board games.

This research did not conduct any empirical measurements to evaluate the performance limitations of cross-device ecologies. Future work could address this, including testing the number of tiles and controllers that can be connected simultaneously using the centralised server approach employed by *Makeshift* and comparing it to a decentralised server approach.

Chapter 7

Conclusion

This research investigated the use of cross-display ecologies for multiplayer role-playing games and their impact on player experience and social presence. By developing the *Makeshift* framework and conducting a study comparing cross-display setups against using individual handheld devices, we found that cross-display ecologies can increase behavioural involvement, measuring players' attention to one another, and autonomy, measuring the extent to which a game provides interesting choices.

We conducted a thematic analysis on the players' open-ended feedback and identified several key themes, including general preference for either tiled displays or individual devices, the impact of cross-display ecologies on collaboration and social interaction, players' spatial awareness and visibility across screens, the effects of gaps between devices on gameplay, and the potential relevance of different gaming genres and platforms for cross-display setups. This feedback provided key insights into the usability challenges that arise from adapting cross-device ecologies for role-playing games.

Based on this feedback, cross-device ecologies were also found to encourage both collaboration as well as competition, indicating that the shared displays can be used as a way to increase interdependence between players. Providing a larger playing area allowed the game experience to inherit characteristics typical of larger screens such as tabletop surfaces, while preserving the mobility and flexibility offered by mobile devices.

Appendix A

Appendix: Demographics Survey

The Gaming Habits Survey filled out by each participant at the start of the studies has been attached over the next two pages.

Gaming Habits Questionnaire

Gaming Frequency:

1. How often do you play video games?

    - ❏ Daily
    - ❏ Several times a week
    - ❏ Once a week
    - ❏ Several times a month
    - ❏ Once a month or less

Gaming Duration:

2. How long is your typical gaming session?
    - ❏ Less than 15 minutes
    - ❏ 15-30 minutes
    - ❏ 30-60 minutes
    - ❏ 1-2 hours
    - ❏ 2-3 hours
    - ❏ More than 3 hours

Types of Games Played:

3. What types of games do you play most often? (Select all that apply)
    - ❏ Action / Adventure
    - ❏ Role-playing (RPG)
    - ❏ Simulation
    - ❏ Strategy
    - ❏ Sports
    - ❏ Racing
    - ❏ Puzzle
    - ❏ Idle
    - ❏ Other: ___________________________

Gaming Context:

4. Do you usually play games alone or with others?
    - ❏ Alone
    - ❏ With friends online
    - ❏ With friends in person
    - ❏ With strangers online

Preferred Gaming Platforms:

5. Which platforms do you use for gaming? (Select all that apply)
   - ❑ Phone
   - ❑ Tablet
   - ❑ PC
   - ❑ Console (e.g., PlayStation, Xbox)
   - ❑ Other: ______________________________

Mobile Devices:

6. How many mobile devices do you own, including phones and tablets?
   - ❑ 0
   - ❑ 1
   - ❑ 2
   - ❑ 3
   - ❑ 4
   - ❑ 5 or more

Motivation for Gaming:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
7. I play video games for entertainment.	☐	☐	☐	☐	☐
8. I play video games to unwind and to relax.	☐	☐	☐	☐	☐
9. I play video games to socialize with friends.	☐	☐	☐	☐	☐
10. I play video games for the challenge / sense of achievement	☐	☐	☐	☐	☐
11. I play video games for the immersive stories and worlds.	☐	☐	☐	☐	☐

Appendix B

Appendix: Guiding Questions for Feedback Interview

The guiding questions for the open-ended feedback section at the end of each study is attached on the following page. These questions were only used as discussion prompts, and participants were allowed to direct the discussion toward any topic they wanted to provide feedback on.

Feedback Interview – Guiding Questions

Guiding questions for the open-ended interview at the end of the trial:

1. What did you think of the game?
2. What did you think of playing on the shared playing area?
3. Did you prefer playing on separate or shared devices? Why?
4. How did you find playing with the other player/s on a shared playing area?
5. How did you find collaborating with the other player/s on a shared playing area?
6. How did you find competing with the other player/s on a shared playing area?
7. Do you have any ideas on how playing on a shared playing area could be improved?
8. Do you think that the shared playing area would work for other types of games? Which games and why?
9. Is there any other feedback you would like to give?

Bibliography

(2012). Junkyard Jumbotron. https://www.media.mit.edu/projects/junkyard-jumbotron/overview/. [Cited on page 14.]

Antle, A. N., Bevans, A., Tanenbaum, T. J., Seaborn, K., and Wang, S. (2010). Futura: Design for collaborative learning and game play on a multi-touch digital tabletop. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '11, pages 93–100, New York, NY, USA. Association for Computing Machinery. [Cited on pages 3 and 9.]

Baldauf, M., Fröhlich, P., Adegeye, F., and Suette, S. (2015). Investigating On-Screen Gamepad Designs for Smartphone-Controlled Video Games. *ACM Trans. Multimedia Comput. Commun. Appl.*, 12(1s):22:1–22:21. [Cited on page 22.]

Ballendat, T., Marquardt, N., and Greenberg, S. (2010). Proxemic interaction: Designing for a proximity and orientation-aware environment. In *ACM International Conference on Interactive Tabletops and Surfaces*, pages 121–130, Saarbrücken Germany. ACM. [Cited on page 1.]

Barendregt, W., Börjesson, P., Eriksson, E., and Torgersson, O. (2017). StringForce: A Forced Collaborative Interaction Game for Special Education. In *Proceedings of the 2017 Conference on Interaction Design and Children*, IDC '17, pages 713–716, New York, NY, USA. Association for Computing Machinery. [Cited on pages 4 and 17.]

Bateman, S., Gutwin, C., Mansoor, H., Nacenta, M., Van Der Kamp, M., Baliesnyi, M., Gagnon, K., and Rollheiser, J. (2023). WAMS: A Flexible API for Visual Workspaces Across Multiple Surfaces. *Proceedings of the ACM on Human-Computer Interaction*, 7(EICS):1–40. [Cited on page 15.]

Biocca, F., Harms, C., and Burgoon, J. K. (2003). Toward a More Robust Theory and Measure of Social Presence: Review and Suggested Criteria. *Presence*, 12(5):456–480. [Cited on pages 4 and 7.]

Biocca, F., Harms, C., and Gregg, J. (2001). The Networked Minds Measure of Social Presence: Pilot Test of the Factor Structure and Concurrent Validity. [Cited on page 34.]

Brudy, F., Budiman, J. K., Houben, S., and Marquardt, N. (2018). Investigating the Role of an Overview Device in Multi-Device Collaboration. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–13, Montreal QC Canada. ACM. [Cited on page 11.]

Brudy, F., Holz, C., Rädle, R., Wu, C.-J., Houben, S., Klokmose, C. N., and Marquardt, N. (2019). Cross-Device Taxonomy: Survey, Opportunities and Challenges of Interactions Spanning Across Multiple Devices. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–28, Glasgow Scotland Uk. ACM. [Cited on pages 2, 11, and 14.]

Brudy, F. M. and Marquardt, N. (2017). The Tabletop is Dead? - Long Live the Table's Top! https://www.ucl.ac.uk/computer-science/. [Cited on page 3.]

Chaboissier, J., Isenberg, T., and Vernier, F. (2011). RealTimeChess: Lessons from a participatory design process for a collaborative multi-touch, multi-user game. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, ITS '11, pages 97–106, New York, NY, USA. Association for Computing Machinery. [Cited on pages 3 and 9.]

Chartrand, T. L. and Bargh, J. A. (1999). The chameleon effect: The perception–behavior link and social interaction. *Journal of Personality and Social Psychology*, 76(6):893–910. [Cited on page 8.]

Coppola, G., Costagliola, G., De Rosa, M., and Fuccella, V. (2020). Domus: A multi-user TUI game for multi-touch tables. In *Proceedings of the International Conference on Advanced Visual Interfaces*, AVI '20, pages 1–3, New York, NY, USA. Association for Computing Machinery. [Cited on page 9.]

Dang, C. T. and André, E. (2013). TabletopCars: Interaction with active tangible remote controlled cars. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*, TEI '13, pages 33–40, New York, NY, USA. Association for Computing Machinery. [Cited on page 9.]

De Kort, Y., Ijsselsteijn, W., and Poels, K. (2007). Digital Games as Social Presence Technology: Development of the Social Presence in Gaming Questionnaire (SPGQ). In *Journal of Applied Mechanics-transactions of The Asme - J APPL MECH*. [Cited on pages 3, 4, 7, 9, 24, 34, 35, and 53.]

Dearman, D., Guy, R., and Truong, K. (2012). Determining the orientation of proximate mobile devices using their back facing camera. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, pages 2231–2234, New York, NY, USA. Association for Computing Machinery. [Cited on page 13.]

Deci, E. L. and Ryan, R. M. (2000). The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychological Inquiry*, 11(4):227–268. [Cited on pages 35 and 54.]

Depping, A. E., Johanson, C., and Mandryk, R. L. (2018). Designing for Friendship: Modeling Properties of Play, In-Game Social Capital, and Psychological Well-being. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*, CHI PLAY '18, pages 87–100, New York, NY, USA. Association for Computing Machinery. [Cited on page 4.]

Depping, A. E. and Mandryk, R. L. (2017). Cooperation and Interdependence: How Multiplayer Games Increase Social Closeness. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, CHI PLAY '17, pages 449–461, New York, NY, USA. Association for Computing Machinery. [Cited on pages 4, 8, and 56.]

Depping, A. E., Mandryk, R. L., Johanson, C., Bowey, J. T., and Thomson, S. C. (2016). Trust Me: Social Games are Better than Social Icebreakers at Building Trust. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play*, CHI PLAY '16, pages 116–129, New York, NY, USA. Association for Computing Machinery. [Cited on page 8.]

Dietz, P. and Leigh, D. (2001). DiamondTouch: A multi-user touch technology. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, UIST '01, pages 219–226, New York, NY, USA. Association for Computing Machinery. [Cited on pages 11 and 23.]

Döweling, S., Tahiri, T., Riemann, J., and Mühlhäuser, M. (2016). Collaborative Interaction with Geospatial Data—A Comparison of Paper Maps, Desktop GIS and Interactive Tabletops. In Anslow, C., Campos, P., and Jorge, J., editors, *Collaboration Meets Interactive Spaces*, pages 319–348. Springer International Publishing, Cham. [Cited on pages 11 and 23.]

Eriksson, E., Baykal, G. E., Torgersson, O., and Bjork, S. (2021). The CoCe Design Space: Exploring the Design Space for Co-Located Collaborative Games that Use Multi-Display Composition. In *Designing Interactive Systems Conference 2021*, pages 718–733, Virtual Event USA. ACM. [Cited on pages 17, 18, 22, and 23.]

Eriksson, E., Petersen, J. O., Bagge, R., Kristensen, J. B., Lervig, M., Torgersson, O., and Baykal, G. E. (2022). Quadropong - Conditions for Mediating Collaborative Interaction in a Co-located Collaborative Digital Game using Multi-Display Composition. In *Adjunct Proceedings of the 2022 Nordic Human-Computer Interaction Conference*, pages 1–2, Aarhus Denmark. ACM. [Cited on pages 4 and 17.]

ESA (2024). 2024 Essential Facts About the U.S. Video Game Industry. https://www.theesa.com/wp-content/uploads/2024/05/Essential-Facts-2024-FINAL.pdf. [Cited on pages 3 and 7.]

Garcia, M. B., Rull, V. M. A., Gunawardana, S. S. J. D., Bias, D. J. M., Chua, R. C. C., Cruz, J. E. C., Raguro, M. C. F., and Perez, M. R. L. (2022). Promoting Social Relationships Using a Couch Cooperative Video Game: An Empirical Experiment

With Unacquainted Players. *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS)*, 14(1):1–18. [Cited on page 9.]

Garcia-Sanjuan, F., Jaen, J., and Nacher, V. (2016). Toward a General Conceptualization of Multi-Display Environments. *Frontiers in ICT*, 3:204921. [Cited on pages 11 and 14.]

Goel, M., Lee, B., Islam Aumi, M. T., Patel, S., Borriello, G., Hibino, S., and Begole, B. (2014). SurfaceLink: Using inertial and acoustic sensing to enable multi-device interaction on a surface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1387–1396, Toronto Ontario Canada. ACM. [Cited on page 13.]

Gonçalves, D., Pais, P., Gerling, K., Guerreiro, T., and Rodrigues, A. (2023). Social gaming: A systematic review. *Computers in Human Behavior*, 147:107851. [Cited on pages 4, 7, 8, and 35.]

Google (2013). RACER: A Chrome Experiment. http://g.co/racer. [Cited on page 17.]

Gryphon, K., Vu, V., and Chung, H. (2023). A Design Space of Multi-Display Spatial Interactions for Visualization Tasks. In *Proceedings of the 2023 ACM Symposium on Spatial User Interaction*, pages 1–13, Sydney NSW Australia. ACM. [Cited on page 15.]

Halbrook, Y. J., O'Donnell, A. T., and Msetfi, R. M. (2019). When and How Video Games Can Be Good: A Review of the Positive Effects of Video Games on Well-Being. *Perspectives on Psychological Science*, 14(6):1096–1104. [Cited on page 7.]

Hall, E. T. (1966). *The Hidden Dimension*. Knopf Doubleday Publishing Group. [Cited on pages 1, 10, 12, and 23.]

Harris, J. and Hancock, M. (2018). Beam Me 'Round, Scotty! II: Reflections on Transforming Research Goals into Gameplay Mechanics. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*, CHI PLAY '18 Extended Abstracts, pages 193–204, New York, NY, USA. Association for Computing Machinery. [Cited on pages 4 and 8.]

Harris, J. and Hancock, M. (2019). To Asymmetry and Beyond! Improving Social Connectedness by Increasing Designed Interdependence in Cooperative Play. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, pages 1–12, New York, NY, USA. Association for Computing Machinery. [Cited on page 8.]

Hinckley, K. (2003). Synchronous gestures for multiple persons and computers. In *Proceedings of the 16th Annual ACM Symposium on User Interface Software and Technology*, pages 149–158, Vancouver Canada. ACM. [Cited on page 13.]

Hinckley, K., Ramos, G., Guimbretiere, F., Baudisch, P., and Smith, M. (2004). Stitching: Pen gestures that span multiple displays. In *Proceedings of the Working Conference on Advanced Visual Interfaces*, pages 23–31, Gallipoli Italy. ACM. [Cited on page 14.]

Holz, C. and Baudisch, P. (2013). Fiberio: A touchscreen that senses fingerprints. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, pages 41–50, St. Andrews Scotland, United Kingdom. ACM. [Cited on pages 11 and 23.]

Huang, D.-Y., Lin, C.-P., Hung, Y.-P., Chang, T.-W., Yu, N.-H., Tsai, M.-L., and Chen, M. Y. (2012). MagMobile: Enhancing social interactions with rapid view-stitching games of mobile devices. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*, pages 1–4, Ulm Germany. ACM. [Cited on pages 4, 15, 16, and 22.]

IJsselsteijn, W., de Kort, Y., and Poels, K. (2013). *The Game Experience Questionnaire*. Technische Universiteit Eindhoven, Eindhoven. [Cited on page 35.]

Ijsselsteijn, W., Hoogen, W., Klimmt, C., De Kort, Y., Lindley, C., Mathiak, K., Poels, K., Ravaja, N., Turpeinen, M., and Vorderer, P. (2008). Measuring the experience of digital game enjoyment. *Proceedings of Measuring Behavior*. [Not cited.]

itch.io (2024). Most used Engines. https://itch.io/game-development/engines/most-projects. [Cited on page 22.]

Jensen, H. P., Olsen, M. P., and Skov, M. B. (2016). PinchPan: Investigating Children's Collaboration in Cross-Device Interaction. In *Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology*, pages 1–6, Osaka Japan. ACM. [Cited on page 14.]

Jin, H., Holz, C., and Hornbæk, K. (2015a). Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, pages 147–156, Charlotte NC USA. ACM. [Cited on page 13.]

Jin, H., Xu, C., and Lyons, K. (2015b). Corona: Positioning Adjacent Device with Asymmetric Bluetooth Low Energy RSSI Distributions. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, UIST '15, pages 175–179, New York, NY, USA. Association for Computing Machinery. [Cited on page 13.]

Johnson, D., Gardner, M. J., and Perry, R. (2018). Validation of two game experience scales: The Player Experience of Need Satisfaction (PENS) and Game Experience Questionnaire (GEQ). *International Journal of Human-Computer Studies*, 118:38–46. [Not cited.]

Kim, S., Ko, D., and Lee, W. (2017). Utilizing Smartphones as a Multi-Device Single Display Groupware to Design Collaborative Games. In *Proceedings of the 2017 Conference on Designing Interactive Systems*, DIS '17, pages 1341–1352, New York, NY, USA. Association for Computing Machinery. [Cited on page 17.]

Langner, R., Horak, T., and Dachselt, R. (2018a). Demonstrating vistiles: Visual data exploration using mobile devices. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces*, pages 1–3, Castiglione della Pescaia Grosseto Italy. ACM. [Cited on page 15.]

Langner, R., Horak, T., and Dachselt, R. (2018b). VISTILES: Coordinating and Combining Co-located Mobile Devices for Visual Data Exploration. *IEEE Transactions on Visualization and Computer Graphics*, 24(1):626–636. [Cited on page 15.]

Li, M. and Kobbelt, L. (2012). Dynamic tiling display: Building an interactive display surface using multiple mobile devices. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*, pages 1–4, Ulm Germany. ACM. [Cited on page 13.]

Lucero, A., Holopainen, J., and Jokela, T. (2011). Pass-them-around: Collaborative use of mobile phones for photo sharing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1787–1796, Vancouver BC Canada. ACM. [Cited on page 14.]

Lyons, K., Pering, T., Rosario, B., Sud, S., and Want, R. (2009). Multi-display Composition: Supporting Display Sharing for Collocated Mobile Devices. In Gross, T., Gulliksen, J., Kotzé, P., Oestreicher, L., Palanque, P., Prates, R. O., and Winckler, M., editors, *Human-Computer Interaction – INTERACT 2009*, pages 758–771, Berlin, Heidelberg. Springer. [Cited on page 14.]

Magerkurth, C., Cheok, A. D., Mandryk, R. L., and Nilsen, T. (2005). Pervasive games: Bringing computer entertainment back to the real world. *Computers in Entertainment*, 3(3):4. [Cited on page 10.]

Magerkurth, C., Engelke, T., and Memisoglu, M. (2004a). Augmenting the virtual domain with physical and social elements: Towards a paradigm shift in computer entertainment technology. *Comput. Entertain.*, 2(4):12. [Cited on pages 9 and 24.]

Magerkurth, C., Memisoglu, M., Engelke, T., and Streitz, N. (2004b). Towards the next generation of tabletop gaming experiences. In *Proceedings of Graphics Interface 2004*, GI '04, pages 73–80, Waterloo, CAN. Canadian Human-Computer Communications Society. [Cited on pages 10, 11, and 23.]

Mandryk, R. L. and Maranan, D. S. (2002). False prophets: Exploring hybrid board/video games. In *CHI '02 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '02, pages 640–641, New York, NY, USA. Association for Computing Machinery. [Cited on page 9.]

Marquardt, N., Henry Riche, N., Holz, C., Romat, H., Pahud, M., Brudy, F., Ledo, D., Park, C., Nicholas, M. J., Seyed, T., Ofek, E., Lee, B., Buxton, W. A., and Hinckley, K. (2021). AirConstellations: In-Air Device Formations for Cross-Device Interaction via Multiple Spatially-Aware Armatures. In *The 34th Annual ACM Symposium on User Interface Software and Technology*, pages 1252–1268, Virtual Event USA. ACM. [Cited on page 15.]

Marquardt, N., Hinckley, K., and Greenberg, S. (2012). Cross-device interaction via micro-mobility and f-formations. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology*, pages 13–22, Cambridge Massachusetts USA. ACM. [Cited on page 12.]

Nacenta, M. A., Pinelle, D., Stuckel, D., and Gutwin, C. (2007). The effects of interaction technique on coordination in tabletop groupware. In *Proceedings of Graphics Interface 2007*, GI '07, pages 191–198, New York, NY, USA. Association for Computing Machinery. [Cited on page 10.]

Nielsen, H. S., Olsen, M. P., Skov, M. B., and Kjeldskov, J. (2014). JuxtaPinch: Exploring multi-device interaction in collocated photo sharing. In *Proceedings of the 16th International Conference on Human-computer Interaction with Mobile Devices & Services*, pages 183–192, Toronto ON Canada. ACM. [Cited on pages 14, 24, and 25.]

Ohta, T. and Tanaka, J. (2012). Pinch: An Interface That Relates Applications on Multiple Touch-Screen by 'Pinching' Gesture. In Nijholt, A., Romão, T., and Reidsma, D., editors, *Advances in Computer Entertainment*, volume 7624, pages 320–335. Springer Berlin Heidelberg, Berlin, Heidelberg. [Cited on pages 4, 14, 16, 22, 24, and 25.]

Ohta, T. and Tanaka, J. (2015). MovieTile: Interactively adjustable free shape multi-display of mobile devices. In *SIGGRAPH Asia 2015 Mobile Graphics and Interactive Applications*, pages 1–7, Kobe Japan. ACM. [Cited on page 14.]

Pais, P., Gonçalves, D., Reis, D., Godinho, J. C. N., Morais, J. F., Piçarra, M., Trindade, P., Alexandrovsky, D., Gerling, K., Guerreiro, J., and Rodrigues, A. (2024). A Living Framework for Understanding Cooperative Games. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 1–17, Honolulu HI USA. ACM. [Cited on pages 10 and 23.]

Piper, A. M., O'Brien, E., Morris, M. R., and Winograd, T. (2006). SIDES: A cooperative tabletop computer game for social skills development. In *Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work*, CSCW '06, pages 1–10, New York, NY, USA. Association for Computing Machinery. [Cited on pages 3, 9, 10, and 11.]

Poulose, A., Kim, J., and Han, D. S. (2019). Indoor Localization with Smartphones: Magnetometer Calibration. In *2019 IEEE International Conference on Consumer Electronics (ICCE)*, pages 1–3. [Cited on page 27.]

Qiu, J., Chu, D., Meng, X., and Moscibroda, T. (2011). On the feasibility of real-time phone-to-phone 3D localization. In *Proceedings of the 9th ACM Conference on Embedded Networked Sensor Systems*, pages 190–203, Seattle Washington. ACM. [Cited on page 13.]

Rädle, R., Jetter, H.-C., Fischer, J., Gabriel, I., Klokmose, C. N., Reiterer, H., and Holz, C. (2018). PolarTrack: Optical Outside-In Device Tracking that Exploits Display Polarization. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–9, Montreal QC Canada. ACM. [Cited on page 12.]

Rädle, R., Jetter, H.-C., Marquardt, N., Reiterer, H., and Rogers, Y. (2014). HuddleLamp: Spatially-Aware Mobile Displays for Ad-hoc Around-the-Table Collaboration. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*, pages 45–54, Dresden Germany. ACM. [Cited on page 12.]

Rashid, U. (2012). *Cross-Display Attention Switching in Mobile Interaction with Large Displays*. University of St Andrews. [Cited on page 16.]

Reda, K., Chau, D., Mostafa, Y., Sujatha, N., Leigh, J., Nishimoto, A., Kahler, E., and Demeter, J. (2014). Design Guidelines for Multiplayer Video Games on Multi-touch Displays. *Computers in Entertainment*, 11(1):1:1–1:17. [Cited on page 9.]

Robinson, R. B., Reid, E., Fey, J. C., Depping, A. E., Isbister, K., and Mandryk, R. L. (2020). Designing and Evaluating 'In the Same Boat', A Game of Embodied Synchronization for Enhancing Social Play. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI '20, pages 1–14, New York, NY, USA. Association for Computing Machinery. [Cited on pages 4 and 8.]

Ryan, R. M., Rigby, C. S., and Przybylski, A. (2006). The Motivational Pull of Video Games: A Self-Determination Theory Approach. *Motivation and Emotion*, 30(4):344–360. [Cited on pages 35 and 54.]

Schell, J. (2020). *The Art of Game Design: A Book of Lenses*. CRC Press/Taylor & Francis Group, Boca Raton, third edition edition. [Cited on page 2.]

Schreiner, M., Rädle, R., Jetter, H.-C., and Reiterer, H. (2015). Connichiwa: A Framework for Cross-Device Web Applications. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, pages 2163–2168, Seoul Republic of Korea. ACM. [Cited on page 15.]

Scott, S. D., Carpendale, M. S. T., and Inkpen, K. (2004). Territoriality in collaborative tabletop workspaces. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, pages 294–303, Chicago Illinois USA. ACM. [Cited on page 10.]

Sykownik, P., Karaosmanoglu, S., Emmerich, K., Steinicke, F., and Masuch, M. (2023). VR Almost There: Simulating Co-located Multiplayer Experiences in Social Virtual

Reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, pages 1–19, Hamburg Germany. ACM. [Cited on page 8.]

Tandler, P., Prante, T., Müller-Tomfelde, C., Streitz, N., and Steinmetz, R. (2001). Connectables: Dynamic coupling of displays for the flexible creation of shared workspaces. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, pages 11–20, Orlando Florida. ACM. [Cited on page 12.]

Terrenghi, L., Quigley, A., and Dix, A. (2009). A taxonomy for and analysis of multi-person-display ecosystems. *Personal and Ubiquitous Computing*, 13(8):583–598. [Cited on page 12.]

Thompson, M., Nordin, A. I., and Cairns, P. (2012). Effect of Touch–Screen Size on Game Immersion. In *The 26th BCS Conference on Human Computer Interaction*. BCS Learning & Development. [Cited on pages 18 and 54.]

Trepte, S., Reinecke, L., and Juechems, K. (2012). The social side of gaming: How playing online computer games creates online and offline social support. *Computers in Human Behavior*, 28(3):832–839. [Cited on pages 3, 7, and 9.]

Uz, C. and Cagiltay, K. (2015). Social Interactions and Games. *Digital Education Review*. [Cited on pages 3 and 7.]

Wang, F., Cao, X., Ren, X., and Irani, P. (2009). Detecting and leveraging finger orientation for interaction with direct-touch surfaces. In *Proceedings of the 22nd Annual ACM Symposium on User Interface Software and Technology*, UIST '09, pages 23–32, New York, NY, USA. Association for Computing Machinery. [Cited on page 11.]

Weiser, M. (1991). The computer for the 21st century. *SIGMOBILE Mob. Comput. Commun. Rev.*, 3(3):3–11. [Cited on pages 1 and 12.]

Xambó, A., Hornecker, E., Marshall, P., Jordà, S., Dobbyn, C., and Laney, R. (2013). Let's jam the reactable: Peer learning during musical improvisation with a tabletop tangible interface. *ACM Transactions on Computer-Human Interaction*, 20(6):36:1–36:34. [Cited on page 10.]

Zagermann, J., Pfeil, U., Rädle, R., Jetter, H.-C., Klokmose, C., and Reiterer, H. (2016). When Tablets meet Tabletops: The Effect of Tabletop Size on Around-the-Table Collaboration with Personal Tablets. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pages 5470–5481, San Jose California USA. ACM. [Cited on pages 9 and 11.]

Zhang, Z., Chu, D., Chen, X., and Moscibroda, T. (2012). SwordFight: Enabling a new class of phone-to-phone action games on commodity phones. In *Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services*, pages 1–14, Low Wood Bay Lake District UK. ACM. [Cited on page 13.]