Moving Out From the Focus:

Exploring Gaze Interaction Design in Games

Argenis Ramirez Gomez

MScR Computer Science, Lancaster University, UK.
MSc Cognitive Systems and Interactive Media, Universitat Pompeu Fabra, Spain
Bachelor degree in Audiovisual Systems Engineering, Universitat Pompeu Fabra, Spain

School of Computing and Communications
Lancaster University
United Kingdom

Thesis submitted for the degree of Doctor of Philosophy
September 2020

Para Edgar; sigue explorando, sé curioso

Abstract

Eye trackers have become an affordable and compelling input device for game interaction that is targeting the PC gaming community. The number of games adopting gaze input for in-game interaction has rapidly increased over the years with examples in mainstream game franchises. However, games have focused on integrating gaze input on top of fully functional games, utilising gaze as a pointing device and a tool for efficiency; e.g. for the faster selection of game objects the player looks at to improve their performance. We deem this is limiting because the use of gaze is obvious, it does not harvest the full potential and richness of the eyes, and only considers that players look at game elements to interact with them. Accordingly, this thesis investigates new opportunities for gaze in games by exploring gaze concepts that challenge the interaction metaphor "what you look at is what you get" to propose adopting "not looking" gaze interactions that reflect what we can do with our eyes. Three playful concepts stem out from this principle: (1) playing with tension; (2) playing with peripheral vision; and (3) playing without looking. We operationalise each concept with game prototypes that pose different challenges based on visual attention, perception in the wider visual field, and the ability to move the eyes with the eyelids closed. These demonstrate that ideas tested playfully can lead to useful solutions. Finally, we look across our work to distil guidelines to design with "not looking" interactions, the use of dramatisation to support the integration of gaze interaction in the game, and the exploration of interactive experiences only possible when taking input from the eyes. We aim to inspire the future of gaze-enabled games with new directions by proposing that there is more to the eyes than where players look.

Declaration

This thesis is a presentation of the author's original research work. No part of this thesis has been submitted for any other degree or qualification.

The work presented in this thesis was done under the guidance of Professor Hans Gellersen at Lancaster University's School of Computing and Communications.

For the work presented in Chapter 7, the author was responsible for the ideation of the concept, development of the applications and conducting the user study in section 7.4. The user study in section 7.3, and the exploration of techniques in section 7.5 and 7.6, is the product of collaborative work with colleagues Ludwig Sidenmark and Dr Christopher Clarke at Lancaster University.

The discussion in Section 8.2 is the product of conversations and collaboration with Dr Michael Lankes from the University of Applied Sciences Upper Austria.

The author of this thesis was the lead researcher on the research work presented in all the chapters. All the game prototypes and applications presented in this thesis were developed by the author, using custom-made and creative commons graphics.

Author: **Argenis Ramirez Gomez**

Acknowledgements

This research work would not have been possible without the support of many people. Firstly, I would like to express my gratitude to my advisor Professor Hans Gellersen for his guidance and open-minded attitude towards my (sometimes crazy) ideas. He has shared so much knowledge with me during the years, and I am so grateful for his honesty and the opportunity he gave me to pursue a PhD degree.

I want to thank my lab friends, for the long days, the conversations, the baking and the fun. Special thanks to my dear friend Kim Sauvé for the daily joy and motivation, you have always help me to get the best creative self. I want to thank Claudia Daudén Roquet for her friendship, the support and the many conversations, to make me feel closer to home, wherever that is - may our future masterplan come true one day. To my friend and colleague Chris Clarke, thank you for the long discussions about work, life and the future. To Ludwig Sidenmark for his hard work and support. Finally, I want to thank Pierre Weill-Tessier for the fun times, the early morning chats and for always being welcoming. I feel so lucky to count all of you amongst the friends that have been there for me day after day.

I would also like to express my gratitude to Dr Michael Lankes for his support, the stimulating and exciting conversations, and for the work we have done together. Moreover, I want to thank my thesis examiners Dr Elisa Rubegni and Dr Jussi Holopainen for the challenge, encouragement and invaluable feedback.

Finally, I could not have achieved this without the love and support of my family. Thanks to Leo for his inexhaustible patience, for believing in me, his support, and for always being keen to voice-over my research videos. I thank my parents, Laura and Manuel, for their effort over the years that has led me to achieve this, I could not have done it without knowing they were there for me. Special thanks to my sister Laura, for her encouragement and understanding - I missed many important events of your life. For that, I want to thank my nephew Edgar, who was born in the midst of my research work. Meeting you has been one of the best things an uncle could experience. Watching you grow, although in the distance, has been the best source of energy one could wish for.

Related Publications

Parts of this work have been published in peer-reviewed publications. Below are the references of these publications at the time of writing, alongside the associated chapter when appropriate.

- **Ramirez Gomez, A.**, & Gellersen, H. (2019, April). SuperVision: Playing with Gaze Aversion and Peripheral Vision. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (p. 473). ACM.
  [Chapter 5]
- **Ramirez Gomez, A.**, & Lankes, M. (2019). Towards Designing Diegetic Gaze in Games: The Use of Gaze Roles and Metaphors. Multimodal Technologies and Interaction, 3(4), 65.
  [Chapter 8.2]
- **Ramirez Gomez, A.** (2019, October). Exploring Gaze Interaction Design in Games: Playing with Vision. In Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts (pp. 55-61). ACM.
- **Ramirez Gomez, A.**, & Gellersen, H. (2019, October). Looking Outside the Box: Reflecting on Gaze Interaction in Gameplay. In Proceedings of the Annual Symposium on Computer-Human Interaction in Play (pp. 625-637). ACM.
  [Chapter 4]
- **Ramirez Gomez, A.**, & Gellersen, H. (2019, November). Exploring the Sensed and Unexpected: Not Looking in Gaze Interaction. In Proceedings of the Halfway to the Future Symposium 2019 (p. 35). ACM.
  [Chapter 1 and 8.1]
- **Ramirez Gomez, A.**, & Gellersen, H. KryptonEyed: Playing with Gaze Without Looking. (2020). In International Conference on the Foundations of Digital Games (FDG '20), 4 pages.
  [Chapter 6]
- **Ramirez Gomez, A.**, & Gellersen, H. More than Looking: Using Eye Movements Behind the Eyelids as a New Game Mechanic. (2020). Annual Symposium on Computer-Human Interaction in Play (CHI Play).
  [Chapter 6]

Other publications not related to this thesis:

- **Ramirez Gomez, A.**, & Gellersen, H. (2018, June). Smooth-i: smart re-calibration using smooth pursuit eye movements. In Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications (pp. 1-5). ACM.

Contents

List of Figures

List of Tables

1 Introduction

Gaze interaction is coupled with looking. Intuitively, we look at the objects we want to interact with [289]. Eye trackers provide information about where exactly the user is looking to enable interaction following the metaphor "What you look at is what you get" [118]. Therefore, the immediate - and obvious - use of gaze for interaction has been to adopt it as a pointing device for explicit interaction or in combination with other input modalities. Accordingly, the ability to interact with objects the user looks at has emerged as a compelling tool for interaction in video games. Here, we are interested in investigating the creative potential of gaze input for game interaction.

Gaze interaction has been explored in the emerging area of play with a commercial potential by adopting gaze input for game control [263]. The main thrust of applications has been to adopt gaze for accessibility by replacing the original game controls with eyes-only hands-free interaction [112, 116, 113, 231], or to support the efficiency and performance of existing game controllers, e.g. faster movement of the mouse towards the gaze point [265]. Other work has embraced gaze as implicit input leveraging the natural attention of the eyes, for example, to enable gaze-responsive storytelling to progress in the narrative depending on what you look at [234]; control of the game camera viewpoint [231, 180], and the integration of social gaze behaviours to interact with avatars [271], e.g. look down to show submission.

Accordingly, gaze interaction is becoming very popular with mainstream game franchises embedding gaze-enabled game control. Players can automatically tag the enemies they look at [255]; aim weapons to the centre of their gaze [231, 59]; fire by just looking [179]; select the objects they look at in the scene [29, 282], or make their character move to their gaze point [231, 220]. However, the prevailing adoption of gaze interaction in games is as a supporting feature or add-on and not a game-changing standalone technology. For instance, in game-streaming and eSports, eye tracking is used to show the audience where in the game athletes are looking at to provide insights on their strategies. In gameplay, gaze interaction is a utility for game efficiency, e.g. faster selection of the targets you look at. In this thesis, we are motivated to explore how gaze input can be adopted in games more creatively and provide engaging but challenging playful experiences. We deem the adoption of gaze as a mere pointing device in games is an obvious use of gaze input, and it removes the game challenge.

The prominent adoption of gaze as a pointing device resides in that the eyes are a natural sensor, and we look at the objects we want to interact with. If gaze is simultaneously used for game control in games, we might involuntarily trigger unwanted outcomes and create tension, for instance, the selection of an object that we are just looking at with no further intention, known as the Midas Touch problem [262]. Therefore, designers tend to avoid this conflict by adopting gaze in cases where it works hand-in-hand with other game controllers. For instance, gaze directs the weapon, but a gamepad button press triggers the firing. As a supporting feature, gaze interaction becomes unappealing beyond eyes-only control for accessibility. This makes the use of eye trackers not essential for broader gameplay - if we were to remove the eye tracker, the game could still be played with another input modality.

We believe the problem is rooted in that mechanically, eye trackers transform the input from the user's eyes into a single point on the interface, and this is used for in-game interaction. The underlying principle is to leverage gaze as a pointer and selection mechanism for virtual objects users align with their vision. However, gaze is something that has a meaning, notably social and cultural [271]. For example in film theory, gaze refers to the camera perspective [214]. In game theory, to the player's perspective [279]. In Virtual Reality applications, gaze is associated with the term "head-gaze", the direction of the user's head and the response to represent gaze behaviour in the virtual environment. In quotidian situations, gaze is rich, complex and could have different meanings. For instance, we might look at the person we want to engage with; look at a location to draw their attention; close our eyes to think or rest our sight; avoid eye contact to escape from social situations, or focus on something to engage concentration.

Accordingly, gaze input has the potential to integrate a natural mapping for game control, translating what the eyes can do in real life into actions happening in the virtual world. If games embrace this use of gaze, gaze interaction could become a must-have and provide more meaningful experiences. Moreover, game experiences could be designed to feel as natural as possible, creating seamless interactions between the player and the game that could lead to a greater feeling of immersion - the feeling the experience is real. This has been widely explored in the Natural User Interfaces (NUI) research corpus. For instance, work on voice interaction in games emphasised the importance of the relationship between the users' game and real-world identity [26]: when it's your voice coming out of the character, you feel more closely identified with them. Accordingly, there is a need to investigate how what can be accomplished with the eyes can be integrated into the game space to provide similar groundbreaking gameplay experiences.

The recent emergence of eye trackers in the consumer space has spurred research interest in novel uses of gaze leveraging the richness and complexity of the visual system, introducing more challenging game explorations [251, 263]. Compelling research-based examples of gaze interfaces that are challenging by design are Ekman et al.'s *Invisible Eni* and Vidal et al.'s *Shynosaurs. Invisible Eni* [56] challenges players to control game elements with pupil dilation or by blinking, whereas in *Shynosaurs* [270] players face an attention dilemma between staring down monsters and hand-eye coordination. In a similar spirit, this thesis is motivated to join efforts and explore the creation of gaze interactions that make games inherently more challenging. Accordingly, this thesis investigates the potential of gaze interaction in games with the following research question:

- How can gaze interaction be used more creatively, so it becomes essential to the gameplay experience?

Based on this fundamental question, we reflect that gaze interaction is more than pointing, which is limited to looking. In doing so, we unfold "looking" to open up a distinct space of inquiry: "not looking" as an interaction metaphor.

1.1 Exploring Gaze Interaction Beyond Looking

As previously mentioned, gaze interaction is coupled with looking. It is important to emphasise this to understand the adoption of gaze input as a pointing device and start moving away from it. Eye tracking sensing technology enables interaction by providing where precisely in the screen the user is looking at. Therefore, what is expected is that interactions are designed based on looking, the same way a touchscreen is designed to detect touch. The design of sensing-based interactions is often guided by considering what the technology senses or what is expected. *Benford et al.* [16] defined what is sensed by the sensor is what it can measure. Accordingly, the expected interactions are the natural actions the user performs to the interface. For example, touching a touchpad; speaking into a microphone, or looking at a screen with an integrated eye tracking system. If designers want to think about broader interactions, they must consider what is unexpected, thinking of extremes and bizarre scenarios - the unusual interactions often performed when the interface is used in an atypical way or context. If we think of the extreme for gaze interaction, one could suggest "not looking". However, it is not obvious how to design gaze interactions in this unexpected space.

Interfaces using the space of unexpected actions are uncommon and underexplored in Human-Computer Interaction (HCI) because they are ambiguous and create tension. For instance, not touching a touchscreen to select makes no sense. It might create an incompatible context that disrupts preconceptions of how the sensing technology is used [77], and yields unexpected interactions. Although ambiguity is seen as a problem in HCI, it could be introduced as a resource for design [219]. *Gaver et al.* [77] see in *Ambiguity of Context* an opportunity to enable designers to go beyond the limits of technology and to craft interactive designs that are engaging and thought-provoking. The range of applications using the contextual ambiguity of the sensor is less crowded but present in examples like the *POUTs* [184]. Usually, pins are designed so the user can attach them to a pinboard, and it is unexpected for the pin to eject itself. *POUTs* are pins designed with this unexpected space of the interaction in mind: they pop out. This application created the opportunity to link physical and digital documents [185], which is useful, for instance, when removing a document in the digital space, the *POUT* will eject the documents from the physical pinboard.

If we apply this analogy to gaze interaction, eye tracking applications use gaze as a pointing device. Therefore, what is unexpected is that the user stops looking. However, an eye tracker can sense when and where on the screen the user is looking at, but also when they are not, and the gaze signal is absent. Nonetheless, *not looking* could take many forms, such as closing our eyes; a quick blink, or even looking elsewhere or away with the eyes open. In general HCI applications, "*not looking*" is mostly associated with meditation apps in which users are asked to close their eyes, and they are guided through different exercises. In gaze interaction applications, *not looking* is an unexpected dynamic, only used in accessibility contexts with eye blinks to indicate a gaze selection [133, 282]; or to *"look away"* as an in-game gaze behaviour to avoid *eye contact* with game avatars [40].

In this thesis, our objective is to investigate novel playful game experiences that introduce gaze mechanics aligned with the concept of *not looking.* We use games as a safety net to test challenging interactions that disrupt the preconceived context of interaction. We explore unexpected and creative uses of gaze in games but will demonstrate how playful exploration can create opportunities for the broader HCI design space. The research presented in this thesis aims to provide insights into the future of gaze-enabled games with the following objectives:

- Exploring the design space of playful experiences that leveraging what we can do with the eyes and move away from traditional gaze pointing.
- Developing game prototype examples illustrating novel playful concepts that adopt gaze input in their gameplay beyond "looking" metaphors that are engaging and fun.
- Investigating how games can adopt challenging gaze interaction based on metaphors related to vision to support the interaction in play.
- Investigate the usability, feasibility and benefits of playing with the explored concepts to identify opportunities for gaze interaction.
- Identifying the "not looking" design space for gaze interaction in games. We aim to develop design frameworks that support the design of novel playful gaze-based game experiences based on the insights gained from the study of the game prototypes.

1.2 Moving Out From the Focus:

The research presented in this thesis aims to provide insights into the future of gaze-enable games by identifying the design space of playful experiences that leverage what we can do with the eyes (vision capabilities). We investigate different concepts that explore the creative potential of gaze, playing with narratives and metaphors related to vision to support new gaze interaction mechanics for gameplay. We explicitly intend to push the boundaries of what is knows as "expected" gaze interactions. As previously mentioned, gaze interaction literature has focused on designing mechanics that are considered "natural" to use and of good usability. Moreover, the gaze pointer directs the interaction, so interactions are based on looking directly at objects we want to interact with and explicit attention of the eyes to the screen.

Accordingly, we want to move away from this design focus. We explore the creative potential of gaze by adopting a gaze point with poor usability (or tension), an unexpected use, and considering that gaze is much more than the focus of attention, including the broader field of view or the actions we can perform with our eyes to direct gaze (with open and closed eyes). Three new playful concepts emerge from this reflection of designing "unexpected" gaze interactions. We propose: (1) *Playing with Tension*; (2) *Playing with Peripheral Vision*; and (3) *Playing Without Looking.* These move away from traditional eye pointing to propose novel, challenging, engaging, and fun ways to adapt gaze for game control. Finally, we analyse the proposed concepts to discuss emerging design frameworks aiming to aid the design of novel playful gaze-based game experiences.

In the following chapters, we unfold gaze interaction to open up a distinct inquiry space into "looking" versus "not looking". Each chapter presents a game concept exploring the use of gaze interaction. They reflect that looking can mean different things, e.g., not being able to look because it is physically impossible; looking away or elsewhere; blinking, or keeping the eyes shut. Each concept moves out from the "what you look at is what you get" metaphor to explore the creative potential of gaze input in games.

(1) Playing with Tension:

We define tension as the strain added to the game experience that creates conflicting implications on how the game should be played or interaction happens. Tension has been used as an asset to create original games with challenging controls. For instance, the game *Brothers: A Tale of Two Sons* challenges the player to control two characters at the same time coordinating both halves of a single game controller [238]. In gaze-enabled games, we can find examples introducing tension by triggering unexpected outcomes to looking at the scene. In the gaze-enabled version of the game *Dying Light* [243], the player needs to pay attention to where they look at while they can aim firearms at gaze or control a flashlight with their eyes. In this dystopian post-apocalyptic survival adventure, zombies notice the player presence when they are looked at, making them responsive to gaze interaction. In other examples, tension is presented as an attention dilemma, requiring the player to juggle between looking at two parallel game events. In the game *Shynosaurs* [270], the player needs to balance the time they spend looking at the dinosaur-like enemies to intimidate them and paying attention to the game's drag-and-drop task. These examples illustrate how gaze interaction can be challenging by introducing different levels of tension. Chapter 4 goes a step further by exploring the use of gaze "side effects" in the game *Twileyed* to challenge traditional gaze interactions in games. The game introduces tension by imposing opposing rules, biasing the gaze point mapping, or using gaze input against the player by spoiling their intention to the game enemies. These side effects add tension to the interaction because they demand an ambiguous and straining use of gaze in the game context.

(2) Playing with Peripheral Vision:

The design of gaze interactions using gaze input as a pointing device are limited by only considering what users align with their foveal (central) vision. This is inherited from how eye trackers combine the input from both eyes into a single gaze point for interaction. However, the visual field is much more and covers approximately 135 degrees of visual angle vertically and 210 degrees horizontally, with only 2 degrees dedicated to the foveal vision [87]. We propose to play with gaze involving what we can see with the wider visual angle. Although visual acuity drops sharply outside of the foveal region, peripheral vision is essential in helping to notice information or objects that pop out in the scene without prior focus [213], e.g. when the user notices a notification appearing on a corner of the interface without disrupting the task they are looking at [123]. In games, gaze interactions are not designed accounting for the broader field of view, but peripheral vision remains an asset in the game. For instance, in the game *Shynosaurs* [270] which presents tasks that are competing for visual attention, the player must rely on peripheral vision to notice changes on the task they are not attending. Moreover, the game *Virus Hunt* [266] challenges the player by not allowing them to look at virus they should remove by tapping on them, thence players must rely on peripheral vision to avoid game penalisation. Chapter 5 investigates the use of peripheral vision in a collection of three mini-games named *SuperVision*. In the games, players need to overcome mouse manipulation tasks and perceptual challenges in peripheral vision of objects with different size; colour; and form. When players look at the game objects, they are penalised, forcing them to look away and work only with what they can see in their peripheral vision.

(3) Playing Without Looking:

Not looking is an unexpected use for an eye tracker, but it can be sensed as either the absence of the user's presence when they are not in front of the tracking system, or when the user closes their eyes, with a wink (one eye) or a blink (both eyes). In interaction, blinks and winks have been used as a tool for accessibility [230], e.g. the user can look at the object they want to select and blink to confirm its selection [133]. In gaze-enabled games, winks have been used to integrate non-verbal social behaviours of the eyes such as "winking to charm" characters in the game [40]. In other examples, closure of one eye has been used to trigger sniper view [94], whereas blinks have been used to re-load guns [6], and the closing of both eyes to pause the game automatically [171]. In the game *Invisible Eni* [56], the game character disappears into a puff of smoke to evade the monsters that chase her when the player closes their eyes as a protection mechanism. Chapter 6 extends this body of work to explore that the eyes can do much more when they are closed, and leverage it for eyes-only game control. In the game *KryptonEyed*, players are required to close their eyes and perform eye movements behind the eyelids before opening them to aim the teleportation of the main character. Moreover, the insights gained through exploring the concept through play allowed the creation of Gaze+Hold (Chapter 7): a technique that leverages the eyes as two separate sources of input to support continuous direct manipulations in multiple desktop interfaces, e.g. drag and drop or map navigation.

Each concept must not be viewed as a separate theme, but as it will become more evident throughout every chapter in this thesis, they are intertwined. For instance, concept (1) introduces tension to gaze interaction by adding a "side effect" to how the gaze point is used in the game. This game mechanic will require to rely on the broader visual field (and peripheral vision), requiring players to look away or playing without looking at the game objects they control. Moreover, concept (2) focuses on the capabilities of playing relying on peripheral vision, which can be understood as another type of tension as the player's attention is moved from the focus to the periphery, and they must solve the game puzzle without looking at objects of interest. Finally, without explicitly avoiding repetition, concept (3) introduces another type of tension by requiring players to close their eyes to play the game. Accordingly, the game challenge is grounded in not looking at objects that, nonetheless, can be perceived in peripheral vision.

1.3 Thesis Structure

The following chapters divide the work by presenting each of the proposed playful concepts separately:

Chapter 2 introduces the Methodology followed in every relevant chapter highlighting two main focuses on the core of this thesis: a Research-through-Design approach and the further empirical evaluation of the game concepts presented.

Chapter 3 presents an overview of the current state of the art in the adoption of gaze-based interaction in games. We provide a brief introduction on how gaze interaction has been used in general HCI to expand this into how research has tried to understand the use of gaze in play through different surveys. Moreover, we describe related work providing insights on game dynamics and experiences that emerge when using gaze input, and games that adopt different gaze behaviours in gameplay beyond using the eyes as a pointing device.

Chapter 4 challenges state of the art by moving beyond the obvious ways of using gaze interaction and proposing to *"play with tension"*. The chapter explores the limits of designing gaze interactions in the game *Twileyed* by twisting commonly used forms of adapting gaze for interacting in games to create tension.

Chapter 5 reflects on the potential to extend gaze-enabled play by considering the broader field of view. We developed *SuperVision*, a collection of three peripheral vision games. The game designs are disruptive in requiring players to rely on peripheral vision for tasks they would normally, and more easily, perform with foveal vision.

Chapter 6 introduces the use of eye movements behind the eyelids to "*play without looking*". In this chapter, we propose to play at a glance, using eye movements behind the eyelids, and gaze pointing when the eyes are opened. We designed the game *KryptonEyed* to demonstrate the use of the technique in three playful scenarios, introducing the act of closing and opening the eyes to control the character's powers to teleport.

Chapter 7 demonstrates how concepts that are tested playfully can lead to new techniques for eyes-only interaction. We describe the Gaze+Hold interaction technique emerging from the insights gained in the game exploration from the previous chapter. Gaze+Hold interactions leverage the eyes as two separate sources of input by using explicit closing of one eye to modulate gaze input from the open eye. Finally, we explore the use of the technique in tasks including drag and drop; menu navigation and selection; selection of multiple objects; scrolling, zooming and panning; and navigation, teleportation and view control.

Chapter 8 discusses the work included in this thesis by presenting three frameworks: (1) *Not Looking in Gaze Interaction*; (2) *Gaze Roles and Metaphors*; (3) *Gaze in Play.* Each framework emerges from the analysis of state of the art games and the reflection on our research work. In (1), we discuss a taxonomy tackling the core of this thesis: opening up a distinct space of gaze interaction design into *looking* versus *not looking.* The taxonomy is described with five discrete categories based on whether specific game events mean the player *might not*; *cannot*; *should not*; *must not*; or *does not look*. In (2), we discuss gaze diegesis (how gaze is integrated) with the game elements via the use of *Gaze Roles* and *Metaphors*. The third framework (3) discusses gaze interaction in games as the attention relationship between the user (the subject) and the game (the object). We present four dimensions (*Identity*; *Mapping*; *Attention*; and *Direction*) that could serve as a design and inquiry toolbox to guide research questions, analyse and communicate gaze mechanics in play.

Finally, Chapter 9 presents a final discussion about the scope of the work and the three presented frameworks and a reflection on how they open up the space to create novel gaze interactions for gameplay. The chapter concludes with the implications of this thesis and highlights emerging opportunities and directions for future work.

1.4 Contributions

The work presented in this thesis makes the following contributions:

- **Advancing "Gaze and Games" research with an exploration of three novel playful mechanics.** Beyond the game concepts as such, the work opens up a distinct space of inquiry into "looking" versus "*not looking*" for the design of gaze-enabled interaction in play.
- **Design and empirical evaluation of three game artefacts demonstrating novel concepts for gaze interaction in play**: (1) Playing with Tension; (2) Playing with Peripheral Vision; (3) Playing Without Looking. We designed and implemented a constellation of gaze-enabled games, presenting specific research questions. Each game chapter makes individual contributions:
  - **Twileyed**: We describe three mini-games using gaze interaction paradigms that integrate tension in their gameplay interactions. The games are used as data to motivate a discussion and reflection on the use of gaze in games. Based on the presented discussion and design outcomes, future work can engage in continuing the debate on the adoption of gaze input in games.
  - **SuperVision**: We contribute a framework of playing with peripheral vision, and a novel game dynamic created by elements that players must perceive and manipulate without directly looking at them. We describe three mini-games illustrating the implementation of the concept in playful and engaging experiences. The empirical insights gained from player experience, performance, and skill development evidence that games such as demonstrated can affect our visual skills and might influence inhibition control.
  - **KryptonEyed**: We describe three possible scenarios and mechanics that illustrate the use of eye movements behind the eyelids in different games. We give empirical results on target selection accuracy in the feasibility study with a discussion of the design implications. Finally, we discuss the opportunities to use "*not looking*" metaphors with the proposed technique. Based on our results, future work can explore the potential of integrating the proposed gaze dynamic with other inputs and in different game genres.

- **Development of an eyes-only interaction technique emerging from playful concepts**. We demonstrated how a technique that is explored through the creation of games could lead to novel uses of eye tracking for interaction and proposing a new solution for the Midas Touch. KryptonEyed inspired Gaze+Hold to use the eye closing/opening of one eye as initiation and confirmation events that modulate continuous input from the open eye. We described a wide variety of applications using the technique for continuous direct manipulation and enabling hands-free interaction which is of particular interest for accessibility.

- **Development and presentation of three different Conceptual Frameworks.** We meta-analysed related work and the presented gaze concepts through concepts that emerged from the design and evaluation of the described games. Beyond discussing the new space of gaze interactions based on *not looking*, the emerging frameworks make specific contributions to gaze interaction design:

  - **Introducing the aspect of diegesis in the design of gaze-based interactions in games**. We reflected on existing frameworks of gaze-enabled play and extend them by using the concept of gaze roles and metaphors to characterise and categorise gaze interactions in games. We discuss metaphors and of gaze behaviours beyond pointing (e.g. communicative signal, adoption of challenges or hurdles, empowerment of the player via gaze, among others).
  - **Introducing a new taxonomy of conceptual dimensions to describe gaze interactions based on game identity, context and gaze behaviour**. The framework highlights the concept of gaze identity and behaviour that could influence the game experience. We guide a new design structure, providing design guidelines that aim to work hand-in-hand with state of the art frameworks. We outline in this design space future opportunities aiming to inspire future research and gaze interaction design in games.

- **Identifying future directions for gaze interaction in game design and HCI**. Our work has significance as it points to opportunities for using eye tracking and gaze playfully. This contrasts the prevailing adoption of eye tracking as a utility for efficiency (e.g. faster selection of targets) with ideas for using gaze more centrally in games, as an element that is defining the experience and/or challenges.

2 Methodology

This chapter outlines the methodology employed in our research work to highlight the wide variety of methods used and the conceptual background in forthcoming sections.

In this thesis, we intend to understand the potential of gaze input for gameplay based on one fundamental question:

> *How can gaze be used more creatively in games?*

We follow a Research-through-Design approach [294, 295, 76, 293, 131] to answer this question and explore the space of gaze interaction in games. We focused on developing game prototypes that investigate new concepts highlighting the potential of embedding gaze input in games. We intend to go beyond the usability-focused "what you look at is what you get" metaphor to explore the "unexpected" to investigate what playing by "not looking" means for gaze interaction in games.

Research-through-Design (*RtD*) is a research approach that use methods of design practice to generate new knowledge [293], and it has been widely used for interaction design in HCI [294]. According to Gaver [76], the output of *RtD* takes the form of research artefacts and systems that sometimes are used in a field test, but can also present a variety of methods, theory, and conceptual frameworks. *RtD* contributions focus on evaluating and formalising interaction design research through the description of the design process; the account of how the invention works; its relevance to the field and context; and an interpretation of the future possibilities and how it can be extended [294, 293].

RtD is relevant in this thesis for two reasons. Firstly, it allows to answer generic and open questions [274] - such as the one presented above - and go beyond finding ways to improve state of the art but actively imagining the potential future [295]. Secondly, *RtD* puts the creation of prototypes at the core of the research [11] enabling reflection during and after the design process and the discovery of new and unexpected solutions [131].

RtD is usually present as a method in game design research [99], e.g., to create a Live action role-playing game to explore the use of social wearable technology [41], or to analyse "playful hacking" as a research process [81]. However, *RtD* might not be explicitly outlined in games research methodology [145], but be embedded in the design of a digital game to test a research question.

RtD is an appropriate method for interaction design and game research because it emphasises the creation of knowledge through reflective practice and experimentation rather than proposing a project solution [99]. In games, the design experiments are not about refining a particular game, but to elicit more abstract qualities [274]. In our case, we will systematically focus on creating games that explore qualities of the gaze input and capabilities of the eyes, rather than focusing on creating "good games" that focus more on other factors like player satisfaction. As such, our goal is to use this type of design experimentation to explore the design space of gaze input in games and leverage the creative potential of the eyes.

2.1 Exploring the Creative Potential of Gaze Input

This thesis's research objective is to explore the future of gaze-enabled games by designing interactions and playful experiences that leverage the eyes' creative potential. To do so, we explore game concepts highlighting aspects of gaze that have been underexplored or sometimes overlooked, namely:

(1) Visual attention and challenging gaze behaviours (Chapter 4: *Playing with Tension*);

(2) The active use of peripheral vision and the broader field of view (Chapter 5: *Playing with Peripheral Vision*);

(3) Leveraging the physical function of the eyes and the eyelids to create new interactions (Chapter 6: *Playing Without Looking*).

Each concept emerges from thinking about gaze input differently and pushing the boundaries of what we can do with gaze. For example, our work is noteworthy by focusing on creating what might appear as game interactions with "poor usability". However, in doing so, we leverage and emphasise the design of games that exploit and explore what we can do with the eyes. This allows gaining a better understanding of the broader possibilities and opportunities to use gaze interaction for gameplay. Accordingly, each game concept surfaces as a provocation to gaze interaction in games state of the art by proposing critic designs that focus on the following secondary research questions:

(1) What is the effect of tension, challenge, and gaze interaction on the game experience? Given the design of anti-intuitive gaze control that adds tension to the interaction, we aim to investigate the effect on the player experience. Moreover, we explore whether adding tension to the interaction requires players to rely on other relevant visual capabilities (e.g., visual awareness, attention) rather than utilizing the eyes' focus as a pointing device.

(2) *How can we engage peripheral awareness skills and their development in a game context?* We investigate to what extent players can perceive game objects and their features when they can only bee seen in the periphery. To do this, we explore the use of gaze aversion as a dynamic that could ensure the active use of peripheral awareness capabilities.

(3) *How can we create engaging game experiences that require to play with the eyes closed?* We aim to explore the ability to explicitly direct our eyes with the eyes closed, investigating how accurate can we control where we are going to look next behind the eyelids.

2.1.1 Concept Design and Evaluation

After the refinement of each proposed research question and objective for each proposed playful concept, we aimed to conceptualise, design, and evaluate them by following the following process (A–E). The methodology followed in this thesis was conducted by the authors unless specified.

(A) *Literature Review*: Using the research questions described above, we performed a systematic literature review. Firstly, each question sets a need to understand visual capabilities, e.g., visual attention, peripheral vision awareness, and eye movements behind the eyelids. Secondly, each ability requires a detailed review of the state of the art research to get insights on how each concept (tension and attention; peripheral vision and aversion; closure of the eyes and eye movements) has been used not only in general gaze interaction but in the context of games.

(B) *Preliminary Ideation and Formulation of Conceptual Frameworks*: Step (A) is of high relevance for developing a preliminary interaction concept and a list of requirements to meet the intended experience. These would influence creating a conceptual framework that details the "ingredients" necessary to guarantee the exploration and execution of each research question from concept to an artefact. Moreover, the work presented in this thesis consistently looks for metaphors from fiction that contextualise the proposed gaze interaction. The mapping of the requirements set in the conceptual framework onto the metaphors provides a first iteration on how each concept could be conceptualised.

(C) *Game Design (From Brainstorming To Prototype Development)*. We systematically focused on developing game prototypes that explore each proposed concept in three mini-game experiences to showcase new and creative uses of gaze. We have also explored how the insights gained through playful explorations can be useful in other applications or interfaces in different domains of HCI. Fiction and culture metaphors have been used as game design inspiration to provide a context to each proposed gaze interaction concept. This approach is in line with muse-based game design [126] (an example of *RtD* research), which uses a player as the muse to influence and inspire the design of the game experience. In contrast, we have adopted metaphors as the muse, whose role is to inspire the designer to create a relevant game experience that relates to the concept and back to the muse.

(D) *Evaluation*. Each gaze interaction concept and game artefact are evaluated using user-centred methods for data collection to validate them and provide empirical grounds and insights on the appropriate research questions. We conducted user studies designed

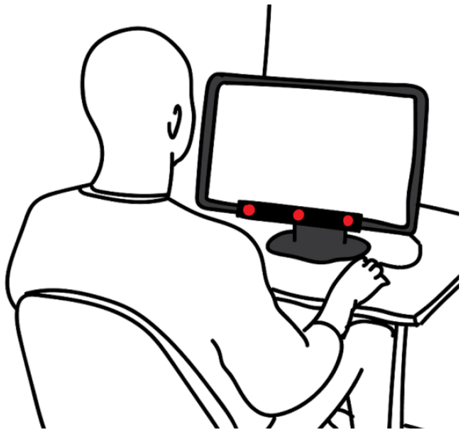


Figure 2.1: Participants sat in front of a 27" display (Resolution: 1920x1080; Aspect Ratio: 16:9). A Tobii EyeX eye tracker was placed under the monitor at 40cm from the user.

to evaluate the game experiences developed and the gaze interaction concepts' usability. To conduct the user studies, participants were asked to sit in front of a computer display. Moreover, we used a *TobiiEyeX* eye tracker under a 27" monitor (Resolution: 1920x1080; Aspect Ratio: 16:9) at 40cm from the user - see Figure 2.1. This experimental apparatus was consistently used for every user study outlined in this thesis. However, further information is included in the forthcoming chapters about the procedure and modifications to the apparatus (when appropriate). For example, panels were used in the study presented in Chapter 5 to block distractions in the visual field.

(E) *Reflective practice*. Beyond this thesis's game design-driven approach, we have followed an analytical methodology using reflective practice to define new theories in emerging frameworks. The meta-analysis of the concepts presented in this thesis emerges into three new design frameworks that highlight novel uses of gaze in games. These aim to advance the gaze-enabled game research corpus and inspire new gaze interactions and game explorations that propose new playful experiences that take input from the eyes.

2.1.2 Summary of Methods

The following chapters address our main research question by using a wide variety of methods (see Table 2.1 for a summary):

Chapter 3 presents an overview of how gaze input has been adopted in games. To provide an understanding of the state of the art, we conducted a systematic survey of 221 research-based, commercial, and independent gaze-enabled games. We analysed them to develop the sections in the chapter. First, we provide an overview of how gaze interaction is mapped to traditional game controls, known as the EyePlay game mechanics. We continue to highlight the relevance of adopting gaze input in the game environment leading to novel types of control experiences.

Chapter 4 introduces the concept *"playing with tension"* in the game *Twileyed*. The game was designed to include three mini-games that "twist" the usability of commonly used gaze mechanics. We twist these interactions with rules, and ambiguous (maybe anti-intuitive) uses of gaze to create tension and open the space for reflection. The games are inspired by stories of duality in fiction and present the players with game rules introducing side effects to gaze interaction. In the games, we directly investigate *Gaze Selection*; *Gaze Navigation*; and *Gaze Aiming*, but also include events related to *Implicit Interaction* and *Social Gaze* mechanics. The games surface as data and the device to reflect and discuss design challenges, questions, and conceptual dimensions of gaze interaction in gameplay. We invited twelve participants to play the mini-games. We observed them playing and collected their insights on the experience. We performed a thematic analysis of the gathered data and used reflective practice to discuss the emerging themes that point out future opportunities.

Chapter 5 investigates the active use of peripheral vision in gaze-enabled games by creating a conceptual framework for *"playing with peripheral vision"*. We validated it with the design and development of *SuperVision*, a collection of three games that rely on peripheral vision to succeed. The games are inspired by stories of harmful gaze in mythology and popular culture and present the players with game elements they must not look at directly. Each game poses perceptual challenges for assessing the game situation with peripheral vision and interaction challenges for mouse manipulation of objects without gazing directly at them. We conducted a study of SuperVision with 24 users and a follow-up study with five users. To evaluate our gameplay concept, we assessed player experience using the Game Experience Questionnaire [107], and player performance and behaviour based on game logs and gaze heatmaps. Besides, we evaluated the participants' peripheral visual capabilities before and after playing the games to test for skill development.

Chapter 6 investigates the use of eye closure and eye movements behind the eyelids to "*play without looking*". We explore the act of closing and opening the eyes as a novel eyes-only technique and test it as the power to teleport in three scenarios in the game *KryptonEyed*. The game story is inspired by superheroes and stories of power balance. Moreover, we studied the feasibility of the proposed dynamic during two user studies. We conducted a preliminary study with 12 participants and a second one with 20 participants. Firstly, we investigated whether it is possible to move our eyes behind the eyelids to predict the position of static targets. Secondly, we tested the prediction accuracy based on targets with different motion features using the technique and evaluated the resulting game experience.

Chapter 7 describes the Gaze+Hold interaction technique, which utilises the closure of one eye to modulate the continuous input of the open eye. We investigate the feasibility, performance, and the user's spontaneous choice of closing one eye in a small-scale feasibility study and a user study with 12 participants. These provide insights on gaze accuracy, precision, and task usability when pointing with one eye closed. Moreover, we assessed Gaze+Hold on a drag-and-drop task. Finally, through the design of concrete interaction methods for general user interface tasks, we explore the technique's variety and expressiveness.

Chapter 8 discusses design frameworks emerging from the discussion of the explored game concepts and a reflection on state of the art to detail the lessons learned in designing new opportunities for gaze-enabled games. Accordingly, each framework picks up the insights from the constellation of game examples we present to set new lenses to analyse the survey of related work presented in Chapter 3. In (1) *Not looking in Gaze Interaction*, we analyse games that use gaze interaction and make the user look away from the game action up to the extent they close their eyes. In (2) *Gaze Roles and Metaphors*, we reflect on the ambiguous meaning of gaze interaction by analysing the state of the art to come up with a list of surveyed *Gaze Roles* and *Metaphors*. Gaze interaction roles represent ambiguous mechanics in gaze, namely, *Social*, *Hurdle* or *Power*. On the other hand, gaze *metaphors* serve as narrative figures that symbolise, illustrate, and are applied to the interaction dynamics. In the last framework (3) *Gaze in Play*, we go back to the gaze-based experiences described in Chapter 3 to develop a taxonomy based on gaze attention. Based on the multiple dimensions identified, we visualise the design space, highlighting opportunities for gaze interaction design and future HCI gaze research.

2.1.3 Brief Reflection on Methodology

Readers must note that the difference in the methods employed in this thesis is intentional. The nature of the different research questions necessitates that different methodology is used. For instance, studying the effect of *Tension* in gaze interaction is dependent on individual perception; thus, a thematic analysis of qualitative data extracted from observation is appropriate. On the other hand, the study of the performance in peripheral vision or eye movements behind the eyelids is best suited by quantifiable and customised tasks.

Nevertheless, there is a lack of consistency in evaluating similar parameters across chapters such as Game Experience, e.g., custom-made questionnaires vs. the *Game Experience Questionnaire* (GEQ) [107]. The decision to use a custom-made questionnaire was influenced by a need to adapt better the statements to the concrete research questions studied for each game. The custom-made questionnaires were not intended to be used for cross-comparison between games but to provide individual insights, justifying the lack of questionnaire validation. However, to better understand the change of methods employed, we must clarify that chapters' written order differs from their chronological implementation. The study presented in Chapter 5 preceded the research of this thesis. Accordingly, when planning the following user study, presented in Chapter 4, we considered using the GEQ. However, scientific research published at the time of the user study planning declared some of the statements used in GEQ and the *Player Experience of Need Satisfaction* (PENS) [121, 146], making both of the most used game experience-based standardised questionnaires invalid. Therefore, the creation of an adapted and custom-made questionnaire seemed appropriate at the time.

Nevertheless, new methods have been validated and made publicly available since the publication of the research included in this thesis. If we could do things differently, we would use the *Player eXperience Inventory* (PXI) [2], and we encourage future work necessitating to evaluate the player experience to use this comprehensive tool.

Table 2.1: Summary of methods used in each Chapter.

Chapter	**Concept**	**Evaluation Topic**	User Study Participants	**Data**	**Method**	**Result**
3	-	Related Work	-	State of the Art	Systematic Literature Review	Identification of different taxonomies and gaze-based game experiences
4	Playing with Tension	Game Experience: Twileyed	12	Participants answers	Custom-made questionnaire	Insights on Player experience and usability
		Qualitative analysis of Tension		Observation notes	Thematic analysis + Reflective Practice	Discussion of challenges, questions and conceptual dimensions of gaze interactions in games leading to future opportunities
5	Playing with Peripheral Vision	Game Experience: SuperVision	24	Participants answers	Game Experience Questionnaire (GEQ)	Insights on Player experience and usability
		Player Performance		Game Score, Time	Quantitative analysis	
		Player Preferences		Participants answers	Custom-made statements	
		Gameplay Behaviour		Gaze data Logs	Heatmap analysis	Insights on player strategies and skill development for inhibition
		Peripheral Awareness Skill Development		Participant answers	Custom-made Protractor Test	Insights on peripheral awareness skills improvements after playing the game
		Follow-up Skill Development	5	Participant answers	Custom-made Protractor Test	Insights on peripheral awareness skills improvements after playing the game during two weeks
6	Playing Without Looking	Feasibility and Performance of technique	12	Gaze data Logs	Fitts' Law-like task, quantitative analysis	Insights on the accuracy when using the proposed technique
		Task Workload		Participant answers	NASA-TLX	Workload demand when using the technique
		Eye Tracking Accuracy	20	Gaze data Logs	Gaze Accuracy Test	Gaze accuracy values of looking at the display with both eyes open
		Technique Performance: Prediction Targets without looking		Gaze data Logs	Custom-made performance Task	Insights on usability and gaze accuracy values of looking at targets after predicting their position with closed eyes
		Game Experience: KryptonEyed		Participant answers	Custom-made questionnaire	Insights on Player experience and usability
7	Gaze+Hold	Accuracy and Precision During Wink	4	Gaze data Logs	Gaze Accuracy Test	Insights on gaze accuracy with one eye closed
		Performance of the technique	12	Gaze data Logs	Fitts' Law-like task, quantitative analysis	Insights on the usability and performance of the technique
		Spontaneous Preference		Gaze data Logs, Participant actions	Custom-made Task, Eye Dominance Test, Wink Dominance	Insights on usability of preferred eye configuration to use the technique
		Task Workload		Participant answers	NASA-TLX	Workload demand when using the technique
		Technique Opportunities	-	Conceptual Framework	Metaphor-seeking, Brainstorming session	List of technique variants demonstrating the expressiveness of Gaze+Hold
8	Emerging Frameworks	Gaze Interaction in games Opportunities	-	Games Survey Game Concepts	Literature Review and Comparison + Reflective Practice	Taxonomies that serve as design tools and identify opportunities for gaze input design in games

3 Related Work

In this chapter, we briefly account for how gaze interaction has been adopted in Human-Computer Interaction (HCI). This includes the description of techniques that emerge from using the limited amount of movements the eyes can perform. We follow with the description of research surveys that tried framing the use of gaze input in games and continue describing the most relevant game examples that showcase the disparate bodies of work. In our methodology, we draw from previous research to contextualise an updated survey of gaze-enabled play. We surveyed 221 research-based and commercial/indie gaze-enabled games to present related work that highlights the relevance of using gaze input for gameplay (see Appendix A for the list of the surveyed games). Firstly, we cover the description of gaze interactions for game control, introduced by the *EyePlay* framework taxonomy [263]. We continue by presenting game examples and concepts that lead to new game experiences that move away from traditional game control.

3.1 Gaze in Human-Computer Interaction

Eye tracking has enabled the creation of a wide range of techniques that allow interacting with content by just looking at it. We can use our eyes for explicit aiming at targets to acquire them [118], or implicit indication of interest, for instance, to enable a gaze-responsive storytelling experience [234].

Eyes-only computer control had been demonstrated since the 90s [106, 225]. Jacob's work [118] established a general style of eye movement from a design perspective for discrete selection of objects and commands by pointing with the eyes, with dwell time as click method facilitated by the ability to keep our eyes focused on a static object, known as a fixation. Gaze pointing for interaction supports interaction with graphical user interfaces but is limited by the risk of the *Midas Touch*, happening when users accidentally look at items without the intention to select them [262].

The *Midas Touch* has been addressed in state of the art by multimodal combination of gaze pointing to signal interest with key or button input to confirm the selection [118, 135, 95]. In a similar fashion, we can find examples in related work complementing gaze with the use of mouse [289]; touch [235, 266, 196, 247]; voice [190]; gamepads [29] and mid-air gestures [201]. Others used blinks and winks as a method of selection of the targets the users look at [133, 230].

Alternative solutions include a large body of work on other forms of gaze interaction beyond point and dwell that utilise the limited amount of movements the eyes can perform. This includes basic saccadic eye movements, smooth pursuits, vergence or the vestibulo-ocular reflex (VOR).

Saccades are quick jumps the eyes make to change focus from one location to another while exploring the scene. Saccades can be deliberate and they have been used for interaction to encode gaze gestures for interface control (e.g. left, right, up, down) [51, 93, 292, 290]; glances off-screen [114] or to confirmation targets [152] and gestures "drawn" with multiple saccades [51, 286].

Moreover, smooth pursuits are smooth movements performed by the eyes when they follow the movement of an object in motion, moving in sync. Pursuits have been leveraged to indicate the selection of moving objects [272, 60, 264, 227].

Vergence is the movement that adjusts the visual focus on different depths planes by either converging (both eyes looking towards the nose) to focus on an object that is close or diverging (both eyes looking away) to focus on an object farther away. Vergence has been used for interaction, for instance, to explicitly control the depth position of objects in the virtual space [215].

VOR is the ability to stabilise eye movements in the presence of head motion, e.g. by nodding while fixating on an object the eyes compensate the eye movements to keep the object in focus. VOR has been used to enable target disambiguation of occluded objects in 3D environments [157].

Moreover, eye movements can also happen behind the eyelids. For example, when we are sleeping, there are involuntary jerky movements of the eyes called Rapid Eye Movements (REM) [155]. This has enabled interfaces that utilise gaze gestures behind the eyelids to input passwords discretely [63]by using electrooculography sensors in smart glasses.

Beyond utilising gaze input for interaction in general Human-Computer Interaction (HCI) applications, we focus on the use of gaze interaction in play experiences. The recent emergence of eye trackers in the consumer space has spurred interest in novel creative uses of gaze interaction and it is swiftly being introduced in mass-market gaming media, with affordable, portable, or embedded into gaming computers' eye trackers. In 150+ commercial game titles [245], including popular franchises such as *Far Cry* [255]; *Tomb Raider* [172]; *F1* [32]; *Tom Clancy* [59]; or *Assassin's Creed* [254], players can trigger game actions by aligning their gaze with objects of interest. This offers the opportunity to use gaze to augment the feeling of immersion (defined as the deep but effortless involvement in a game experience [242]). To unfold 'looking' as not only gaze input in interactive systems, we first need to understand how state of the art utilises gaze interaction in play.

3.2 Gaze in Games

The main thrust of gaze-enabled games use gaze pointing to provide accessible game controls by replacing or complementing the original input modality [112, 116, 113, 231], or adopting gaze input to enhance the feeling of immersion by adjusting visual graphics via controlling the camera viewpoint [231, 180] and adaptive rendering [96]. Others use gaze to augment the player experience by adapting the difficulty of the game based on the player's gaze behaviour [177, 5]; moving the avatar with the eyes [115, 220]; automatically aiming at targets [113, 45]; or supporting the performance of game controllers [265].

Creative uses of gaze in games focus on designing dynamics based on eye movements other than fixations, such as smooth pursuits [272, 129]; winks [40] or pupil dilation and blinks [56]. Moreover, gaze input has enabled game dynamics that integrate the social use of the eyes in multi-player games to allow the control of tools and weapons [198, 9]; or support communication between players [141] in collaborative [161] and competitive [182, 139] games. The underlying mechanic in all these examples is to leverage the use of gaze and vision, exploring new and compelling ways to use gaze that are challenging by design.

In research, different surveys have been conducted to gain a better understanding of gaze interaction in games [113, 240, 3, 241, 263]. *Smith et al.* [231] investigated on how gaze is represented in games. Their focus was to describe how to use eye movements for interaction, and compared gaze with the mouse for game control. *Isokoski et al.* [113] reviewed eye tracker gaming with a focus on accessibility. They analysed future development possibilities in different game genres and domains. The authors argued in their survey on the potential and the requirements needed to integrate the use of eye tracking for game control, the device input and the technical implementation of the game.

Moreover, *Almeida et al.* [3] developed a survey that differentiated between the use of gaze interaction in games as the sensor and the interaction actuator. They focused on the use of eye trackers to either substitute or complement traditional input game control methods; or as an input method to analyse how players look at the game.

Finally, *Velloso et al.* looked at the use of gaze, and how it can be incorporated in games, coining the term *EyePlay*, referring to the *"playful experiences that take input from the eyes"* [251]. In the *EyePlay* survey [263], the authors proposed a taxonomy from a game mechanics-driven perspective, e.g. how gaze maps to traditional game control such as directing weapons or moving the character. They created a framework highlighting the compelling future of gaze for gameplay by categorising eye movements and game control dynamics, with different types of input (discrete vs continuous), and organising them in five game mechanics: Selection and Commands; Navigation; Aiming and Shooting; Implicit Interaction; and Visual Effects.

Going forward, we aim to provide an understanding on how gaze has been widely adopted for interaction in games. We reviewed research-based; commercial; and independent gaze-enabled games. We started with the games included in previous surveys [113, 240, 3, 241, 263]; and research articles and other media citing them since their publication. We selected Google Scholar and the ACM Digital Library as the source to find research examples. In our search, we used the combined terms: *gaze*; *interaction*; *play*; and *game*. Additionally, we set the time frame from 2016 to 2019, as this covered the years from the publication of the last survey. Finally, we reviewed the Tobii-gaming games library [245]; Tobii-Developers online forums, and media streaming websites (YouTube) in search of commercial and independent games.

We included results describing titled and untitled gaze-enabled games; eye tracking input techniques for gameplay; game-like virtual environments using gaze for interaction; and gaze-based applications self-determined as a game or as a playful/entertainment experience by the authors. Both physical (hardware artefacts) and digital games were considered. We excluded the results that presented the use of eye tracking input to gain a better understanding of players' cognitive processes and behaviours during gameplay. Although the focus of this framework is gaze interaction, we do acknowledge that other uses of gaze in games exist. Overall, we discarded all results that did not use gaze interaction to affect the dynamics of the game in real-time, e.g. research on how to visualise gaze data to understand the player's gameplay behaviour.

We gathered a total of 221 games including research-based games; video demonstrations of independently developed games; FOVE VR experiences; and the 152 games listed in the Tobii Library [245]. We found 67 research-based games: five of them set in VR; two were hardware artefacts; two are played on hand-held devices, and the rest were screen-based games. We found two independent games, and one of them was a large-scale interactive installation. For each of the games, we read their description or watched a video of their gameplay to understand the embedded gaze capabilities.

In the following sections, we look at state of the art games to understand how gaze interaction has been used in the play context. First, we revise the game mechanics gaze has enabled in related work inline with Velloso et al.'s *EyePlay* framework. Moreover, we expand this knowledge to give an insight on the use of gaze interaction for game control, immersion, and to create novel game dynamics, supported by the description of the most relevant games found in the literature review. These showcase the rich and disperse environment of gaze-enabled play design.

3.3 EyePlay Game Mechanics

The *EyePlay* framework [263] is seminal in identifying a set of game mechanics enabled by gaze input. Game mechanics is the term used to describe the specific way in which players invoke actions in the game to interact with the game world, for instance, jumping, firing a gun, or moving. The EyePlay taxonomy showcases the disparate collection of gaze-enabled game mechanics that have been adopted by commercial games beyond research-based applications. Table 3.1 lists a summary of the most popular gaze-enabled game mechanics as advertised in the Tobii Games Library [245] and categorised using the EyePlay taxonomy. The table highlights the trend in using gaze input to automatically move the game camera when looking at the sides of the screen to extend the game view, or hide the user interface when the player is not looking at it for a cleaner screen. Moreover, another widespread adoption of gaze input has been to aim the direction of weapons at gaze, and trigger selections of the game elements the players look at.

3.3.1 Gaze Selection and Commands

The fundamental principle of gaze interaction is to leverage gaze as a natural pointer and selection mechanism for objects the users align with their eyes. Therefore, an object is selected when it is looked at [45], triggering the object's choice or modulating an

Table 3.1: Summary of Gaze-enabled Game Mechanics and population of games categorised following the EyePlay taxonomy.

GAME MECHANIC	# GAMES	GAME MECHANIC	# GAMES
Selection and Commands		**Implicit Interaction**	
Interaction at Gaze	33	Clean UI	53
Select at Gaze	14	Environment Awareness	17
Menu Navigation and Interaction	9	Highlight at Gaze (e.g. survival instinct)	11
Map Navigation	3	Response to Eye Contact	10
Enemy Tagging	5	Affect AI at Gaze	4
Mark at Gaze	5	Affect Environment at Gaze	3
Target at Gaze	5	Auto-Pause	3
Other Game Actions (e.g. Hack, Magic)	13	Reveal Viewcone at Gaze	2
Navigation		Peripheral Effects	1
Navigate at Gaze	8	**Visual Effects**	
Cover at gaze	4	Extended View - Eye & Head Tracking	122
Auto-Turn	3	Depth-of-Field & Dynamic Light	15
Auto-Climb	2	Bungee Zoom	12
Warp at Gaze	2	Center Camera at Gaze	10
Dash at Gaze	2	Gaze Cursor Visualisation	8
Guns for Hire	1	Zoom at Gaze	6
Aiming and Shooting		Camera Control (e.g. pan, free view)	6
Aim at Gaze	39	Light Effects (e.g. sun effects)	5
Gamepad Cursor Warp	17	Dynamic Depth of Field	4
Throw at Gaze	7	Head Pose Tracking and Mirroring	2
Flashlight Control	2	Character Eyes Control	1
Aim Assist with Gaze	2		
Character Head Movement	1		
Steer with Gaze	1		

action or command. Once the selection is made, gaze can move away leaving the object selected. This mechanic could be used, for instance, to look at all the objects you want to collect [231]. In commercial games, players can mark, target or tag enemies by selecting them by gaze; or interact with in-game widgets such as maps and menus.

Gaze selection was made available in games to substitute other controllers, such as the mouse, designing for accessible gameplay [12]. However, in other examples gaze preselects the object and another input modality confirms the selection, e.g., voice [190]; gestures [28]; or touch in an AR application [142]; thus avoiding the *Midas Touch* problem [262] that happens when gaze is both the sensor, when we scan the scene, and the actuator, when interacting at gaze.

Another approach is to use unconscious gaze attention for implicit selection. For instance, in *Jalaliniya*'s guessing game [119], the engine would "guess" which character the player chose, based on their eye movements and the time they look at the selected target. In other examples, players can select the object they want to interact with by matching the movement of a moving target with their gaze motion [272]; or confirming a selection by just looking at an item during a dwell time [29, 282].

3.3.2 Gaze Navigation

Where the eyes look at in the game has also been used to control the game's avatar's motion. Some examples use a direct mapping between gaze and the avatar position in the screen; for instance, moving the game character towards the point where the player is looking at in the game scene [231, 220]; directly controlling the position of a paddle [49, 269]; or aiming the direction of the movement (steering) that is triggered with a different input modality, e.g. voice to navigate through tunnels [190], or "jump" between platforms [257]. In commercial games, navigation mechanics, allow the player to look at locations in the scene where they want the character to automatically move and cover from enemies; climb or move allies ("*guns for hire*" mechanic in Tom Clancy's: The Division 2 [59]) when the controller's key is pressed.

Other examples used eye gestures, to encode the direction of the characters' movement in desktop [115], and mobile games [1]. In *GazePilot* [188], *Nielsen et al.* used the gaze-point to steer the direction of the plane in the game. If the players were looking at the upper part of the screen, the plane would tilt and point up while automatically moving forward. In the game *BreakOut* [49], the player can move the game paddle to where they look. Overall, gaze navigation is used as a mechanic to *"look to go there"* [231, 220], or to point at a *Cartesian space* (areas associated to the different directions on the scene, e.g. up, down, left, right) [115, 188].

3.3.3 Gaze Aiming & Shooting

The player's gaze-point in games has also been used to shoot and aim the direction of weapons, superpowers and tools towards the game scene. The integration of gaze input for game control has enabled players to explicitly aim a torch [9, 266]; focus their attention on an opponent character to intimidate and stop them [270, 140]; or to use the power to freeze enemies at gaze [179].

Gaze input has also been used to support other input modalities; thus the eyes are used to aim at the target whereas mouse [231]; keyboard [239, 113]; touch [198]; mid-air hand gestures [266]; or voice [282] are used to confirm the firing of weapons or super-powers. Others, leveraged gaze pointing to improve the mouse performance in a shooter game [265], by wrapping and swiftly move the mouse cursor towards the gaze point. Moreover, in research games, players can also shoot with gaze only by confirming the shooting with blinks [282]; with an upwards gaze gesture [112]; or by following a moving target in VR [129].

3.3.4 Implicit Interaction and Visual Effects

As seen in the previously described mechanics, gaze interaction has generally been used for explicit game control in which the player consciously seeks to interact with the game at gaze, e.g. to select, move the avatar or shoot. However, gaze interaction can also be implicit when players have no intention to interact at gaze and game effects happen "behind the scenes", as seen in Jalaliniya et al.'s guessing game [119]. Accordingly, gaze input has enabled responsive game engines that adapt their difficulty [177, 5]; predict player's intentions [96]; make something appear in the interface when players look at specific locations [80, 20, 254, 59]; challenge the player by displaying to an opponent player where they look at in competitive games [141, 183], or even invisibly calibrate the eye tracker during gameplay so it can be used for later interaction [211]. All these examples use gaze data implicitly, leveraging the natural gaze behaviour to scan and capture information we attend to in the scene.

Another body of related work leverages the eyes as a tool for communication to integrate social behaviours into the gameplay. The way we look can encode different meanings in a social context, e.g. distraction, submission, or attention. State of the art has used implicit gaze input to enhance interaction with avatars that can react and adapt their conversation depending on where the player is looking [271, 68].

Finally, implicit gaze input has been used to control in-game visual effects. Examples include adaptive depth-of-field blur to improve the perception of 3D game objects and compensating camera motion [96]; automatic adjustment of the game graphic's rendering to the game objects that are looked at or to dynamically compensate the scene brightness when looking at dark/light areas [254], and centering the camera on the gaze-point for greater immersion [231, 172]. However, the most widespread gaze-enabled mechanic is to slightly move the camera view when the player looks at the edges of the screen. This enables an extended view which aims to provide a greater feeling of immersion.

3.4 Gaze Gameplay and Game Control

Beyond specific gaze-enabled game mechanics, related work has adopted gaze input to provide different control and gameplay experiences. As with any game controller, gaze input allows the player to become an active actor and the omnipotent entity outside the game that controls the main character actions. Accordingly, gaze is introduced as an alternative input that leverages the natural attention of the eyes to facilitate interaction. For example, in Djamasbi et al.'s *Simon Says* game, gaze is used as the pointing device that selects the buttons in the digital interface of the game.

Alternatively, the player's gaze can be integrated into the game as if it is the avatar's gaze that is looking at the game world (Figure 3.1, A). This enables the player to adopt the game character's "abilities". In *Medusa's Lair* [98], an installation-like game that uses body tracking and gaze interaction, the players can run around an open space controlling the position of their avatars in the game world. Another player is in front of a screen in a remote desktop computer, and taking the gaze powers of *Medusa*, a creature that can turn anyone into stone when looking at them. In the game, the user looks at other players' avatars to petrify them.

Accordingly, the integration of gaze interaction in play allowed game experiences that leverage the eye's natural capability to encode social cues, e.g. looking at someone to demonstrate attention or looking down to show submission. For instance, when the player looks at a passerby in *Assassin's Creed* [254], they wave at the main character and not the game camera (the location of the player in the game's perspective). In research, Vidal et al. investigated the use of social gaze interactions as a game mechanic in *The Royal Corgi* [271]. In the game, the player assumes the role of the dog trainer candidate (in a First-Person perspective) that needs to talk to different characters in the game scene. When the player interacts with these characters, they can modify their conversation depending on whether the player is looking at them, other characters or somewhere else in the scene. For instance, when talking to the *Military Advisor*, players need to show respect by maintaining eye contact. Moreover, when talking to the *Budget Advisor*, they need to be careful and not glance at his wife, or he will get offended. These examples leverage the eyes' non-verbal communication capabilities to introduce realistic social gaze

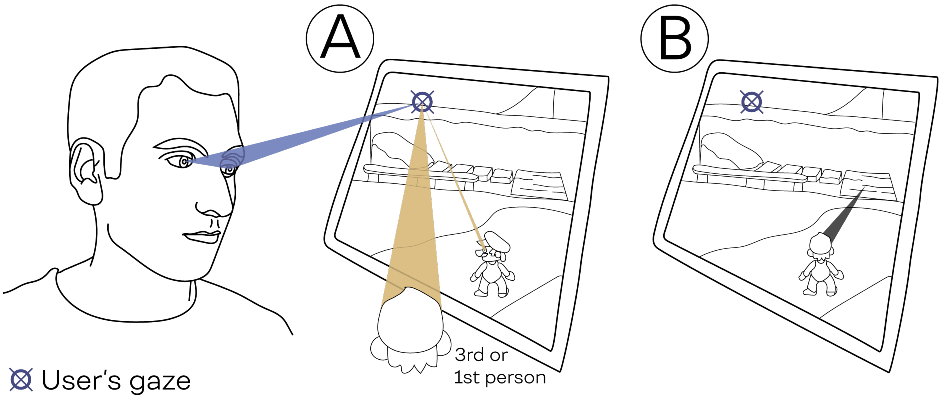


Figure 3.1: Gaze input can provide different gameplay experiences depending on how gaze is embedded in the game mechanics. A) Gaze is integrated in the game world, e.g. the player's gaze is the avatar's gaze. B) Gaze is independent from the game scene and it encodes in-game commands, e.g. gaze input is a pointer for control.

interactions in games.

Another body of work expanded on the use of social gaze mechanics to facilitate non-verbal communication between users in multi-player games [141]. For example, Maurer et al. displayed each player's gaze-point to their partner in the game *Ibb & Obb* [161], so they could communicate with each other and work out the game challenge together. We can find similar examples that display a visualisation of the gaze-point to other players to guide them through the game task, e.g. to complete a puzzle [42] or support hand gestures to help escaping a virtual labyrinth [160]. Other multiplayer games, use the player's gaze input to roll the eyeballs of the virtual avatar so the other player can see their "natural" gaze [222]. In contrast, in the competitive split-screen First-Person Shooter multiplayer game *Screencheat* [139], players are invisible and need to look at each other's screens to win. Each player needs to find the other and kill them first. To do this, they are encouraged to look at the half of the screen where the other player is playing. In the scene, they can see where the player is but also where they are looking at (the gaze point).

Beyond adopting the social gaze for game control, games have widely used gaze input to either substitute traditional controllers or support them, both providing an alternative and compelling novel game control modality. Traditionally, gaze is transformed into a pointing device that is disjointed from game elements (Figure 3.1, B) but can encode in-game control commands. Concretely, where the player looks at is not where the main avatar looks but could be used to control their position, e.g. the "look to go there" navigation game mechanic. Velloso et al. utilised gaze in *Battlefield 3* to support the mouse's performance [265]. On mouse movement, the cursor would speed up towards the gaze point to facilitate the swift control of the weapons carried by the mouse. In Vidal et al.'s *Pursuit Frog* game [272], the player follows with gaze the motion of moving flies, performing smooth pursuit eye movements, to select them so the frog can feed on them. Moreover, Istance et al.'s version of the game *World of Warcraft* [115] or Bates et al. gaze-enabled controls for *Second Life* [12] are examples presenting accessible and gaze-only game controls. In both games, the player can look at the arrow-shaped buttons

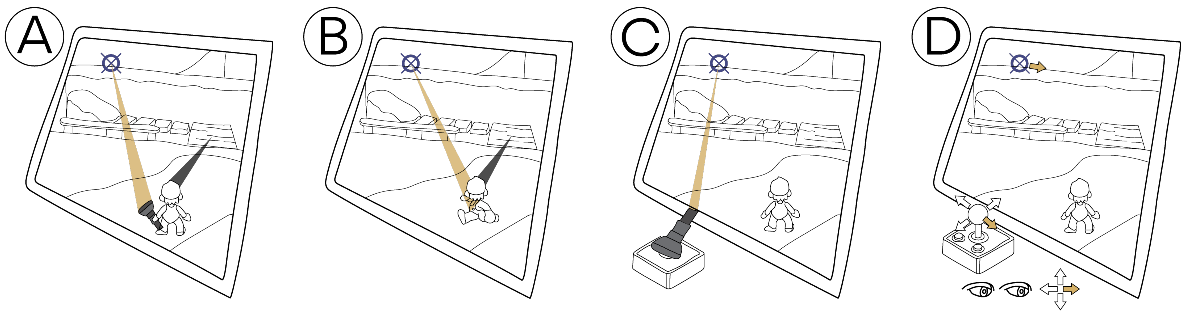


Figure 3.2: Gaze pointing enables the control of game elements inside and outside the scene, e.g. A) weapons and tools the avatar carries; B) The avatar's body position or orientation; C) Physical artefacts in the real world; or D) encoding different control directions with eye gestures.

overlayed on the game scene to move their avatars with their eyes only.

Gaze pointing has allowed the integration of different paradigms for game control in gaze-enabled play. Related work has showcased different uses of gaze to control the main avatar, the firearms they carry, physical artefacts or encoding control gestures. In some examples, gaze controls something that is operated by the main avatar. For instance, the control of the direction of weapons or other objects and tools such as torches or vehicles (Figure 3.2, A). This game mechanic has widely been integrated into commercial game franchises, e.g. *Tom Clancy* [59] and *Tomb Raider* [172], or research-based games such as *StarGazing* [266] that uses gaze to control the direction of a torch that illuminates the scene. Other examples use gaze pointing to directly move the avatar or orient their body towards the gaze-point in the game world (Figure 3.2, B). For instance, in the game *Schau Genau!* [220], the game avatar (a butterfly) always moves toward the gaze-point. In *Dying Light* [243], players can look at the top of ledges while sprinting to make the main avatar automatically climb walls.

Gaze control is not only limited to moving game elements, but has been used in related work to direct objects outside the game scene (Figure 3.2, C), e.g. a physical artefact that the player wears in the real world, or virtual objects that are superposed between the game scene and the player. For instance, in *LaserViz: Cup game* [261], the player wears a head-mounted eye tracker holding a laser pointer, which visualises where the player is looking at in the space. In the game, players need to follow how the opponent mixes three cards and guess where the special card is when they stop and select it using the gaze laser visualisation. In contrast, in *Maurer et al.*'s *Mario Bros.* game [159], gaze controls a "virtual" object an spectator user can control. In the game, the primary player is challenged with a hidden half of the screen, and they are unable to see what is coming next in the game world. A secondary player, traditionally a spectator, can take control with gaze of a virtual pinhole (working like a torch) to help the main player see through the dark screen during gameplay. This example highlights the potential to integrate gaze with other game controls to transform the role of an audience user into an active player.

Finally, mechanics for game control can take input from the physiology and behaviour of the eyes aligned with related work on gaze gestures. This includes how the eyes move and their motion's direction, but not the precise location of the gaze-point in the game scene. For instance, in the game *TrackMaze* [1], the player can control the direction of a ball with eye gestures. The eyes simulate joystick actions, and the player needs to roll their eyes side to side to move a ball in the maze (Figure 3.2, D).

3.5 Gaze-enabled Game Dynamics and Immersion

Beyond game control and mechanics, gaze input promises PC gaming an improved experience with augmented controllers, enhanced gameplay and a greater feeling of immersion. Depending on where the players look at in the game scene, different game dynamics might emerge. Generally, the player's gaze interacts with the space where the game develops, the game scene. In digital games, it corresponds to the 2D/3D virtual world, whereas, for physical or analogical games, it is the board or space where the game takes place. The simple act of looking around the game scene can create different game dynamics based on the player's attention to the scene. In *Antunes et al.*'s *Zombie Runner* [5], the avatar is automatically running and will avoid obstacles or enemies only when the player has looked at them beforehand, requiring they are attentive to the hurdles they encounter. In the game, like in real life, the avatar trips on obstacles you have not seen. Similarly, other examples use gaze attention to control the storytelling experience. In the VR experience *Rapture of the Deep* [204] or the 3D game *Fractile* [143], the player can unravel hidden stories and advance on the narrative as they look around the scene. These examples showcase how gaze interaction is more than explicit or implicit pointing, but it yields the player's intention.

Digital games can contain overlaid information such as maps and game statistic's visualisations among other elements the player can interact with at gaze, e.g. navigate and select options in the game menu in the commercial games *Aragami* [287] or *Dreamfall Chapters* [75]. In game design, we can find examples that leverage the player's intention to either attend or interact with the game scene (Figure 3.3, A) against the overlaid information in the user interface (Figure 3.3, B) to allow greater immersion by providing a cleaner scene. In games such as *Tom Clancy's The Division 2* [59], or *Hitman* [109], the player might look at the scene corners in search of game information such as a game map, the avatar's life statistics or a weapon menu. In contrast, when the player looks at the game scene and is not looking at the GUI elements, the latter turn semi-transparent, facilitating greater game immersion and a wider field of view.

We can find other creative game dynamics that arise from the concept of gaze attention for interaction during gameplay. The game *Shynosaurs* [270] draws from concepts associated with social gaze previously seen in games such as *The Royal Corgi* [271], to introduce attention dilemmas as a novel gaze-enabled game dynamic. The game challenges the player to pay attention to the game scene to solve the game task while necessitating to focus their attention on other game characters at the same time (Figure 3.3, C). In *Shynosaurs* [270], the players need to drag and drop the "cuties" (sheep-like creatures) to safety with the mouse. However, "shynosaurs" (dinosaur-like enemies) will attempt to steal them while the player is concentrated in solving the task. Gaze interaction enables the player to intimidate the "shynosaurs" by looking at them and stop their attack. This introduces an attention dilemma as the player needs to pay attention to the "cuties" to accurately pick them up and drop them, but also needing to look at the other characters

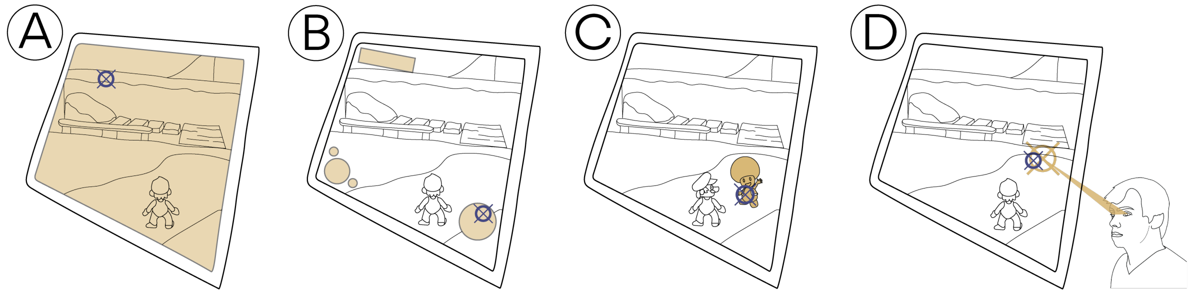


Figure 3.3: Gaze input creates different game dynamics depending on where the player looks at: A) the game scene; B) the overlaid user interface; C) other characters; or D) other player's gaze marker.

to prevent their attempt of theft.

In multi-player games, gaze interaction has also been used to create game dynamics that rely on collaborative gaze attention. In *GazeArchers* [198] two players need to attack passerby enemies by aiming their weapons with gaze. However, some enemies are gaze-aware and will protect themselves with a shield if they detect they are looked at. To solve this, both players need to collaborate and look at the enemies together to defeat them.

Other approaches create novel game dynamics by allowing the player to look at where another player is looking at in the game [141], displaying their gaze-point with a marker (Figure 3.3, D). This allows a player to be aware of where their partner/opponent is looking at, creating game experiences that rely on being aware of where the other player is looking at during gameplay. In competitive games, this paradigm has been used to create compelling uses of gaze input that influence players to change their attention behaviour. Newn et al. used the digital version of the board game *Ticket to Ride* [182] to add a visualisation of the opponent player's gaze-point so they have a reference to where the other player is looking at during gameplay. In the game, the player can see where in the game board the other player is looking at, thus being able to predict their intentions and strategy. However, if the opponent knows they are being watched, they could deliberately look elsewhere to deceive the player.

3.6 Gaze Interaction Beyond Pointing

Gaze-enabled play is coupled with looking at the game. In general, gaze interaction is defined by the interaction metaphor "What you look at is what you get" [118]. Indeed, we have seen in the previous sections gaze interaction in play leverages gaze as a pointing device for game control providing different game experiences. However, there is a limited amount of related work that designs gaze interaction considering other gaze behaviours that are described beyond just pointing. For instance, in commercial games, the eye tracker senses the player presence (whether they are in front of the sensor) and use it to automatically pause the game when the player is not in front of the screen, e.g. in *Assassin's Creed: Rogue* [252] and *Nevermind* [171].

Related work that moves away from using gaze input for direct pointing designed game experiences with rules that require the player to avoid looking at specific game

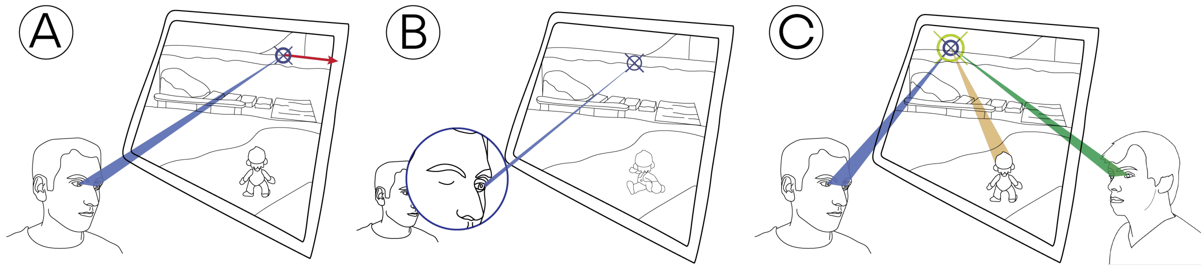


Figure 3.4: Other gaze mechanics have been explored considering other behaviours beyond just looking at the game for interaction, such as: A) avoiding to look, B) the use of winks; C) joint gaze between multiple players or the player and the avatar.

elements (Figure 3.4, A). In *Ejdemyr's Maze* game [54], the player navigates the game world inhabited by different types of monsters. Some of them are violent but will stop their attack if the player looks at the monster to pacify them. Other monsters are calmed and would only attack if the player lays eyes on them, thus it is advised to avoid looking at them to prevent their attack. In other cases, the player must avoid looking at the game to win. In the game *VirusHunt* [266], the player needs to tap the screen to remove viruses, but if they look at them, the illness will spread. These examples showcase compelling game dynamics based on the players' awareness of what they are looking at in the scene.

There are other creative uses of gaze in games that do not rely on the position of the gaze-point but include different ways to "look" at the game scene, e.g. winking (Figure 3.4, B). In *Da Silva et al.*'s game set at *La Rochelle Lab* [40], the player is confronted with a mean student that steals their homework. To retrieve it, the player needs to look at the student and wink to charm her. Accordingly, other examples have used blinks to encode game commands. In *Blink Blink Boom* [6] the player can recharge their gaze-controlled firearm when they close both their eyes at once.

Another non-conventional game including novel gaze interactions is *Invisible Eni* [56]. In the game, the player can move the main character (Eni) by fixating during a dwell time at the location they want her to go. The goal of the game is to free butterflies by feeding them with magic nectar found inside flowers. In her adventure, Eni is followed by the butterflies she collects but can encounter enemies that chase her. However, the player can close their eyes to make her disappear into a puff of smoke to protect herself. Nevertheless, what is different about *Invisible Eni* is that the player will only be able to open magic flowers by staring at them with dilated pupils.

There is another body of related work that integrated different gaze behaviours in multi-player games. These are characterised by including gaze collaboration between either two players or a player and the game character, requiring both of them to look (or not) at the same location in the game scene (Figure 3.4, C). Lankes et al. designed the game *Limus and the eyes of the Beholders* [140] exploring the effect on the player's perceived presence by using different gaze interaction conditions during gameplay. In this 2D platform game, Limus has to reach a magic portal to escape a dark cellar. However, players need to avoid the "spikees", enemies that chase Limus when they see him, and they can freeze their attack at gaze. In one of the versions of the game, the enemy gets frozen when it is looked at by both *Limus* (facing the enemy, controlled with a gamepad) and the player at the same time. In contrast, another version of the game introduces a rule to cancel this power if both Limus and the player look at the enemies at once. Accordingly, they can only freeze the monsters if Limus, and not the player, looks at them, necessitating to look away to avoid it.

Equivalently, in the multi-player game *Keyewai* [9], the players explore a forest by steering a torch with gaze. However, when encountering a cannibal, they are attracted to the torch's light and attack the player. This requires the players to be aware of where they are looking to avoid attacks. However, players can help each other by aiming their torch at the cannibal at the same time to dazzle them and stop their attack.

3.7 Conclusion: Moving Out From Gaze Pointing

In this chapter, we accounted on how related work focuses on the use of gaze input to enable interactions that rely on pointing. In gaze-enabled games, players can aim at targets; control the camera movement; tag opponents; or control the direction of guns, just by looking at the game scene [172, 255, 254]. Overall, the use of gaze in games is obvious and we believe, it provides no challenge. On the contrary, gaze is used to support and improve the gameplay performance. For instance, if we seek to shoot an enemy in a gaze-enabled *"Tom Clancy's: The Division 2"* [59], we need to press a button, and the gun will automatically aim at the enemy we look at. We deem designing this type of gaze interaction might remove the game challenge.

If we exclude some of the more creative research-based game explorations previously outlined, the lack of challenge in gaze-enabled play resides in that the eyes are a natural sensor, and when used as a controller in games at the same time, we might involuntarily trigger unwanted outcomes [262]. This is known to create tension, and thence designers tend to avoid this conflict, e.g., looking at a game element but triggering its selection with a button; or slightly moving the camera when looking close to the edges to move the extend the field of view. We believe the lack of challenge makes gaze interaction unappealing beyond accessible control because gaze input becomes a supporting feature, not something essential to the gameplay experience.

We challenge this approach to reflect that gaze interaction is more than pointing. Related work has highlighted the use of eye trackers as game controllers with a natural mapping can lead to gameplay experiences that go beyond game mechanics and control, e.g. applying concepts of social gaze. In the following chapters, we explore how we can use gaze interaction in games differently, and more creatively. We aim to unfold what "looking" as an interaction metaphor means. We move out from utilising gaze input for pointing and explore the landscape of opportunities arising from thinking about the richness of gaze, attention, vision, and behaviour.

4 Playing with Tension

Gaze interaction has been widely adopted for game control as a pointing device. We believe the interaction mechanics emerging from this are obvious uses of gaze that remove the game challenge. For instance, players can look at an enemy and fire as the gun is automatically directed to the gaze point. In this chapter, we want to move beyond the popular ways of using gaze interaction to identify new creative ways of adopting gaze input. We investigate the concept of *playing with tension* with the following research objectives:

- Exploring the limits of designing gaze interaction by thinking outside the box and proposing ambiguous uses of traditional gaze-enabled game mechanics.
- Investigating: (1) the effect of additional tension to gaze interaction in the creation of engaging and fun game experiences; (2) whether players can overcome the challenge of playing with ambiguous gaze interactions going against the 'natural' use of gaze as a pointing device.
- Identifying and discussing the challenges and potential design opportunities emerging from the reflection on gaze interaction design in games.

We present the game *Twileyed*, a collection of three mini-games. The games draw from the state of the art game mechanics set by the *EyePlay* taxonomy [263] and add tension to them with challenging rules. We investigate Gaze Navigation, Selection and Aiming and Shooting mechanics, but also include ideas from Implicit Gaze interaction and Social Gaze in the games' narrative (e.g. looks that intimidate). We investigate with *Twileyed* whether players can complete the game and what strategies, themes and conversations about gaze interaction emerge from the gameplay. The games we develop surface as data we analyse to open up a space for reflection. We discuss the design challenges and set a conversation agenda to propose new opportunities for gaze in games.

4.1 Using Ambiguity as a Tool for Reflection on Gaze Interaction in Gameplay

Ambiguity is the uncertainty and inexactness that obscures the meaning or use of something, inviting to create multiple and rich interpretations. In Human-Computer Interaction (HCI), ambiguity is generally seen as a problem. However, it has also been introduced as a resource and an opportunity for design [219].

Gaver et al. [77] described the advantages of enabling designers to go beyond the limits of their technologies by devising ambiguity in their applications. In their view, ambiguity is a powerful design tool that provides a framework to use inaccurate sensors and inexact mappings to create engaging and thought-provoking interactive applications that encourage users to make their interpretations. Moreover, they claim ambiguity allows designers to give perspective and suggest issues to be considered rather than imposing solutions. In this chapter, we use ambiguity in the design of gaze mechanics in the games to introduce tension. Besides, it allows us to stretch the limitations of gaze input in games allowing renouncing to propose solutions or answers but to question and raise themes for discussion, opening the space for reflection.

Accordingly, reflection is a necessary component of learning [21] and has been broadly used within the HCI research community [66, 13]. *Reflective Design* is concerned with how we considerate and think about a product according to subjective factors, and it is essential during the design process [223]. In games, players usually reflect on the gaming experience in online forums and game communities; thus games have been used to encourage reflection in research [78], with a focus on the player perspective [127, 164, 192], but also used by designers to reflect on the game design process [65, 111]. *Harteveld et al.* [90] reflected in their work on the tension of game design, analyzing, for example, the dilemmas on the design process.

Moreover, playing with "tension" requires the definition of game rules that create *ambiguity of context* [77] of the gaze mechanic to disrupt the interaction with incompatible uses; add functions to break the gaze dynamic; and modify the expected functionality. We draw from Gaze Selection mechanics and leverage the Midas Touch problem to increase tension in the gameplay. We set game rules that make player trigger unwanted outcomes by enabling the selection of the character they want to move at gaze. Moreover, we adopt gaze navigation implementing a *look to go there* mechanic. This uses gaze to point at the direction the player wants the avatar to move towards; however, we introduce a biased mapping of the gaze point to add tension to the game controls. Finally, we leverage the use of gaze aiming and shooting mechanics to enable players to aim with gaze and fire with a keypress. Nevertheless, this advantage comes with a price, and enemies move towards the gaze point to increase the game challenge.

We use the designed game playing with tension to reflect on the player experience from the gaze-enabled games' designer perspective rather than asking players to reflect on the games themselves. We propose to focus on observations of the users playing the games to question gaze interactions, and therefore, to learn and discuss the design opportunities that the ambiguity of context emerging from the introduced game rules.

4.1.1 Game Design Process

Designing gaze interactions with "*tension*" is not a trivial challenge because it tends to be avoided. Indeed, gaze as an input suffers from an innate tension during interaction. The eyes are both used for sensing (to scan the game scene attentively) and actuate (for interaction). Therefore, designing *tension* requires distinguishing gaze mechanics with poor usability from posing rules to use usable gaze in an anti-intuitive manner. Here, we propose to use traditional gaze interaction in games that are twisted with rules to make them less intuitive, with a great cognitive challenge but still usable. These require players to explicitly attend where they are looking at the game scene, rather than trigger interactions as they naturally look at the screen.

To design the game, we reviewed the literature on gaze-enabled games that posed similar challenges requiring attention to where the player looks. For instance, playing with an attention dilemma [270] or playing with interaction rules integrated into the game narrative that limit where the player can look at [266]. These set the requirement that several rules need to act at once, creating a duality in how gaze input is used during game interaction.

Before starting the game ideation and brainstorming process, we looked for potential metaphors from cultural and fictional stories that could help contextualise the challenge of playing with gaze interaction duality. Using ambiguity as a tool for design and the concepts of anti-intuitiveness and duality, we looked for characters with stories of strong bonds (connection), needing to live with rules and characters that, indeed, are considered to have a dual identity. We found inspiration in characters that met this last criterion, e.g., witches (a symbol of dualism between feminism and the mystical), Dorian Gray (a story between life and dead), or Jekyll and Hyde (two faces of the same character). Based on each character's story, we brainstormed gaze metaphors that could be used to contextualise the target gaze mechanics (Aiming, Navigation, Selection) and use sketching to create a first prototype concept. As different ideas emerged, we filtered them and chose the ones that showed cohesion with the game requirements to inform the development of a puzzle game.

4.2 Game: Twileyed

We developed the game *Twileyed* containing three mini-games that challenge the use of gaze interaction. We represent each game by characters, mostly from fiction, representing *"duality"* to implement the ambiguity in the different gaze mechanics. The games objective is to complete a collection task with challenging interaction in the game control. Gaze interaction is used to modulate navigation by selecting characters to move; aiming direction; or shooting with gaze for protection. Gameplay videos available in Appendix B.

We chose to use multimodal interaction for the avatar control to solve the task combining *Gaze* and the *Keyboard*. The *Arrow/WASD* keys are used to move the avatar in the games (either up, down, left or right), whereas the *space* key can be used to trigger events; e.g., an attack. Using this dual interaction allows the concept to split between the fundamental controls provided by the keyboard, and the modulation of such with the use of gaze. In the presented games, both inputs for interaction are dependent on each other and co-exist in the game environment. Therefore, the player cannot overcome the game challenge if one of them is not available.

We designed each game by thinking about how to increase the tension and add ambiguity to the gaze controls that, without the challenge, would more easily be performed. Players need to learn how to use the interaction mechanic and adapt their strategy to overcome each game challenge. We aimed to provide three examples of games that include gaze interaction to explore the potential applications of gaze in games.

4.2.1 Gaze Selection: "Dorian's Pictures"

In the first game, gaze is used for *Selection*. To move a character, players need to look at them to select them. However, the ambiguity in the interaction context is articulated by setting opposed interaction dynamics for selection.

The game story is based on the literary character of Dorian from *"The Picture of Dorian Gray"* by Oscar Wilde [283]. Although Dorian is immortal, he could be killed if he is in front of his picture. In the game, the player controls *Dorian*, who is at a party populated by *Guests*, *Servants* and *Assassins*. The objective of the game is to move *Dorian* and collect the pieces of his picture before anyone else collects them (see *Figure 4.1*). In the meantime, the *Assassins* will attempt to kill *Dorian*. *Servants* and *Guests* can stop the *Assassins* by getting in their way. When that happens, *Guests* will be killed by the assassin, whereas *Servants* will remain in the game. Once the *Assassins* are intercepted, they escape and wait until the next attack.

Dorian is very narcissistic and requires all the attention to move. Moreover, *Dorian* is the host of the party, and when he moves, everybody else will move to try to win his

Figure 4.1: "Dorian's Pictures" game scene. Players need to move Dorian so he collects the pieces of his broken picture before the other characters do.

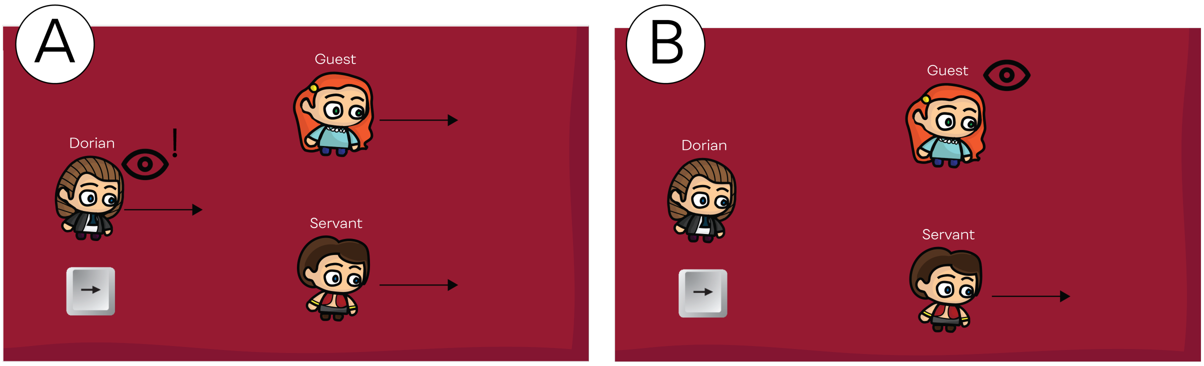


Figure 4.2: Rules for Gaze Selection in "*Dorian's Pictures*" game. All characters move when the keyboard arrows are pressed. However, A) Dorian needs to be looked at (selected) to move; and B) other characters become shy and get paralysed at gaze.

favour. If *Dorian* looks at the *Servants* or *Guests*, they will feel intimidated (implicit "social" gaze) and stop moving. The game challenges the players in forcing them to look at *Dorian* to select him and make him move, and risking the rest of the characters collecting a piece of his picture (*Figure 4.2*, A). Further, if the player looks at any of the other characters, only the unselected characters will move (*Figure 4.2*, B). This can become handy when avoiding the *Assassin*'s attacks.

4.2.2 Gaze Navigation: "Jekyll and Hyde"

In the second game, gaze is used for *Navigation*. Gaze is used to point at the direction of the characters' movement. However, the tension in the interaction context is articulated by biasing the mapping of the gaze point in the scene.

The game narrative is based on the story of *Dr Jekyll and Mr. Hyde* from *"Strange Case of Dr. Jekyll and Mr. Hyde"* by Robert Louis Stevenson [236]. In the story, *Dr. Jekyll* would transform into his alter ego *Mr Hyde* by drinking a special serum. In the game, *Dr Jekyll* managed to separate himself from *Mr Hyde*, but both need to drink a serum to keep it that way. However, the solution has a side effect, and *Mr Hyde* will only move when *Dr Jekyll* moves. The aim of the game is for each to collect their appropriate serum bottles: *Jekyll* the blue ones, and *Hyde* the green ones. They must not collect each others' bottles, or it would have deadly consequences. Moreover, if they touch each other, they will merge into one single person again and will be able to collect the bottles with mixed serum, blue and green (See *Figure 4.3*). Nevertheless, they can separate again by gathering the red serum bottle.

The player can control *Dr. Jekyll* and *Mr. Hyde* simultaneously with the Keyboard arrows. However, the experimental separation has a side effect and made them connected so *Hyde* will move *"through Jekyll's eyes"*. This means that *Hyde* will move when *Jekyll* moves towards the direction the second is looking at (see *Figure 4.4*). As a result, *Jekyll* turns into the centre of a Cartesian space for the movement of *Hyde* (in other words, a joystick controlled by gaze using *Jekyll* as the centre position [0,0]). For example, if *Jekyll* goes to the right, but the player is looking at the top-left of the character, *Hyde*

Figure 4.3: *"Jekyll and Hyde"* game scene. Players need to simultaneously move both Jekyll and Hyde for each to collect their corresponding bottles.

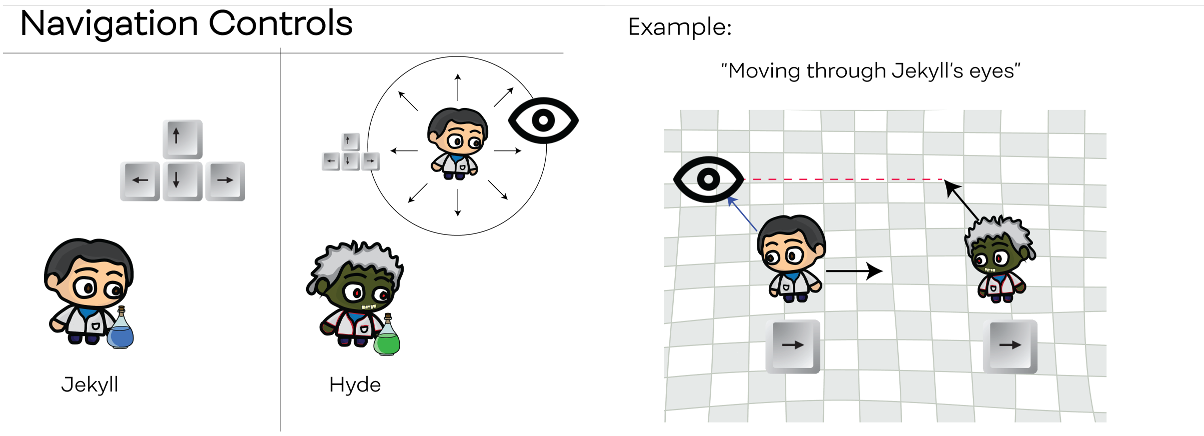


Figure 4.4: Biased Gaze Navigation in "*Jekyll and Hyde*" game. The direction of Hyde is determined by the position of the player's gaze in relation to Jekyll's position, who serves as the centre point of this invisible joystick.

will move towards his top-left. Further, if both characters merge and become a single character, gaze navigation has no bias, and the avatar will move towards the gaze point when the keys are pressed.

The game challenges the players to understand and work out the navigation mapping to move both characters at the same time without collecting the wrong serum. The gaze mapping is anti-intuitive, and some times the player might need to look towards the opposite direction the main character is moving.

4.2.3 Gaze Aiming: "The Witches"

In the last game, gaze is used for *Aiming and Shooting*. The hero witch character can shoot, and players need to look to where they want to point the attack. However, the tension in the interaction context is articulated by giving *Gaze Awareness* to the game opponents, thus spoiling the player intention and strategy.

The game story is based on both historical and fictional figures of the *Witches* during the *Witches Trials*. We set the game during a witch hunt in which a witch is going to be burned at stake. In the game, the player controls a *Witch* that needs to recruit other *Witches* in the forest to help a captive fellow *Witch* escape (see *Figure 4.5*). *Witches* need to be collected one by one and carried to the imprisoned *witch* in the centre of the scene. During the task, there are *Villagers* hunting for them and will kill them at contact; some wander around the scene, and others led by the *Priests* will try to burn the prisoner *witch*. The player needs to be quick, or the captive witch will die if five flames reach her.

The player can cast water spells, aimed by gaze, to extinct the flame keepers fire and make them run away (*Figure 4.6*, A). *Villagers* only need one hit to get scared, but the evil *Priests* keep a second flame with them and will need to be hit twice. However, magic always comes with a price. One of the *Villagers* can detect where magic is about to

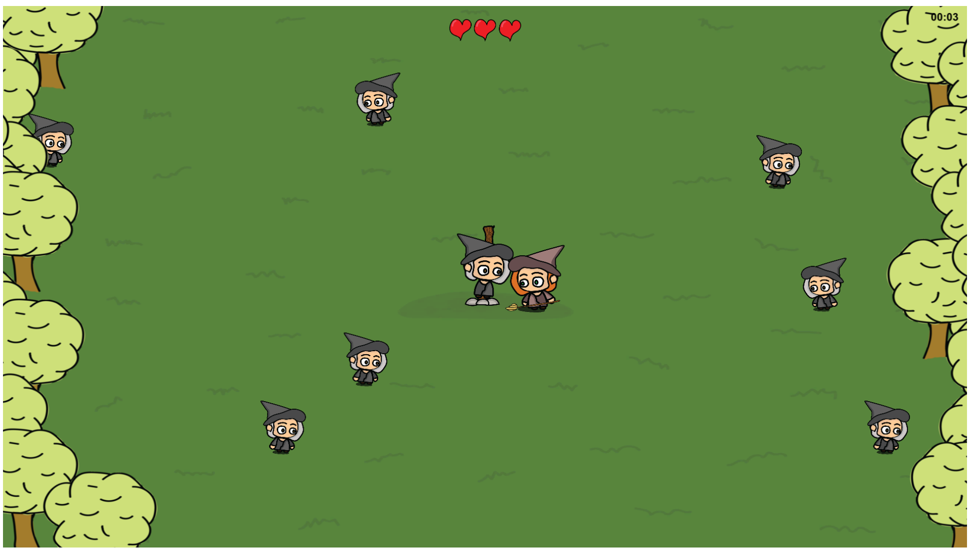


Figure 4.5: *"The Witches"* game scene. Players need to move the witch, so she recruits the other witches and help their trapped fellow witch escape.

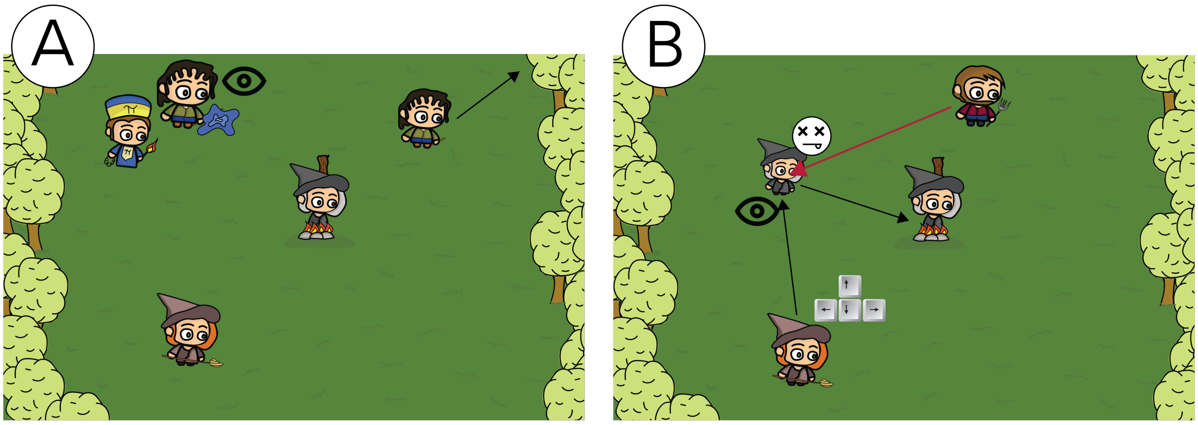


Figure 4.6: Rules for Gaze Aiming and Shooting in "*The Witches*" game. Gaze Aiming uses in The Witches' game. Players can cast the hero witch's water spells on the enemies they look at by pressing the space key to scare them away (A). However, magic comes with a price and enemies will always move towards the gaze point, killing any witch that they encounter on their way.

happen and will always move towards the point where the main *Witch* (player) is looking at and kill any witch he touches on his way, including the hero (*Figure 4.6*, B). Further, if the *Smart Villager* encounters other *Villagers* or *Priests*, they will join him, forming a big horde of people in search of the source of magic.

The game challenges the players to look at the scene to scan it while solving the task and aim at enemies to cast spells while avoiding giving up their strategy (*Figure 4.6*). When players want to collect a witch, they would naturally look at their target (Implicit Gaze). However, this will make the enemy go towards the targeted *witch* and kill her. Similarly, enemies can group when looking at them (to attack them) for too long, extending the area the horde of enemies covers, making the task more challenging.

4.2.4 Game Implementation

Twileyed was developed using Unity Game Engine in 2D, custom graphics and creative commons sounds. The game requires the use of a keyboard for game control, an eye tracker and uses Tobii Gaming SDK for Unity to enable gaze interaction. The calibration of the eye tracker is required before playing the game. The three games have infinite levels. Once the goal is achieved, the level number goes up, placing another set of collectable objects in new randomized locations.

4.3 Gameplay Evaluation

We invited 12 users to individually test the concept introduced in each of the games in *Twileyed*. We used a *TobiiEyeX* eye tracker under a 27" monitor (Resolution: 1920x1080; Aspect Ratio: 16:9) at 40cm from the user and a keyboard to play with the games.

In the session, we gathered participants demographics data, including close-ended questions about the frequency they played video games, type and mostly used device platform. Then, we asked participants to play each game freely for 15 minutes, but they could play longer if they wished to do so. At the start of each gameplay, we explained the instructions and story of the game and calibrated the eye tracker by using *Tobii*'s native application. After playing each game, participants were required to answer their level of agreement with three statements related to the increased tension of the interaction. These evaluated the level of challenge of the game; perceived competence; and willingness to play again (Q1: *"I felt challenged"*; Q2: *"I felt I did well"*; Q3: *"I would like to play again"*). Each statement was rated on a 5-point Likert scale (1 = "Not at all"; 2 = "Slightly"; 3 = "Moderately"; 4 = "Fairly"; 5 = "Extremely"). During the study session, we observed the participant playing and took notes of their game strategies, actions, and out-loud comments. Each session duration was around 1 hour.

Twelve volunteer participants played the three games. Players were aged 21-35, with a mean of 27 ± 4 years old. From the seven men and five women who volunteered, six wore glasses, six have had previous experience with eye tracking, and four were used to play video games regularly (between once a week and almost every day). See Appendix C for further details about participant demographics.

4.3.1 Player Experience

The evaluation of the player experience aimed to analyse the effect of the increased tension in the gaze interaction mechanic and verify we provided a well-designed gameplay experience, both challenging but enjoyable enough to generate interest to play again. *Figure 4.7* show the results from the evaluated statements, indicating that the three games were perceived as fairly to extremely challenging; most players did not (to moderate) feel competent at playing them, but overall seemed moderate to extremely keen to play again. These results suggest the gaze mechanics posed a big challenge but players were engaged

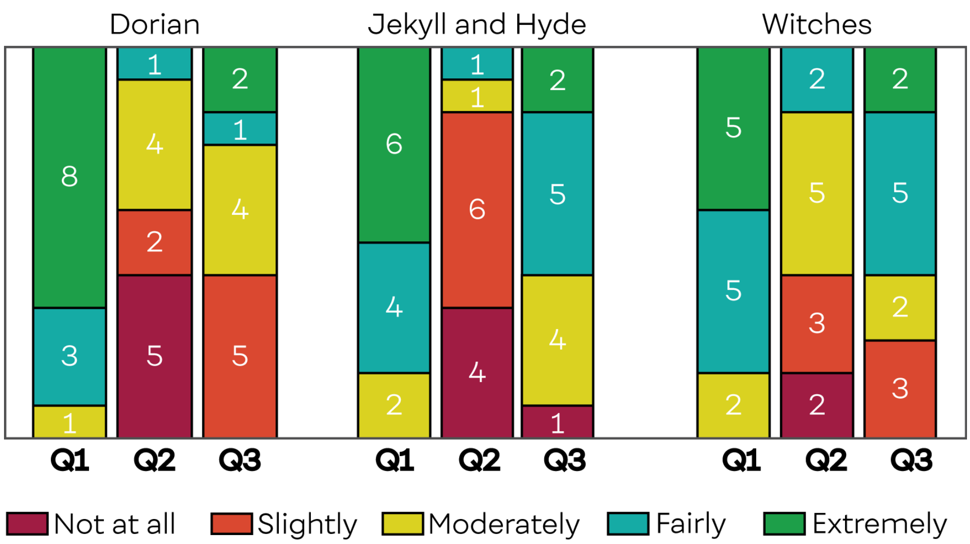


Figure 4.7: Player Experience Results for each game.

Table 4.1: Final codes' set for the thematic analysis of the gameplay experience notes.

Theme	Code Set Name	Data Units
1	*Trouble handling game events*	35
2	*Visual attention issues during the game*	21
	About looking away and not looking	13
3	*Learning to play and managing skills to succeed*	16
	Tactics and strategy development	11
4	*Interaction understanding, meaning and perception*	14
5	*Changing the game rules, twisting the game dynamics*	15
All	*The game experience: challenge, enjoyment and tension*	35
None	*Gameplay description*	35
	Other	21

during gameplay. Although the player experience results give an insight on how the players perceived the experience in terms of difficulty of the games, competence and enjoyment, the data does not provide a clear conclusion to be further discussed in the following sections.

4.3.2 Gameplay Thematic Analysis

We (the author of this thesis) performed a thematic analysis [23] of our gameplay observation notes. The format of the data units was of varying lengths (words, short sentences, and long paragraphs). They ranged from a literal description of the events narrating the order of actions the players followed to solve the game tasks; their reaction to the game events; the observer comments; summaries of the participants' observed strategies; and participants' out-loud quotes and opinion extracts. There were a total of 216 units. We examined the data to develop an initial set of 19 initial codes and grouped the instances in these codes. We refined them, discarding those with little repetition, and discussed within the research team the relevance of the rest, resulting in the creation of 10 themed set of codes based on their common patterns (see Table 4.1). Lastly, we developed a final set of 5 themes based on questions raised by each summarised set regarding the games' challenges, presented interaction concepts, and the mechanic outcomes.

4.4 Reflecting on Gaze Interactions

In this section, we present five themes unpacking questions on the player experience and interaction mechanics based on the gameplay experience observation notes. The themes might provide implications and a set of multiple dimensions for researchers to analyse gaze interactions in games. For each topic, we reflect and discuss how they resulted from the game, the questions that emerged and design implications aimed towards guiding the future directions of gaze-enabled games.

4.4.1 Theme 1: Attention to the Interaction

The games in *Twileyed* are challenging by design. The games aimed to create tension with gaze interaction mechanics. However, we observed how overcoming the interaction challenge inhibited the completion of the games' tasks. In a nutshell, the three games had a collection task set as the primary objective. Players needed to collect all the available objects in the game scene. However, at the same time, there could be other simultaneous events interrupting the primary objective. In *Dorian*'s game, the player faces a *Survival* task when the *Assassin* tries to kill the main character, and a *Prevention* task, to avoid that the other characters collect the objects in the scene. In *Jekyll*'s game, the player needs to prevent the characters from picking up each other's serums. Finally, in the *Witches*' game, attacks from the villagers carrying flames must be survived while stopping the opponents from killing the witches.

This simultaneous juggling of events is not a significant challenge because games usually integrate different parallel tasks during gameplay. For example, in an adventure game such as *The Shadow of the Tomb Raider* [172], *Lara Croft* might need to retrieve an artefact, but in the way, she might be attacked by enemies and need to deal with them first, interrupting the main task. However, this handling of two simultaneous tasks became a challenge in our games. The player is required to prioritise which task comes first while remembering the rules of gaze interaction in the game.

In *Dorian*'s game, we observed two strategies being adopted. The first was to focus on the selection paradigm, forgetting about the *Assassins*' attack, and thus failing when that happened. The second was to move away from the other characters and collect the objects without having to worry about them. Consequently, when the *Assassin* attacked, they had to rush, tried to move them by looking at them (as they did with *Dorian*, and their natural response to look at the character preceding their action), and thus not moving at all and failing. Does this mean we can either be attentive to the interaction or the task at the same time? One can say, the different interactions were anti-intuitive; you cannot require to select one character by gaze to move, but avoid looking at the other to do the same. In general, this might suggest gaze interaction must avoid using tension in interaction, or that when using tension, only one task should be presented.

One might disagree with that. If we think about playing *Flappy Bird* [186], the objective of the game is to make the bird flap upwards to navigate through pipes. When playing for the first time, nobody expects the bird to be affected by gravity and fall if we do not tap the phone screen immediately. The game could be quite addictive while creating tension. Now, let's reimagine it. If in a gaze-enabled version of *Flappy Bird* we need to (anti-intuitively) look up to go down, and down to go up when we tap, would the simple fact that we can be bad at it makes us want to play again and challenge ourselves? In the same way, the players in *Twileyed* were frustrated by the challenging interaction but wanted to keep playing and push themselves to try again.

If we look at the opposite side of tension and think about games that use gaze to support interaction, for example, in an action game [59] we need to decide whether one of the characters is good or bad to attack them. In the game, by just looking at the scene, we can tag them and know the information beforehand. Does this remove all challenge in the gameplay? Sometimes what is not intuitive but challenging can be fun and engaging. For example, in *Virus Hunt* [266] players could not look at the screen to remove the virus, or it would reproduce, creating tension with gaze interaction in a playful and fun way. In *Invisible Eni* [56], the user needs to close their eyes to make the character invisible and protect her from enemies. Not looking as an interaction with a technology that fosters looking seems thought-provoking. Therefore, we ask whether as gaze-enabled games designers, do we want to create engaging experiences even though they are challenging and affect the players' attention to both the game and the interaction? We propose and explore in upcoming chapters the design of challenging gaze-enabled games that play with different levels of tension in gaze interaction.

4.4.2 Theme 2: Visual Dilemmas

Similar to the attention to the game events, the players faced the challenge of dealing with attention dilemmas. When we look, we are limited to focus our visual attention to one object at a time. In games, this requires peripheral awareness to detect events that happen where we are not looking.

In *Twileyed*, the added tension in the interaction inevitably builds on creating an attention dilemma. When moving *Hyde "through Jekyll's eyes"*, we are making players look away from the character they are modulating motion with gaze, and thus keeping him in the player's visual periphery. Besides, when players look at Dorian to move, they cannot look at the other characters, and the same applies the other way round. This requires them necessitating to invigilate the other character always on their periphery. Lastly, in the Witches games, if the player looks at a witch while moving the main character to collect her, it would draw the attention of the villager. Therefore, the player needs to explicitly look away to prevent the enemies attack.

Some games build on attention dilemmas. In *Shynosaurs* [270] the players need to stop looking at the main task, to stare at the enemies to scare them away. However, while in *Shynosaurs*, the attention dilemma is based on the occurrence of two simultaneous events and the limitations of vision to look at two things at the same time. In a way, in *Twileyed*, we force the attention dilemma into the game dynamic by adding consequences to gaze interaction, and this makes players rely on their peripheral vision.

During the playing sessions, two participants referred to *having to balance how much they looked away from the screen and use their visual periphery* (Participant 1 and Participant 5, P1 and P5). This suggests, their visual attention was in their peripheral vision. However, relying on peripheral vision means they will see objects with poor acuity, blurry, and shape-distorted [10, 281]. Nevertheless, peripheral perception is essential in tasks like object detection [213]. Therefore, how could gaze interaction benefit from the capabilities of peripheral vision? In games, this capability has been used to display effects where we are not looking, in the visual periphery, to create scary immersive effects [108]. Moreover, the term *peripheral interaction* is used to describe those short interactions performed to something that is not in the focus of your attention [7]. Does this mean that by relying on the visual periphery, we are making the focus of the gaze interaction short? How can we leverage the abilities that we have in vision when the game does not allow us to look?

Peripheral awareness exists in games, but one might think it is passive, and it is only used to shift attention. For example, in *Shynosaurs* [270], the player needs to be aware that enemies are approaching to change their visual focus to deal with them. With *Twileyed*, we created a game that makes players necessitate to rely on peripheral vision and made focal interaction brief. In the *Witches'* game, the player is required to look away, where there is no game action until they have to scare an opponent away. Is, therefore, brief gaze interaction a new paradigm to consider? To what extent is peripheral vision an opportunity or a burden in interaction? *Virus Hunt* [266] is an example of gaze-enabled research game that engages peripheral vision in gameplay. The game challenges the players to leverage their perception abilities in the periphery of their vision to tap on objects in the game by using gaze aversion mechanics. These penalise the player when they look at the game objects. However, there are not enough examples to generalise how designers could use peripheral vision to create new gaze interaction paradigms beyond forbidding the player to look, and what new opportunities could be created for gaze-enabled games. We explore the active use of peripheral vision for gameplay in the next chapter.

4.4.3 Theme 3: Anti-intuitive Gaze Interactions

We reflected on the interaction dynamics created based on the feedback players gave on the game challenges. Overall, adding tension and anti-intuitiveness to the gaze interactions made the games difficult but engaging, and they encouraged players to play more. As discussed in previous themes, gaze can have creative uses that make the interaction challenging. In *Twileyed*, we used rules and consequences of using gaze interactions. In the design process, we decided that tension could be applied to add handicaps affecting how players use *Gaze Pointing*. We aimed to push players to think about how to use the interaction mechanic in a way that might not be immediately intuitive. We made the gaze interactions inherently difficult to make players experience complex character control by setting rules based on:

Imposition: When gaze is used for selection, the player can be forced or restricted to look at a specific element only. For example, in *Dorian*'s game, the player must either look at the avatar or avoid to look at them to move them. Therefore, although several elements might be available for selection, the rule limits it to one at a time.

Biased-Mapping: It is applied when gaze pointing is used to direct the avatar's motion. The logical relationship between the player's gaze position and the avatar's position in the game scene can be skewed or modified. For *Hyde*'s movement, we set the direction by gaze but translating its origin to *Jekyll*'s position. Other examples could repel the point where you look and move away from it; move towards the opposite side by mirroring directions, or moving the *Cartesian space* away from the avatar and introducing drifts on the mapping.

Spoiling: When the player uses gaze as a pointer for interaction, the players are giving away their strategy. Similarly, the game is aware of where the user is aiming with gaze and can use this information against them (e.g., placing enemies in their way (*Witches*); or even moving collectables away from where you look).

Looking back, some players reported to "*need time to develop the logic*" (P11) or thought the games were "*giving room to get more skilled if they played more*" (P2, P6, P12). They described while playing the mechanics to be "*anti-intuitive*" (P3) but "*interesting*" (P4), making them "*think a strategy*" (P3, P5) to perform something that a priori "*does not look that difficult*" (P8). Therefore, could tension and anti-intuitiveness be useful to design new playful gaze interactions?

We can see tension and anti-intuitiveness as a "*side effect*", or the secondary consequence, that happens by using gaze. Interaction with the eyes does usually help the player in the gameplay. However, what if gaze interaction had a price? Designers can add tension, the same way a reward is given. Maybe in a game using gaze interaction, the avatar can eat a berry that makes them intoxicated, and wherever they look is not where they are going when using gaze for navigation. Others, like in *The Royal Corgi* [271], might want to impose that you look at the character while you act as if avoiding to get caught and checking the other game characters are not looking at you.

We are not implying that gaze interaction needs to be challenging by design, but why would it not include side effects? The use of inaccuracies could serve as a source for design. We want to challenge the game design community to think about the possibilities that an inaccurate interaction could bring to the creation of creative games, as demonstrated with the game presented in this chapter.

4.4.4 Theme 4: The role of Metaphors

Gaze interaction is often presented as a feature that augments the controller [245], for example, to extend the game view; have a cleaner UI; to interact with game objects at gaze; dynamically adapt the scene light; or fire at gaze, among others. However, when you look at creative ways of using gaze, the interaction is described in a narrative and somewhat poetic way, introducing looks that intimidate [270], others could freeze [179], or even charm [40]. In *Watch Dogs 2* [253], for instance, one can "hack at gaze".

During gameplay, players referred to the use of gaze in the games, describing it as something "*necessary*" (P5); "*having a point*" (P3, P5); and even talking out loud about the interaction to say they needed to "*make eye contact*" (P11). This made us think about the meaning of gaze, and how storytelling and metaphors could create novel interactions with gaze. In the game stories, we set a narrative to justify the use of the different gaze interaction mechanics and to give them a context in the game. Our initial idea was to influence how players interact with the game contextualising it in the embedded story. We used the stories from fiction and metaphors as inspiration, and it was not our intention to give it meaning as such.

We can analyse one of the metaphors used in the games as "*Psychical*". They relate to phenomena that are inexplicable by natural laws and affect the characters' behaviour. For gaze interaction, it could be aiming magic with gaze but also leaving a trail that can be followed (in the *Witches* game). We can also consider a *"Symbiosis"* metaphor, to refer to two characters that can be connected making the actions of one affect the other. This sets a dualism between the characters' identities ("*Moving through Jekyll's eyes*"). On the other hand, we also used "*Social*" metaphors. They relate to society, character's hierarchy, personality, and social behaviour. For instance, the *narcissistic* behaviour of *Dorian* to require the player's attention to move. Other characters can get shy when the players look at them and do not move. The metaphors could also affect the "*Physicality*" of the character (physical body or representation). For instance, to create a *reaction* from *actions*, meaning that the action from one character will affect others.

We see the potential of creating compelling interactions by giving them a narrative or metaphor, especially when they have a social meaning. The eyes are part of social communication, and there are examples of social gaze in games [271]. In *The Royal Corgi* players need to be careful where they attend with gaze while conversing with the different characters, this could modulate the story by translating interest into social behaviours like being shy, daring, or even rude. If the eyes are used in the real world to show attention, why not use the same behaviour in the game world?

In mass-market games, gaze attention to the scene has not been explored much. In *Dying Light* [243], zombies would notice the players if they look at them. Similarly, in *Assassins' Creed* [254], passers-by will wave at the player's avatar when looked at. Considering *meaningful* gaze interactions as those which make sense to the user and are not arbitrary. What could designers do to introduce more meaningful uses of gaze in games for playful interactions?

If we follow on the use of metaphors, gaze signals attention, and the lack of it would accordingly, show disinterest. Could this social gaze metaphor fit in the game narrative? For example, in *Tomb Raider* [172], we can decide to talk to an NPC (Non-Player Character) during the game. You can move away from the NPCs, and they will continue talking. We could think of a new interaction like in *The Royal Corgi*, and make conversations evolve with gaze attention. However, what if the NPCs could have different personalities, and one, like *Dorian*, needs all eyes on him. Would the lack of eye contact make the character stop the conversation and angrily move away? Whether this would be compelling for players, is yet to be seen; however, as designers, we think there is potential on creating such grounded in the narrative interactions.

4.4.5 Theme 5: Gaze's Identity and Control

During the *Witches*' game gameplay, players pointed out how much they were enjoying being able to control the enemies and use them as their *"minions"* (P3, P4, P8, P11) to protect the captive witch. It was not what we intended when designing the game, but what happened is that the enemy would move towards the player's gaze point, and when colliding with other opponents, they would join him forming a group. This was first envisioned as a burden, the group of enemies would increase, making them bigger and becoming harder to avoid they caught a witch and kill her. Ironically, players turned this issue around into their favour, considering that in fact, they were controlling the enemy with gaze. However, gaze was supposed to control the powers of the witch. Therefore, this made us question who gaze is representing, and what is the identity of gaze.

We refer to the player gaze identity to what or which game element the user's eyes are related to and therefore it is used for interaction control. Traditionally in gaze interaction, the eyes could represent or adopt either the main character gaze or the users themselves. What this means is that where the user looks can be considered, correspondingly, where the character is looking at, or where the user is looking. Technically it is the same, but contextually in the game narrative, it is different. In a way, we could say that identity could be an iteration on the meaning of gaze in the game; however, we believe it is a topic for discussion alone.

In *Twileyed*, accidentally, we assigned double identities to gaze. When playing *Dorian*'s game, looking at *Dorian* is the user's attention, but when gaze selects the other characters, it is *Dorian* who looks at them and intimidates them. Accordingly, we believe the design of the game could have supported gaze identity to be the player and the avatar at the same time. *Jekyll* and *Hyde* were presented as the two characters of the game.

One can say that both are player's avatars, but also because the player can only move *Jekyll* and *Hyde* acts accordingly, *Hyde* could also be the avatar's *Companion* in the game. Then, if *Hyde* will move towards where *Jekyll* is looking, is gaze's identity *Jekyll*, *Hyde*, or both? It could be *Jekyll* by meaning and through the use of metaphors, but it could also be *Hyde* alone because it is he who gaze controls with a biased mapping. Therefore, does this design support the concept of a double identity? We could argue that it only does by definition of the metaphor, but if both characters merge and gaze pointing is used for navigation of the single avatar, is both of them then gaze's identity?

Finally, in the *Witches'* game, we allowed the control by gaze of the avatar powers and the enemy at the same time. Gaze belongs then to the *Avatar* and the *NPC* (Enemy) correspondingly. But what is "*Identity*"? In games research, identity refers to the user as the player, and the player as "*gamer*" [43]. Identity can also be a player-character relationship within the game [178], meaning that the player identity in the game is the *Avatar*. Generally, *Avatars* in games allow players to project their identity into the virtual world [52]. When customized, avatars can stimulate identification [18], but also a playful exploration of oneself identity [260], or experience gender identity swaps [105].

Moreover, identifying with an avatar, usually, through game controllers [178], can have a positive outcome on player experience and enjoyment [246]. For example, *Carter et al.* explored the effects of identity dissonance in games using voice interaction [26]. However, they differentiate between 4 identities, that may overlay and inform each other during gameplay [27]. They put forward: the user (the "real" person playing the game); the player (the social identity); the character (the identity within the game narrative); and the avatar (the character's virtual embodiment). In their example using voice interaction, through voice control in games, they could overlay the player and character identities.

Therefore, is gaze as a controller a bridge to facilitate identification with the avatar? If so, we could consider that in our game examples, there was an overlap between the player and the character identity. Thus gaze's identity that belongs to the user is mapped into the other two. Nevertheless, what is the rationale in a first camera perspective game? Is gaze identity mapped into the character, the avatar, or is it the player in an immersive context? The answer could have multiple interpretations. Overall, the gaze mechanics used introduced the possibility of the user's gaze to assume a dual identity during the games (Avatar and Player, Avatar and NPC), but they also enabled to control characters (e.g., NPCs) that were not possible to do so before, such as companions or enemies.

We can find a similar dynamic in *Brothers: A Tale of Two Sons* [238], a game that introduces two characters that need to be controlled at the same time with the two halves of the game controller. When looking at gaze interaction, *Far Cry 5* [255] introduces the feature "*Guns for hire*" which is used to show your allies where to move by pointing with gaze. This last short interaction faces the same dilemma for gaze's identity attribution, and overlays the character's avatar and the NPCs'. We could argue that in this case, like in spy-movies, the main character could signal with the eyes where to go, and thus gaze pointing belongs to them alone. However, by pointing with your eyes, you can make the others look at the same position.

Other research works related to gaze and identity have a focus on social presence. For instance, when the player's gaze point visualisation and the player's character (avatar) are present in the scene, the users might not be sure if in the game they are the character or the gaze visualisation [143]. Similarly, when a second user is present, gaze identity could not necessarily be related to the primary user and player but can represent this second spectator, allowing them to have a more active role within the game rather than being mere audience [159]. These examples investigated how different gaze point visualisations during the game may create an ambiguity of the player identity and perceived presence in the game. They relate to a non-diegetic identity of the game that is outside the game story and aligned with conversations about gameplay and control. Here, we discuss the diegetic identity of the players' gaze within the gameplay narrative. We encourage designers to explore the topic of gaze identity to create rich gaze interactions based on the attention to the game scene. Accordingly, we see the potential to study player-avatar identity when using gaze interaction.

4.5 Conclusion

In this chapter, we presented a conversation starter. We discussed the questions and outcomes constructed upon reflection on our game design. The reader can consider this contribution as an opinion, a provocation, or an invitation to think about topics that are not usually discussed within the gaze-in-games community.

Research contributions on gaze interaction for gameplay are populated with user studies to evaluate a novel interaction mechanic and describe their implications for design. To find conversations on the broader opportunities to design with gaze, we need to refer to research surveys and taxonomies, such as *EyePlay* [263]. Although their approach is to look at gaze interaction from a technical perspective based on how gaze interaction maps traditional game controls, we are not arguing their validity as it has patently contributed to the emergence of novel and playful gaze mechanics. However, we are taking a stand to suggest that other dimensions of gaze gameplay design should be discussed, and probably considered when adopting gaze-based interactions in game. Briefly, we summarise the themes discussed:

- Theme 1: Attention to the Interaction. How can tension be balanced to create novel interaction experiences? To what extent is tension playful or inhibits attention to the game tasks?
- Theme 2: Visual Dilemmas. How can designers leverage peripheral vision to augment gaze interaction paradigms in gameplay? What new opportunities can offer to gaze-enabled games by designing gaze interaction with peripheral vision in mind?
- Theme 3: Anti-intuitive Gaze Interactions. Playing with tension, gaze side effects and anti-intuitiveness as a design space in gaze-enabled gameplay.
- Theme 4: The role of Metaphors. What is the influence of the "Meaning" of the gaze mechanic in gaze-based interaction? What other metaphors can be used to inspire, contextualize or augment gaze interaction in future designs? Can designers create new game opportunities by using metaphors of gaze and sight?
- Theme 5: Gaze's Identity and Control. Who is Gaze's Identity? What can gaze interaction bring to player's identity conversations? To what extent modeling Gaze's Identity and attention can create new paradigms with gaze interaction?

Overall, this chapter offers a different perspective to look at gaze interaction in games design based on gaze behaviour but proposing more questions than answers. In doing so, we contribute to starting a conversation, and we hope to inspire new ones by reflecting on current gaze mechanics in game design practice. Some of the concepts discussed are further explored in the following chapters; however, readers can consider them suggested topics that need to be addressed or discussed within the broader gaze-in-games community. We describe opportunities emerging from adding tension to the interaction by thinking outside the box of gaze input that could contribute to gaze interaction design.

5 Playing with Peripheral Vision

Intuitively, gaze input is a compelling tool for interaction because we naturally look at the objects we want to interact with. Accordingly, the design of techniques has focused on gaze pointing, for the acquisition of targets [118], or implicit indication of objects of interest [234]. In this chapter, we consider quite the opposite: we propose novel gaze interactions and game dynamics based on *Gaze Aversion*, objects of interest that players must *not* look at to pose tasks players must accomplish with *peripheral vision*. The previous chapter identified peripheral vision as a potential opportunity for gaze interaction in games. Moreover, *gaze aversion* and *peripheral vision* contribute to continuing studying different forms of *tension* (from the previous chapter) as players must rely on what they cannot directly look at. Here, we explore the concept of *playing with peripheral vision* based on three fundamental questions:

- Can Gaze Aversion create game experiences in peripheral vision that are engaging and fun?
- Is it possible to succeed with gameplay in the visual periphery and develop strategies to overcome the challenge?
- What are the benefits of playing with the periphery? Can players experience the development of their visual abilities for object detection?

We describe the game *SuperVision*, a collection of three games that require the active use of peripheral vision to solve perception and mouse manipulation tasks. In this chapter, we present a conceptual framework for playing with peripheral vision that inspired the games. We investigate with SuperVision whether players can complete the game. Moreover, we test for peripheral vision's skill development to study the benefits and potential of designing this kind of game mechanics for gaze interaction.

5.1 Interaction in the Visual Periphery

The role of peripheral vision is to process the wider visual field preattentively (i.e., without eye movement) as the basis for directing attention and eye movement to events that draw attention and relate to our goals. Many games involve the inherent challenge of maintaining peripheral awareness of "the bigger picture" while focussing on one object or character at a time. Peripheral awareness is an essential skill in many sports as players need to focus on their objective but also keep an eye the surrounding opponents, and it can be trained [285, 130].

The game *Shynosaurs* [270] is a specific example of a game that challenges players' vision by presenting tasks that are competing for visual attention. At any time, a player can only focus on one of the tasks: either moving *'cuties'* to safety or stopping *'shynosaurs'* by staring them down. While players focus their gaze on one task, they rely on peripheral vision to notice other events (e.g., more *'shynosaurs'* appearing from the woods). In contrast, in the work we present, players must use their peripheral vision not only for awareness but actual manipulation of objects and completion of tasks.

Peripheral vision is generally considered for the display of information that can be detected without prior focus, in games [83] and other areas of HCI. For example, deliver notifications without disrupting the main task in focus [123], e.g., keeping the eyes on the road while driving [92]. *Luyten et al.* proposed a near-eye display for presentation of peripheral information that is positioned relative to the user's eyes such that it is impossible to focus on it [153]. This relates in an interesting way to our work as it also enforces reliance on peripheral vision.

Peripheral Interaction has also emerged as an area of HCI research concerned with tasks that can be handled in the periphery, in the sense of not requiring much conscious attention [8], and not disrupting a primary task [91]. In contrast, the games we propose involve deliberate and prolonged interaction with tasks presented in the visual periphery.

5.1.1 Engaging Peripheral Awareness with Gaze Aversion

Gaze interfaces are usually concerned with where users look, although it can be equally relevant to detect when they are not looking. For instance, to interpret manual input differently depending on whether it concurs with visual attention [197, 224]. To require players to necessitate to use their visual periphery for interaction actively, we need to ensure they cannot directly look at objects of interest. In this chapter, we rely on gaze aversion mechanics that penalise the player when they look at game objects, thus "looking away" is not merely detected but required for successful gameplay.

In psychology and behavioural studies, "not looking" is considered as an action that can be related to social factors such as fear [221], or as a mechanism to manage cognitive load [47]. However, our approach is based on the shift of the visual focus as a perception tool. The proposed dynamic is based on inhibitory control of visual attention, i.e., the fundamental human ability to look away and resist a reflexive urge to look. In psychology, this is related to study paradigms such as the anti-saccade task [176], which requires the participant to look away from the presented stimuli.

There are prior examples of games forcing players to not look at game elements by penalising them, known as gaze aversion mechanics. In the *Slender Man*, though not based on eye tracking, the user needs to turn away when they glimpse the adversary, or it will have fatal consequences. In the game *Virus Hunt* [266] looking at viruses spurs their growth, and therefore they must not be looked at to be successful. A variety of attention training games [33] have been proposed that include inhibition tasks training users' ability to resist "automatic" attention to particular events: they must not look at them. In this chapter, gaze aversion serves the purpose of moving game interaction into the visual periphery. Users must not only avoid looking at certain game elements but are challenged to complete tasks with peripheral vision.

5.2 Designing Play in Peripheral Vision

We propose *playing with peripheral vision*, to create a new type of game experience. Our concept is based on understanding human peripheral vision to provide a framework for the design of games that challenge peripheral awareness.

The human visual field covers approximately 135 degrees vertically and 210 degrees horizontally, of which the foveal region of highest visual acuity is limited to only around 2 degrees at the centre (with up to 5 degrees considered as parafoveal) [87]. Outside the foveal region, visual acuity drops sharply, but peripheral vision plays a key role in situational awareness and preattentive attention to features that visually pop out [19, 213, 87]. As peripheral vision has limited acuity, objects seen outside of the foveal region might be perceived as smaller, distorted, blurrier, and more compressed [10]. This effect can be experienced even if we know what the object in the periphery is, or see an identical object in our foveal vision [195]. Peripheral vision is also limited to the number of objects that can be perceived without eye movement, and visual crowding can inhibit object detection [281].

Based on these insights, we put forward a framework to guide the design of peripheral vision games. We propose to use *Visual Challenges* to explore vision capabilities, and to create *Tasks* that players must accomplish, thus putting visual perception to the test. A *Rule* is needed to enforce that only peripheral vision is involved during the task-solving, and *Metaphors* are required to explain and forge the *Rule* with each *Task* and *Challenge*. This framework is as follows:

- **Tasks:** Aims or objectives of the game regarding:
  - *Decision-making:* Objects need to be assessed in the periphery for later interaction based on different challenges and rules.
  - *Interaction:* Objects need to be explicitly manipulated (e.g., mouse clicks or hovers, aim by gaze) either in the periphery or the focus point. Inherently, different input modalities other than gaze must be used if the interaction occurs in the periphery, which may introduce a challenging hand-eye coordination.

- **Visual Challenges:** Exploiting visual theory and perceptual capabilities to differentiate objects based on:
  - *Colour.* Objects that have distinct colours, e.g. bright and vibrant, against an obscured one, or with overlaid information.
  - *Size.* Objects that can be identified because they are different in size, e.g. a larger one from a smaller one.
  - *Focus blindness.* Detection of objects that appear in the focus of our vision when the visual attention is on peripheral vision during the task, e.g. assessing other objects.
- **Rule:** "Objects must not be looked at". This rule is supported by the use of the Gaze Aversion mechanic. The rule is used to move the interaction to the periphery through the following strategies:
  - *Reaction:* Moving objects away from the focus to make it mechanically impossible to interact with them. For instance, when looking at an object, this changes position.
  - *Negative effects:* Crowding of the visual area to lower perceptual capabilities, e.g. fixing the position of the object permanently to make the scene *"noisy"*.
  - *Penalization:* Life losses when the rule is not followed, e.g. looking at objects.
- **Metaphors:** The narrative technique and storytelling to frame the rules with the tasks and challenges. For instance, *Looks that turn into stone*, *looks that kill* or *what you look is what you will ever look*.

5.2.1 Game Design Process

To address the conceptual framework of *playing with peripheral vision* in the game design process, we focused on the concept of "rules". *Gaze aversion* set the theoretical ground that would influence the other dimension of the game (tasks and visual challenges). First, we reviewed the literature on gaze-enabled games that posed similar challenges requiring to look away or not look at objects of interest, e.g., gaze penalisation [266].

We looked for potential cultural metaphors during game ideation and brainstorming that could inspire and contextualise the concept of *gaze aversion*. We set the term"harmful gaze" as our criterion and look for stories and characters that required gaze awareness and/or were able to trigger a penalising effect just by looking or being looked. We found a wide variety of examples, from superheroes (X-Men's Cyclops) to Mythology characters (Medusa, the Basilisk, Narcissus) and fictional or popular culture characters (the Slender Man, the Weeping Angels). We used every character's gaze challenge to sketch different game scenarios that included the targeted *tasks*. As ideas emerged, we filtered them and focused on only three characters (Cyclops, Medusa, and Narcissus) to develop our game prototype.

Figure 5.1: *SuperVision*'s game main title scene. Players need to look at the character they want to select and click the 'play' button without looking at it, or it will move away.

5.3 Game: SuperVision

We designed and developed the game "*SuperVision: Adventurous internships on the periphery*" including 3 mini-game examples. Each mini-game presents characters and *metaphors* from literature and pop culture that experience a gaze challenge (influencing the way they look), and require the use of peripheral vision. In the game, players assume the characters' gaze hurdles and their given tasks. Gameplay videos available in Appendix B.

In each game, the players' *challenge* is to understand the game objects that appear in the scenario while keeping their eyes away from looking directly at them. Given that our eyes are attracted to objects that pop up, it is difficult for players to keep their gaze away and play the game successfully. This *rule* creates a challenging experience. Players need to handle the constant stream of game objects that appear. Their *task* is to carefully identify and decide how to manipulate with the mouse the objects, without looking directly at them, and only being able to see them in their peripheral field of view.

The mouse is augmented with the drawing of the tool relevant to each game so that it can be identified in the periphery. The gaze focus is defined in a 90x90 pixels (around 4 degrees of visual angle) box, not visible to the player.

5.3.1 Introducing SuperVision

In the game's title scene, players are invited to select the game they want to play by looking at one of the game characters associated with each mini-game (See *Figure* 5.1). This interaction aims at demonstrating to the player that the game is gaze aware. Further instructions can be extended by clicking on the plus signs next to each character.

Moreover, players need to click on the play button (size: 330x110 pixels) to start the game. When the mouse hovers the button, it is highlighted and has sound feedback. However, if players look at the button, it moves to the other side of the screen (*Rule*

Reaction). This way, players need to click on the play button without looking directly at it (*Interaction Task*), thus relying on peripheral vision. We introduced this interaction challenge being inspired by *Dark Rides* design. A typical dark ride uses light-controlled passages to leave reality behind and transport riders to a different world [280]. Accordingly, we aimed to introduce the games' concept in *SuperVision* before playing them. We intended to break traditional gaze interaction from the start, to teach how to play with the periphery.

For each game, we introduced different interaction modalities with the mouse and visual perception challenges. We wanted to explore how well we can perceive differences between objects in our periphery; how well can we act on them without looking directly; and how well we can control our gaze behaviour. Moreover, each game is spanned across 12 levels of ascending difficulty. The level goes up after ten elements have been correctly assessed. Players are provided with five lives that can be lost by making tasks mistakes or when the rule is neglected. If a life is lost, the game carries on until no lives are left.

5.3.2 Colour: *"The Cyclops in a Balloons' adventure"*

The Cyclops is a character from pop culture and the X-Men comic books published by Marvel Comics [147]. The Cyclops is a mutant who can release an energy beam from his eyes. In the context of the game, he cannot control his power, causing the destruction of anything he looks at directly (*Metaphor*). The Cyclops *challenge* is to watch over colored hot air balloons traffic flow (see *Figure* 5.2). There are good balloons (*red, blue, green or multi-colored*) and bad balloons (*Pirates*), which can be either *black-and-white* or camouflaged as good balloons but with a *skull* symbol (appearing from level 3). Balloons can be affected by air pollution, appearing with fog around them (all of the balloons, except the camouflaged ones, from level 4 onwards). See *Figure* 5.3 for visual details.

The game *task* is to move the balloons (size: 190x290 pixels) by guiding them while they fly from a randomized point on the x-axis, so they enter their colour-related gate without staring at them. To move good balloons, players need to push them with the

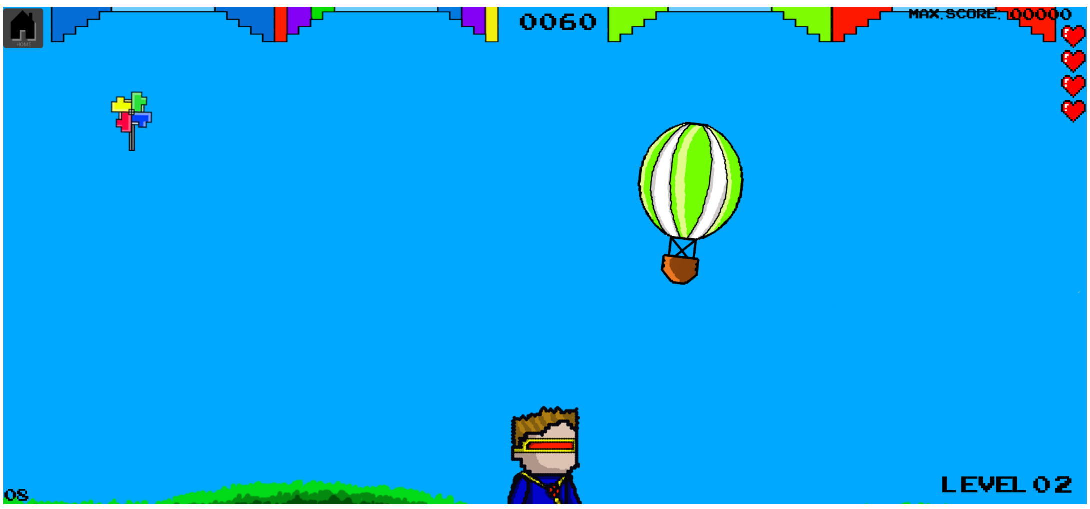


Figure 5.2: *SuperVision*'s Cyclops' game scene.

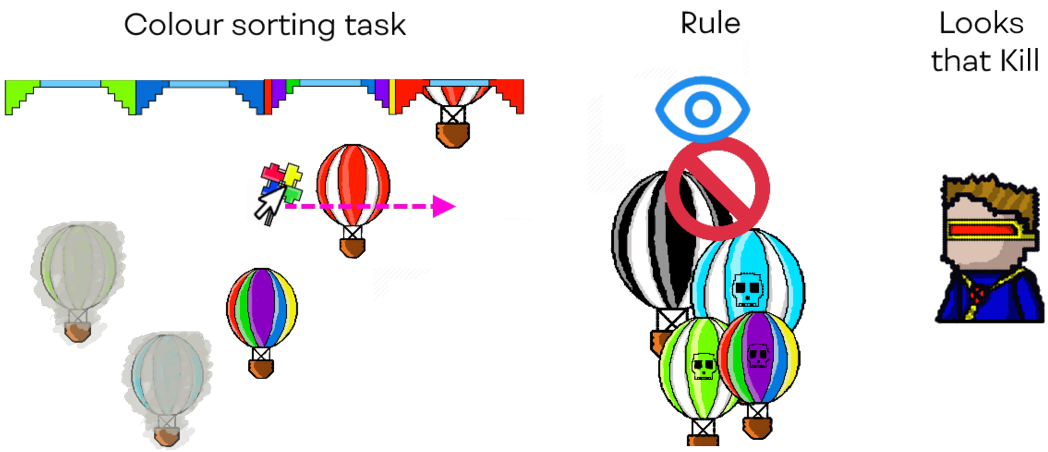


Figure 5.3: Instructions Overview: Cyclops' Game. Players need to 'push' with the fan attached to the mouse all the balloons to their corresponding coloured door. Balloons can have multiple colours or be distorted by pollution clouds (Colour sorting task). However, players need to be careful not to let pirate balloons pass (Rule), but they can look at them to make them fall (Looks that kill).

colorful *fan* (on the mouse), moving it towards the desired direction (sideways) - see *Figure* 5.3. Failing to guide the balloons correctly will cause a game life loss. Players need to correctly direct the good balloons while keeping an eye on the bad ones and do not allow them through. If the player looks at the good balloons, they will pop and fall, besides losing a game life (*Rule Penalization*). However, players can look at the Pirates balloons to make them pop and fall too, so they do not pass. The balloons gates change positions every three levels, and the balloons flying speed increases slightly after every level.

The Cyclops game aims to explore the role of colour and colour differences in peripheral vision. It uses different colours, including colours with a subtle variation (skull) or colours that are less vivid (polluted). Moreover, players need to push the targets with the mouse without much precision required. When the fan collides with the balloon, it is moved away from the fan.

5.3.3 Size: *"Medusa and the mushrooms' attack"*

Medusa is a character from Greek mythology [85]. With a head full of snakes for hair and a half-human half serpent body, Medusa was known to be able to turn anything and anyone into stone by just looking at them (*Metaphor*).

Medusa's *task* is to remove mushrooms from a garden (see *Figure* 5.4). The game *challenge* is to solve this manipulation challenge without looking at the mushrooms and clicking on them in descending size order to remove them, from the biggest to the smallest one. Failing to perform the task in the correct order will make extra mushrooms appear (1 to 3, chosen randomly) scattered around the parcel (scene). This will modify the order (by size) the mushrooms need to be removed, as well as causing a life loss (*Rule Penalization*). As a consequence, the screen will get more crowded. Moreover, if the

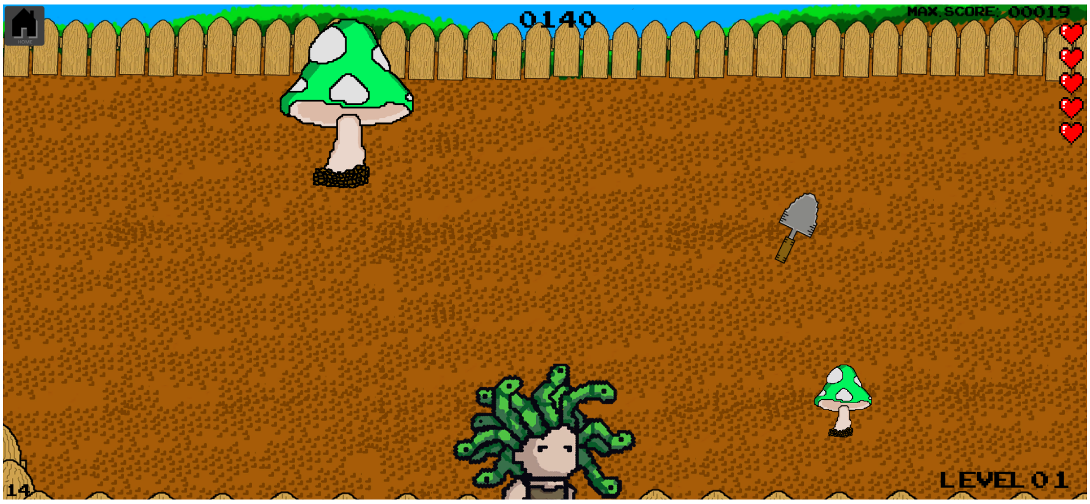


Figure 5.4: *SuperVision*'s Medusa's game scene.

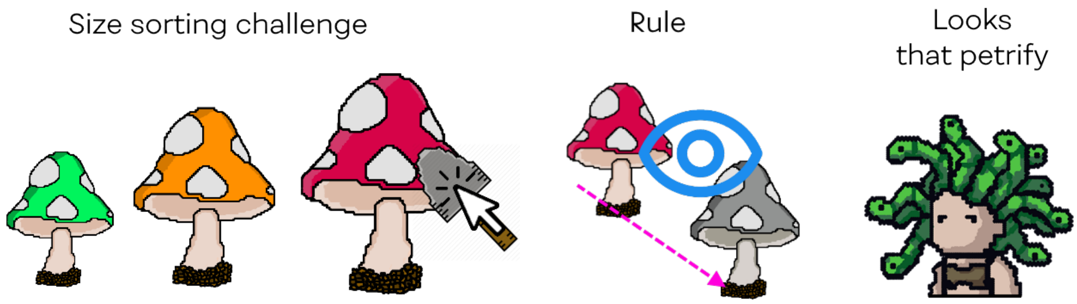


Figure 5.5: Instructions Overview: Medusa's Game. Players need to click on the mushrooms from the biggest fungus to the smallest one (sorting challenge). However, if they look at them, they will turn into stone and crowd the scene (Rule, Looks that petrify).

player looks at a mushroom, it turns into stone and cannot be removed, losing a game life, and also contributing to crowding the game scene (*Rule Negative effect*). These require players to increase their focus on the task as it is harder to identify objects in a cluttered scenario (experiencing the *crowding* effect in their peripheral vision [213]). See *Figure* 5.5 for visual details.

Medusa's game aims to explore the role of targets' size in the periphery of vision. Every pair or group of mushrooms have a size difference of 50% between them, and it decreases gradually towards 10% difference after each level. Moreover, mushrooms can be of different colours. This adds challenge to the task by reducing the contrast between the colour of the background and the mushrooms.

5.3.4 Focus blindness: *"Narcissus and the cursed frames"*

Narcissus is another character from Greek mythology. He was known to be a very handsome man that could make anyone fall in love with him with just a glance from him. The

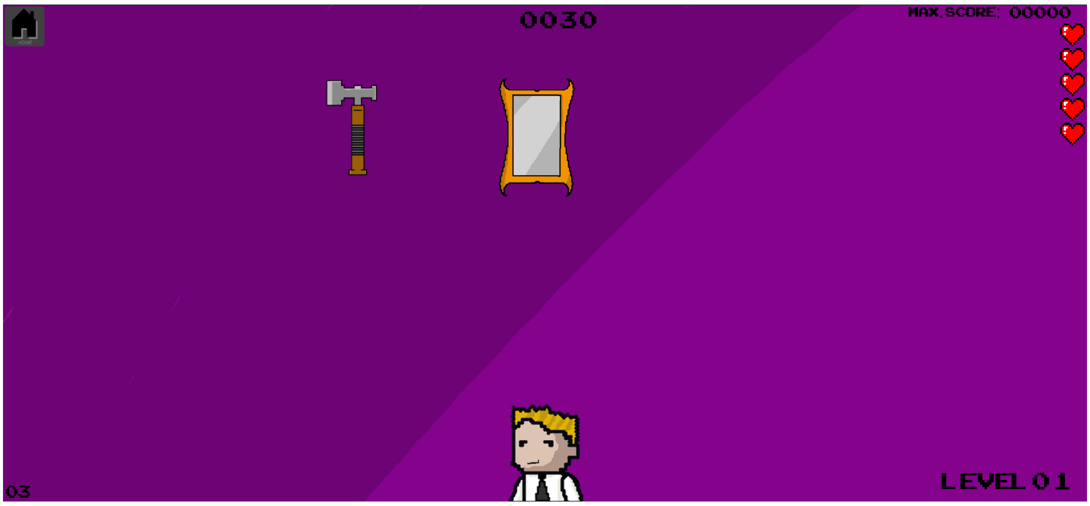


Figure 5.6: *SuperVision*'s Narcissus' game scene.

nymph Echo fell for him, but he continually ignored her, until she *died of love* and turned in what it is known as the echo. As a consequence, the goddess of 'Love', Aphrodite cursed Narcissus with the following warning. If he ever sees his reflection, he will fall in love with himself and be doomed to look at himself for eternity [85] (*Metaphor*).

Narcissus' game is inspired by the game *Fruit Ninja* [88]. Players need to act as Narcissus and help to control the production of frames. During the game, both frames and mirrors (frames with a defect) are continually thrown in random orbital movements from the bottom of the screen, and a randomised position on the x-axis. Only one frame/mirror (size: 145x220 pixels) is released at a time, but the spawning speed increases at every level from 2 seconds to 0.5 seconds. Beyond level 6, two elements are randomly thrown at a time. Frames and mirrors can be either red, blue or orange, and the colour is randomised during the gameplay.

The game's *task* is to control that only frames pass. When a mirror appears, players need to break it with the hammer (size: 100x180 pixels, on the mouse) by hovering it. If a frame is accidentally broken, a game life is lost (*Rule Penalization*). The *challenge* is to classify the frames and the mirrors while trying not to look at any of them. If players look at frames, they will fall in love with them and crowd the screen (*Rule Negative effect*), creating a peripheral *crowding* effect [213]. If a mirror is looked at, Aphrodite's curse will become true, and the mirror will be stuck on the player's gaze point, crowding the gaze focus (*Rule Negative effect*). See *Figure* 5.7 for visual details.

Moreover, while solving the game *task* in the periphery, messages of love from the nymph Echo in the shape of purple hearts (size: 50x40 pixels) will randomly appear around the player's gaze (in a radius of 50 pixels, every 30 to 50 seconds). Players need to click on Echo's hearts to collect them and win extra points. Narcissus' game aims to explore what happens to perception in the gaze focus when the attention is on the periphery. We hypothesise that while players are solving the peripheral task (sorting frames and mirrors), there is a *focus blindness*, and anything appearing in focus will be ignored.

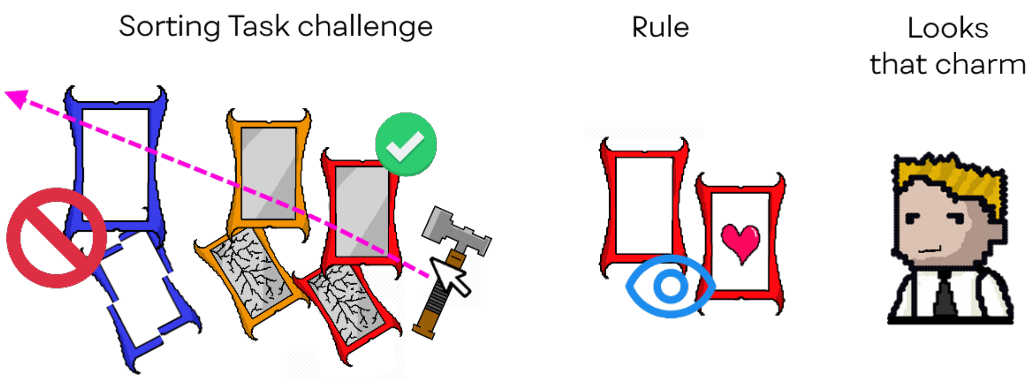


Figure 5.7: Instructions Overview: Narcissus's Game. Players need to hover mirrors to break them. However, they must avoid breaking frames (sorting challenge). However, players need to be careful not to look at any of them. When looking at frames, they will fall in love with Narcissus and crowd the scene. When looking at a mirror, Narcissus will fall in love with his reflection and be doomed to look at yourself for eternity (Looks that charm). This will cause mirrors to get stuck to the gaze point and crowd the visual focus.

5.3.5 Game Implementation

SuperVision was developed using Unity Game Engine in 2D, custom graphics and creative commons sounds. The game requires the use of an eye tracker and uses Tobii Gaming SDK for Unity to enable gaze interaction. The calibration of the eye tracker is needed before playing the game.

5.4 Evaluation

To evaluate the game experience and the potential for skill development, we conducted two user studies. First, we evaluated *SuperVision*'s gameplay experience. Moreover, we performed visual tests to study the effect of playing the game in skill development of visual periphery abilities. Further, we carried out an ad-hoc behavioral analysis during gameplay, using gaze heatmaps. Finally, in a follow-up user study, we tested the influence of playing over time.

5.4.1 Apparatus

To conduct both user studies, we used a *Tobii EyeX* eye tracker under a 27" monitor (Resolution: 1920x1080; Aspect Ratio: 16:9) at 40cm from the user.

Participants played the game sitting in a custom-made booth with a covered ceiling (see *Figure* 5.8). The booth aimed at blocking the participants' field of view so that no visual distractions could happen during the study.

Moreover, we built a 180° cardboard Visual protractor with a 30 centimetres radius and a centre nose hole. A protractor is an instrument for measuring angles, in the form of a flat semicircle (see *Figure* 5.9), used to test and measure peripheral vision [24, 17]. A visual protractor is traditionally employed in visual perception research to determine where in the users' visual field, the stimuli are going to be placed [244, 206]. We aimed to use the DIY protractor to test participants' peripheral vision capabilities before and after playing the game, to check whether visual periphery skills development occurs.

5.4.2 Methodology

To assess the game experience of the game, we used the *Game Experience Questionnaire* (GEQ) [107]. We used the short version of the GEQ, comprised of 14 items combining game-related statements that need to be rated on a 5-point Likert scale (0 = 'not at all', 1 = 'slightly', 2 = 'moderately', 3 = 'fairly', 4 = 'extremely'). GEQ is categorised and averaged into seven experiential game measures, which are: Competence, Sensory and Imaginative Immersion, Flow, Tension, Challenge, Negative Affect, and Positive Affect. Competence refers to the ability to do something successfully or efficiently. Immersion can be defined as the extent of deep but effortless involvement and reduced concern for the sense of time [242]. On the other hand, Flow is defined as the state of enjoyment in which players are completely absorbed in the gameplay [242]. Tension is related to the experienced annoyance or frustration. Challenge is attributed to the mental or physical effort needed to succeed in the game. Affect refers to the difference that playing the game made in pleasantness (Positive) or boredom (Negative). Positive affect, Competence, Challenge, and Tension are part of the Enjoyment dimension, whereas Negative affect, Flow and Immersion relate to game Engagement [71].

Moreover, in addition to the GEQ, we added four extra statements to measure how easy it was to adapt to the proposed challenge of not looking (Easiness), and how eager they would be to play again (Repeatability). The statements are *"I felt difficult not to look"*, and *"I felt the game was easy"* for Easiness; *"I felt I would like to play this game again"* and *"I enjoyed playing with my eyes"* for Repeatability.

We also used a custom-made questionnaire to ask about participant's game prefer-

Figure 5.8: Sketch of the user study set up. Participants sat in front of the screen inside a custom-build booth blocking their visual field to avoid distractions.

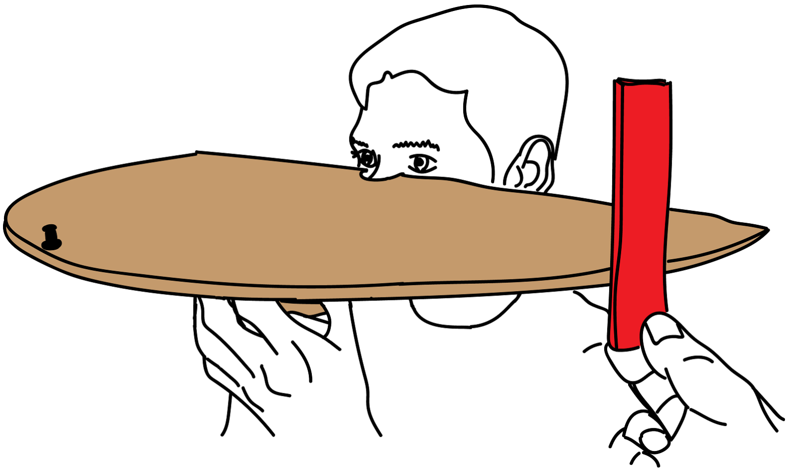


Figure 5.9: Sketch of the peripheral vision test performed with the DIY cardboard protractor and the coloured visual cues. Participants had to hold the protractor looking at the black pin in front of them while the experimenter moved a visual cue from the edge. Participants were asked to indicate out loud when they could determine the colour of the cue they saw in their peripheral vision.

ences. The questionnaire asks users to choose which game was the easiest; the hardest; the one they enjoyed the most; the one they would like to play again; the game concept they like the most; the game concept they disliked the most; and the game they were not interested in playing again. Answers were closed to: None of them, Cyclops, Medusa, Narcissus or All of them. Finally, the questionnaire asks participants to rate *SuperVision* from 1 to 10, and to provide any comments they would like to share optionally.

To perform the visual test, the protractor needs to be held up horizontally to the subject's face with their nose in the nose hole. Participants are asked to keep their gaze on the black push-pin located in front of them at the edge of the protractor. While the participant focuses on the push-pin, the researcher holds a cardboard strip against the outer edge of the protractor on either side (see *Figure*5.9). Then they will move it slowly and evenly along the curved edge towards the middle. Participants are asked to tell the researcher to stop the movement when they can see the strip in their periphery, and the distance is recorded (in degrees) after the participants guess which colour is it or what is it drawn on it.

In the periphery visual test, we used different cardboard strips. They could feature three different colours (red, green, blue); and drawn in them, three possible numbers (1, 2 or 3), three letters (A, B or C) or three shapes (circle, square, triangle). During the game playing, we saved the participants' gaze position data on the screen and the main game's events.

5.4.3 Procedure

In the user study, we asked the participants to fill in a demographics questionnaire. It included close-ended questions about how frequent they play video games, cycle, drive or play any sports, to understand how trained their vision is. Then, participants performed the protractor test. The order of coloured cardboards and eye side (left or right) were randomized. For each colour and side, every extra feature was asked to participants only once (either letter, number or shape related to one of the colours).

After the visual test, we calibrated the eye tracker for the individual participant, using Tobii's native application. We controlled the accuracy of the calibration using the same app before playing each game for 5 minutes. They played, on average, between 3 and 6 times. Participants were invited to continue playing for longer if they wished. The order of games was counterbalanced. After playing each game, participants were asked to fill in a GEQ. Subsequently, they played the next game.

In the end, we asked participants to rate the games and choose which one they preferred. The session was concluded with the repetition of the visual test, using another randomized order to display the visual cues. Finally, they were invited to share their thoughts about the quality of the games and the concept. The study duration was around 40 minutes.

Participants were invited to a follow-up study. They were required to play the three games for at least 15 minutes (5 minutes each) every day for two consecutive weeks, excluding weekends. On both Mondays, they were asked to perform the visual protractor test before playing, whereas the test was performed after the gameplay on Fridays.

5.4.4 Participants

Twenty-four volunteer participants took part in the first user study (10 wearing glasses). Thirteen men, ten women, and one undisclosed gender person participated in individual studies. Nine of them had used an eye tracker before (six considered themselves experienced). Players were aged 20-39, with a mean of 27 $\pm$ 4 years old. Eleven participants indicated being used to play games regularly (between once a week and almost every day) during two hours or more, mainly First or Third-person shooter, action and Real-Time games for PC. The rest of the participants (13) indicated playing sporadically to puzzle games on their phone.

Twelve participants indicated playing sports regularly (2 to 5 times a week) for at least one hour. Only two participants reported to cycle or ride a motorbike for less than 1 hour between 2 and 3 times a week. Finally, seven participants reported driving almost every day for 1 hour or more.

Five participants took part in the follow-up study. Four men and one woman, with a mean age of 27 $\pm$ 4 years old. See Appendix C for further details about participant demographics.

5.5 Results

5.5.1 Player Experience

The player experience was measured using seven scales from the Game Experience Questionnaire (GEQ) and two custom made. They measured the enjoyment, the engagement, the repeatability, and the easiness of the game concept.

Figure 5.10 indicates that participants found the games enjoyable. They reported feeling slightly to moderately successful and competent, and fairly to extremely challenged. All of the games were considered to be slightly frustrating (slight tension) due to the unnaturalness of the game challenge, but pleasant and enjoyable. The Cyclops' game was informed to be the most challenging and frustrating, scoring lesser pleasantness and feeling of success. Participants reported the concept to be engaging. The game story made them feel involved and absorbed, with moderate to fair flow and immersion. Although none of the games was considered to have a negative affect, Medusa's game was indicated to be less engaging than the others.

Overall, participants indicated that the games were moderate to fairly easy to play and that they would like to play again. Narcissus' game was rated to be the game with more interest; the Cyclops' one, the least; and Medusa's game qualified to be the easiest to play. During the post-game discussion, participant 14 (P14) described *SuperVision* as an *"anti-game"*, referring that it is like a standard game, but you are mostly not allowed to look at the main action. They added that you have to force yourself not to look, something that is unusual to other games. P8 said *"you have to trick yourself not to look, and then get frustrated when you look and don't even notice! That's quite funny!"*.

5.5.2 Player Performance and Preferences

We analyzed the game data logs for each participant to measure success in each game. Gameplay logs show how the Cyclops' game was the most difficult to succeed. The maximum level achieved by players was level 5, from 12 levels of difficulty ($M = 2.88 \pm 2.253$). Medusa and Narcissus' game show more players' success. They were able to reach level 10 in both of them (Medusa: $M = 4.58 \pm 2.28$; Narcissus: $M = 4.7 \pm 2.279$). Players completed more than 80% of the levels of difficulty for at least Medusa and Narcissus' games.

Participants with gaming experience reached higher proficiency in all the games, getting to higher levels of gameplay. However, using a One-way ANOVA, we did not find a statistically significant difference for gameplay performance between players exposed to

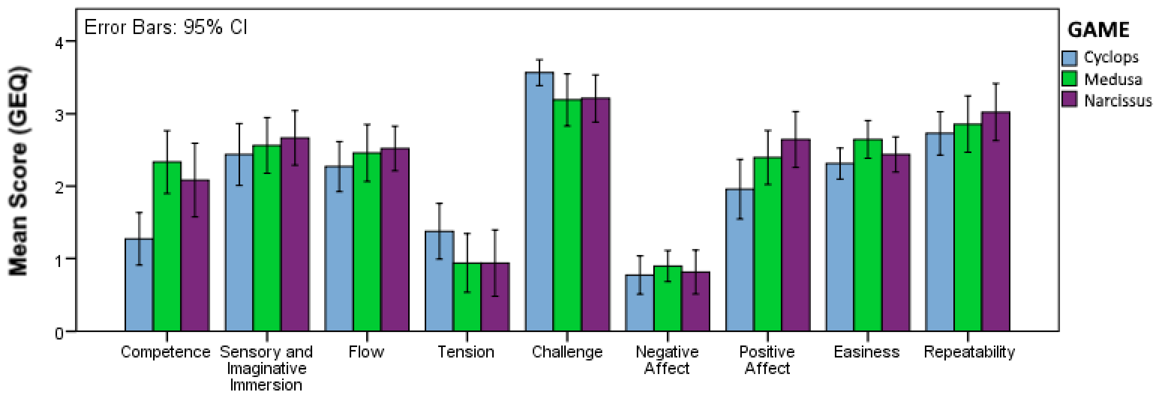


Figure 5.10: Results for the seven experiential game measures from the Game Experience Questionnaire (Competence, Immersion, Flow, Tension, Challenge, Negative and Positive affect) and the two extra added to measure Easiness and Repeatability. Results per each game and questionnaire dimension.

activities that demand peripheral awareness (cycling, driving, playing sports or gaming). Moreover, we extracted from Narcissus' game logs the ratio of success on noticing and collecting Echo's hearts. It measured the influence the peripheral task had on the gaze focus attention. We did not find a statistically significant difference in the order Narcissus' game was played ($\rho = 0.361$) Players were able to collect the bonus objects a mean of 36.91% $\pm$ 3.6% of the times it appeared.

Further, thirteen players reported thinking none of the games were easy, with the Cyclops' game chosen to be the hardest (by 14 participants). Ten participants described Narcissus's game as the most enjoyable, whereas ten other participants preferred the Cyclops' game, and four could not decide between the three. Moreover, 21 participants indicated they liked the game concept. Only one participant reported they would not want to play it again. During the post-game discussions, P24 pointed out that *"it was really hard, but because it was so frustrating I really wanted to play again"*. Participants rated the game concept with a mean score of 8.66 $\pm$ 1.10 out of 10.

On the other hand, results from the follow-up study using a Wilcoxon signed-rank test show that playing *SuperVision* every day elicited a statistically significant improvement in performance, in the Cyclops' game (Z = -2.023, $\rho = 0.043$) with mean 273.40 points $\pm$ 42.027 points the first day, and mean 637.20 points $\pm$ 254.986 points the last day; and Narcissus' Game (Z = -2.023, $\rho = 0.043$) with mean 2421.60 points $\pm$ 1508.404 points the first day, and mean 7354.40 points $\pm$ 4049.867 points the last day. We found no statistically significant difference in Medusa's game performance. We deem this could have been caused by the game's lack of challenge, as it was perceived as the most boring one according to the questionnaire qualitative data. However, these results illustrate how players developed proficiency in overcoming all the perceptual challenges the more they played.

5.5.3 Gameplay Behaviour and Strategies

To analyze players behaviour during gameplay, we used all the logged gaze data to create a series of gaze heatmaps for each of the games. We divided the gaze data into two different groups according to players' behaviours and success during the game:

- *First time*: Corresponds to the first played levels in which players are not familiar enough with the game to succeed.
- *Proficient*: Corresponds to the last played levels, showing the players' success. We considered the last level played (maximum reached for each game) and the two previous ones (according to standard deviation).

We produced a gaze heatmap for each behaviour group and game. We decided to use the game data from levels 1 and 2 in each game for the 'First time' playing behaviour. Levels 8, 9 and 10 logs were used for the 'Proficient' player behaviour for Medusa and Narcissus' game, whereas level 3, 4 and 5 logs were used for the Cyclops.

Figure 5.11 shows the different heatmaps generated for each game and behaviour using all gaze data points from all the participants. We can observe how novice players (*Figure* 5.11, left) display greater screen dispersion of gaze points (areas in blue). During the user study, P12 remarked that they did not know where to look as their eyes wanted

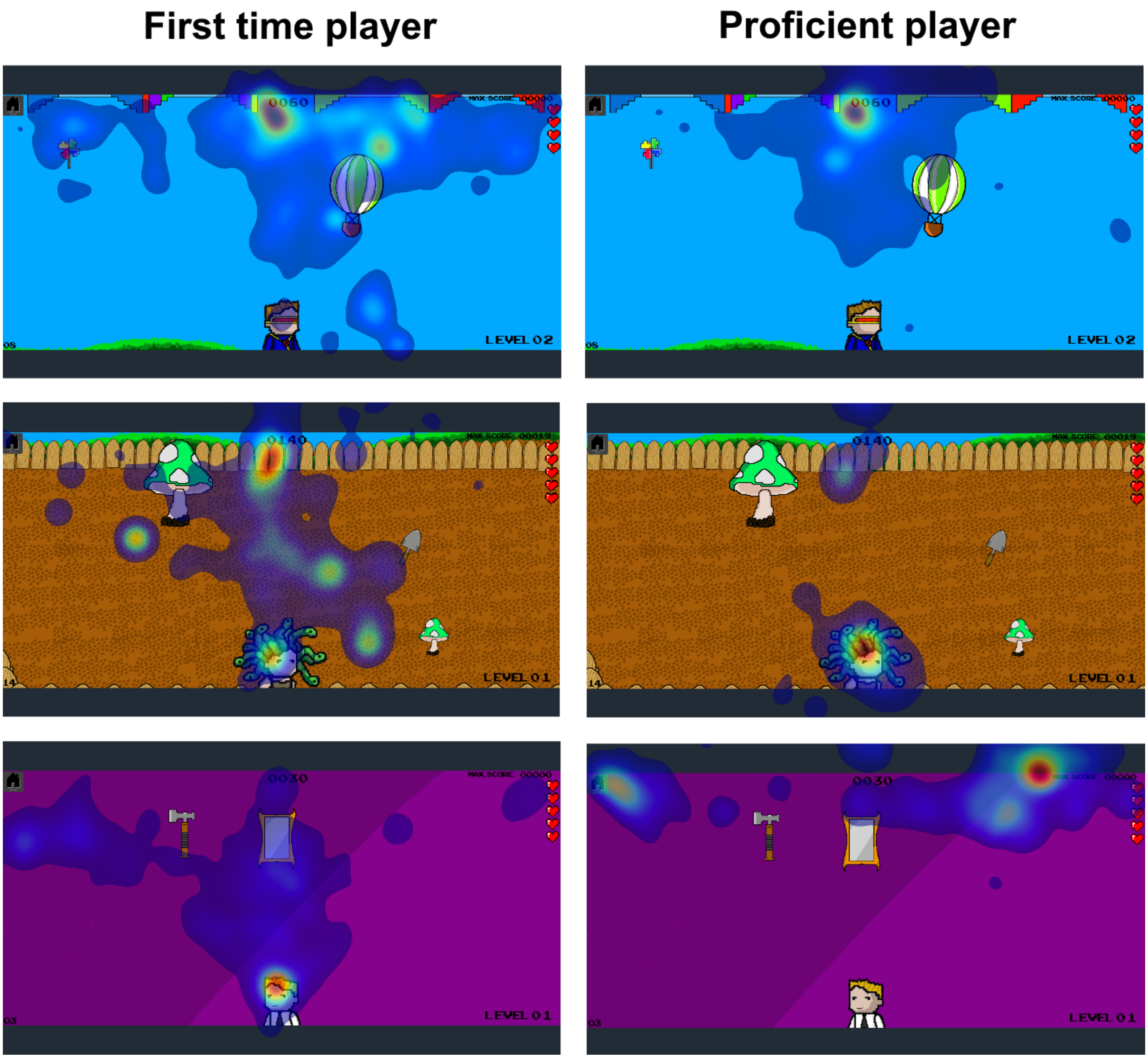


Figure 5.11: Gaze Behaviour Heatmaps for First-time and proficient playing for each game. Players evolved from greater dispersion of gaze points in the scene (looking everywhere as first time play behaviour), to focus on specific (safe) areas - Proficient behaviour.

to go to the item that popped up on the screen. Accordingly, there is evidence that players gaze was in motion rather than staying in a fixed point (green, yellow and red areas).

On the other hand, proficient players (*Figure* 5.11, right) show fewer focus points and less movement around the screen. *Figure* 5.11 (left) shows how participants' gaze turned more static towards the end of the game, once a strategy was adopted. The Cyclops' game (top) presents a strong focal point on the top-centre of the screen, common to all players. Medusa's game (middle) indicates how different users chose between two distinct focal points. The majority of players focused on the characters' head. Finally, during Narcissus' game, players focused their gaze all around the top of the screen.

Table 5.1: Protractor Test Results before and after playing *SuperVision* per each cue and statistical difference.

CUE	*Pre-game*	*Post-game*		
	Mean ± *SD*	*Mean* ± *SD*	Z	ρ
Colour	**80.14° ± 6.33°**	**82.75° ± 4.83°**	**-5.232**	**¡ 0.0005**
Drawn	**40.85° ± 14.08°**	**47.78° ± 12.70°**	**-5.722**	**¡ 0.0005**

During the user study, 3 participants complained about objects moving towards their gaze focus rather than them looking at them on purpose. They reported their strategy was to be concentrated looking at a fixed point. P15 pointed out: *"I was too focused on thinking where not to look that I forgot at times to move the mouse"*. Evidence shown in *Figure* 5.11 (right) indicates that most players decided to keep their gaze point fixed in the same location while playing. These insights suggest players developed a strategy to succeed in the games the more they played. P18 said during a post-game discussion: *"It was hard to find a strategy not to look at the start of the games, but playing them for at least once helped to decide on the strategy and become more successful"*.

5.5.4 Peripheral Vision Skills

We measured participants' ability to detect and identify cues in their peripheral vision with a visual test using a protractor. We wanted to determine whether the test results prior and after playing were significantly different to test for any skill development. *Table* 5.1 shows the mean position in degrees in the peripheral visual field, where the 24 participants were able to identify the different colour and drawn cues. We performed a Wilcoxon signed-rank test for both cues. Results indicate that playing *SuperVision* elicited a statistically significant improvement in the detection of colour and drawn cues in peripheral vision. Moreover, we did not find a statistically significant difference between the test results for either eye; colour cues (red, green and blue); or drawings (letters, numbers, and shapes); nor in the results from participants with or without visual correction (wearing glasses).

Accordingly, with our follow-up study, we wanted to know whether there would be a visual skills improvement over time by playing the games. *Figure* 5.12 shows the visual test mean scores during the study for the five participants. Results from a Wilcoxon signed-rank test indicate that playing *SuperVision* every day during two weeks elicited a statistically significant change in detection of color cues in peripheral vision during the first week, Monday to Friday, (Z = -3.222, $\rho = 0.001$) with mean 81.20° ± 4.08° (Monday) and 84.50° ± 4.32° (Friday); during the second week, Monday to Friday, (Z = -4.240, ρ ¡ 0.0005) with mean 84.13° ± 3.73° (Monday) and 87.90° ± 2.73° (Friday); and during the 2 weeks, first Monday to second Friday, (Z = -4.593, ρ ¡ 0.0005). No statistically significant difference was found in the visual results due to not playing the game during the weekend ($\rho = 0.521$). These results show how participants improved their peripheral awareness by playing the game, and this improvement was not affected when they did not play (during the weekend) but kept improving during the following week. Finally, we did not find any correlation between the game's performance (game score) evolution and reported peripheral visual skills during the two weeks. However, results show how playing every day make not only their visual skills improve, but also their performance in the games.

5.6 Discussion

5.6.1 Playing with Peripheral Vision

The goal of this chapter is to challenge gaze-focus based design and to propose leveraging the capabilities of the broader visual field. We provided a conceptual framework to *"play with peripheral vision"*, illustrated by three game examples. It is very unusual to demand users not to look to assess elements that will only be in their visual periphery when they could do it easily by looking directly at them. Using this dynamic creates not only a challenge but also a task with high cognitive demand.

Results from the GEQ suggest that playing *SuperVision* was very challenging with a high perceived cognitive load. However, the perceived frustration when failing to overcome the perceptual challenges made players want to play more and try to succeed, and they rated the gameplay as a pleasant experience. These results demonstrate how the presented concept created a playful and engaging experience that made people want to play again. However, although the participants seemed keen to keep playing the games because they felt motivated to improve on the peripheral challenges, we do not have enough evidence to guarantee that the experience engagement can be sustained in the long term.

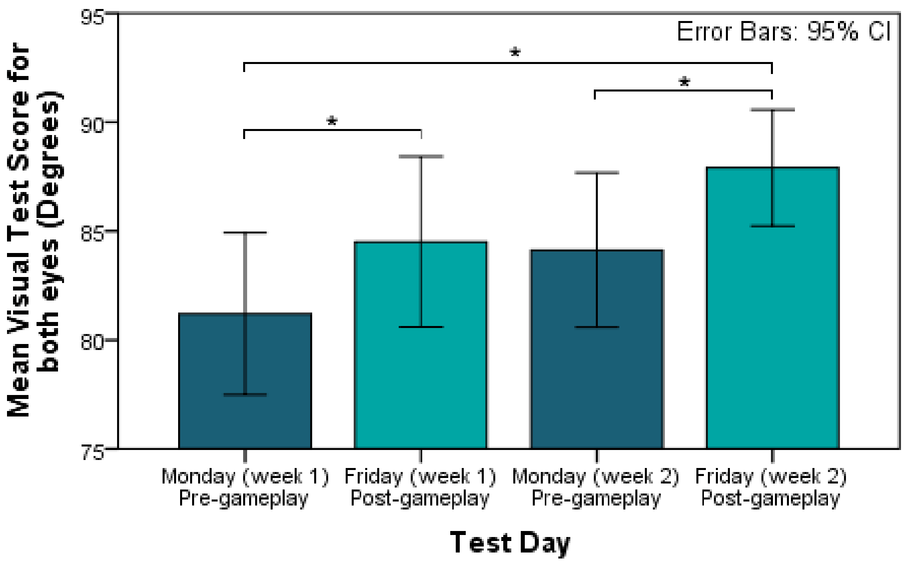


Figure 5.12: Follow-up two weeks study Protractor test results for coloured cues performed every Monday before gameplay and Fridays after playing the game.

5.6.2 Challenges and Strategies

We also wanted to know if playing in the periphery was feasible and whether players could overcome the perceptual challenges by developing clear strategies. Our results show that differentiating different elements in the periphery is possible. Objects with bright colours, with colour variations (skulls for Pirate balloons in the Cyclops' game), less vividness, with a difference of more than a 10% in size from their counterpart, can be differentiated in the periphery.

On the other hand, designing for the periphery poses different questions on how to effectively use colour saliency, contrast, size, shape, interaction modes and feedback for the detection of visual cues in the periphery. Overall, the players showed proficiency in overcoming the perceptual tasks by developing a clear strategy to find a space where they could *"park"* their gaze. This effect might limit the experience when designing the graphics of the game. When gaze remains static, there could be no reason to create *"beautiful"* graphics or too elaborate game objects and stories, as they would only be seen in the periphery.

Nevertheless, our results suggest how the use of metaphors for gaze interaction might have affected the perceived experience of immersion. Further, the proposed challenges may be of interest for entirely different types of games (e.g. serious games to train peripheral vision awareness, or for behavioural training for inhibitory control).

5.6.3 Visual Skills Development

Moreover, we wanted to know if playing games that happen in the periphery could influence the development of players' visual abilities. Although we do not have visual skill development data from a baseline group which did not play the games, our results suggest that playing *SuperVision* could improve visual awareness, as peripheral vision can be trained [288]. This poses our games' conceptual framework as a potential peripheral vision awareness training tool.

Playing with Peripheral Vision opens up opportunities that could have implications for the processing of peripheral notifications, that could be picked up without looking at them. Moreover, it could influence the creation of serious games to train athletes, dancers or industrial workers; and the design of serious games for psychology assessment or behavioural training for cognitive stimulation based on inhibitory control.

5.6.4 Playful Inhibition

Given that human attention gets attracted to elements that pop out in the scene [87], players found hard not look, as they would do naturally. The proposed "not looking" or "looking away" dynamic is related to a process of inhibitory control of the visual focus, which in *SuperVision* becomes an engaging and playful challenge. Players need to be aware of the Gaze Aversion game rule, which goes against their spontaneous or natural behaviour. They attempt to control and resist this reflexive impulse to look, while there is additional stress from trying to solve the peripheral task at the same time.

During our user study, players reported struggling at first to control the impulse to look. This can be illustrated by Edgar Allan Poe's *The imp of the perverse* [202]. In Poe's work, he reasons why people act against their self-interest (tempted by the symbol of *the imp*), only because they feel they should not. In our work, "looking" becomes *the perverse* action that needs to be controlled. Players could do just fine suppressing the impulse, but they cannot stop thinking about it. This compromises the inhibitory control, that can weaken further when a task overload or stress is added [278].

In this way, players know they should not look, but the tasks in the periphery lower their control and make them 'indulge' the reflex of looking, thus failing at the game. This forces them to train themselves to inhibit the impulse if they want to succeed. Moreover, our results (*Figure* 5.11) show how participants overcame this challenge and were able to focus on the peripheral task, adopting a static gaze focus strategy.

In behavioural studies, inhibition is closely related to the Working Memory, and it can be trained [156], for example by showing negative cues (go/no-go test) [101] next to the impulse that wants to be controlled. In our work, given the evolution of the players' strategy and their success, our features to support the game rule (e.g., penalization plus sound feedback) served as negative cues to train the inhibitory control. We can find similar dynamics in psychology studies using the anti-saccades test [176, 37], or products to stimulate cognitively people living with ADHD or OCD [33]. In this way, even though our contribution is focused on presenting playing with the visual periphery as an uncommon mechanic, it could become a potential tool to improve the design of gamified tests for psychology and cognitive assessment. Moreover, the creation of serious games for behavioural change based on inhibitory control. Designing game challenges like in *SuperVision* can offer a promising way to lower the stress for psychology patients and make these tests more engaging and enjoyable.

5.7 Conclusion

In this chapter, we presented the concept of *playing with peripheral vision* introducing a novel game dynamic that leverages the capabilities of the broader visual field. We developed a conceptual framework and put it to the test by designing the game *SuperVision* including three game examples that explore different perceptual and manipulation challenges in the visual periphery through the use of new gaze-based metaphors or game narratives.

Gaze input is a compelling tool for interaction because we intuitively look at the objects we want to select [118]. Accordingly, research on new gaze interaction techniques has consistently been focused on the adoption of gaze as a pointing device. These ignore that the eyes can hold meaning; it is rich and complex, especially in social situations. Nevertheless, the body of work focusing on social gaze is key in investigating gaze interactions based on the meaning of looking, known as social gaze behaviours. For instance, we look at an interviewer in the eyes to show confidence, or we might avoid looking at something we do not like. The work on social gaze identifies there is a context to using gaze as a pointer, setting the grounds to consider more than the visual focus. Here, we suggest we can go even further and involve the active use of our visual capabilities for interaction. Previous work in other fields of HCI already identified the relevance of engaging peripheral attention [7]; however, this has not been fully explored in gaze interaction design. We proposed gaze-based game dynamics based on not looking at elements in the game scene to engage an active use of our peripheral awareness capabilities by posing perceptual and manipulation tasks away from the gaze focus. We investigated with *SuperVision* whether players can be successful in the game, and tested for peripheral awareness' skills development. Results show we created an engaging and playful experience utilising Gaze Aversion to push interaction to the visual periphery. Players developed strategies to overcome the perceptual and manipulation tasks and they experienced an improvement in visual periphery awareness after playing the games. Briefly, we summarise the key takeaways:

- There is more to gaze interaction than where we look at. We can design more creative ways of using gaze interaction in games that move away from the "what you look at is what you get" metaphor.
- The use of metaphors opens up opportunities to explore the design space of gaze interaction in games. We explored narratives that supported interaction in the periphery based on new metaphors that contextualise gaze aversion in the gameplay.
- Playing with peripheral vision can train peripheral awareness and challenge inhibitory control. Results from the user study suggest that a game that engages peripheral vision could support the training of peripheral awareness. Moreover, the game showcased a dynamic that could potentially develop inhibitory control skills.

Overall, this chapter follows up on extending opportunities for gaze interaction in games. Beyond considering different gaze behaviours moving away from direct pointing, we push game interaction to the broader vision. In doing so, we contribute a framework to design games that play with peripheral vision utilising gaze interaction mechanics but also the framework unfolds 'looking' to move the interaction from the focus point towards what we cannot look. This concept further allows the emergence of a new space for inquiring looking versus when we are not looking, which is further explored in the following chapter.

6 Playing Without Looking

The widespread adoption of gaze input is as a utility for game efficiency and performance, e.g. for a faster selection of the targets the player looks at. Generally, there is a limited amount of actions we can do with our eyes for interaction, and gaze-enabled play is coupled with interactions that rely on looking with game mechanics defined by the metaphor "what you look at is what you get". In this chapter, we challenge this approach to reflect that gaze is more than pointing. We push the boundary by exploring what we can do with our eyes closed - eye movements behind the eyelids - and use them playfully. In contrast with previous chapters introducing attention dilemmas and challenges that make players look away with gaze aversion rules, here, we require players to close their eyes explicitly. However, playing with the eyes closed might require greater *peripheral awareness* to get a quick glimpse of the whole game scene in a blink, and it could be seen as a different form of *tension* in gaze interaction. Here, we designed a new gaze mechanic based on our ability to roll the eyes with closed eyelids, framing it as a superpower. We introduce using (1) the closing of the eyelids to signal the start of the interaction, (2) eye movements behind the eyelids predicting the location of targets the player cannot see, and (3) the use of gaze pointing when the eyes are opened to trigger the game interaction - See *Figure 6.1*. Here, we explore the concept of *playing without looking* based on four fundamental research questions:

- How can we create game mechanics that require the player to close their eyes?
- How accurate are players with unsighted gaze pointing when both eyes are closed?
- Is it possible to predict the position of different moving targets by rolling the eyes when they are closed?

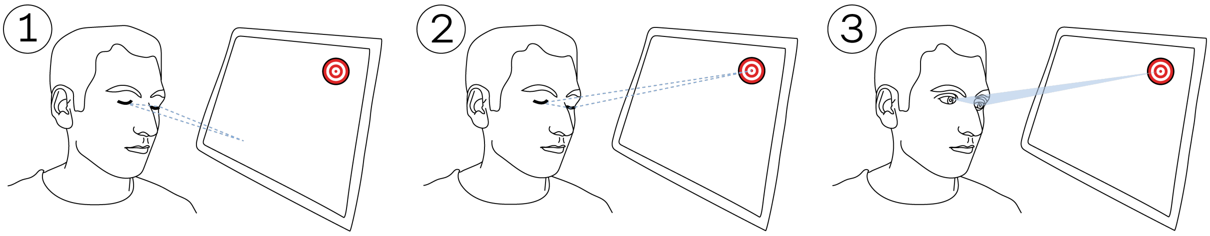


Figure 6.1: The proposed game mechanic requires the player to predict the location of targets with the eyes closed. (1) Closing both eyelids indicates the start of the interaction; (2) the player needs to perform eye movements behind the eyelids; and (3) the interaction (gaze pointing) is triggered when the eyes are opened.

- Can players overcome the challenge of playing without looking?

In this chapter, we describe the game *KryptonEyed* introducing the act of closing and opening the eyes to control the character's powers to teleport. The game includes three instantiations of the proposed technique to demonstrate different playful scenarios where it could be used. Moreover, we investigate with *KryptonEyed* the feasibility of using the technique. Firstly, we investigated whether it is possible to move our eyes behind the eyelids to predict the position of static targets. Secondly, we tested the accuracy of the prediction based on targets with different motion features using the technique and evaluated the resulting game experience.

6.1 Not Looking in Gaze Interaction

We can find examples of requiring users to close their eyes in meditation apps for mindfulness and well-being [4]. In their activities, they ask the user to close their eyes to follow their instructions. Eye trackers provide wherein the screen the player is looking, thus *Not looking* is an atypical and unexpected action to perform. However, some game examples have integrated this behaviour in their gameplay. For instance, *Ekman et al.* introduced closing the eyes in *Invisible Eni* [56] for hands-free game control. In the game, when the tracker loses the information of the eyes when the player closes their eyes (voluntary blink), the game character disappears to escape and protect herself from enemies. This chapter follows this trend to require players to close their eyes for gameplay, making gaze interaction inherently more challenging. Moreover, we do not use closing the eyes for explicit interaction only. It is used as the indicator that when we open them, we are going to use another gaze mechanic.

In interaction, blinks and winks have been broadly used as a tool for accessibility [230]. Blinks are the closing and opening of the eyelids that is performed by both eyes simultaneously [230]. Blinks are generally spontaneous with a duration between 100ms and 250ms [133, 194], or reflective when we naturally close our eyelids as a reflex when in danger [150]. For instance, if someone throws an object to our face, we would close our eyes as a self-reflex. Moreover, winks are defined as the swift closure and opening of one single eye at a time [230].

Other creative uses of blinking for interaction include games integrating blinks to trigger selection in more accessible interfaces [232]; winks (closing of just one eye) to simulate social behaviours and "charm" virtual characters [40], or an interactive art installation that enables participants to make collaborative music by blinking [217]. Here, this chapter follows in this spirit the use of voluntary closing of the eyelids for interaction. However, we are in contrast by dividing blinks into two separate interaction events: closing the eyes and opening them. Moreover, we leverage that when the eyes are closed, they can still move (roll) [64, 168], e.g. during sleep, we perform Rapid Eye Movements [155]. Accordingly, we leverage this ability in gameplay to propose the prediction of game objects that we cannot see as a novel mechanic.

6.2 Designing Gaze Interaction behind the Eyelids

We propose to *play without looking* by leveraging the fact that we can still move our eyes when they are closed. To do so, we combine gaze pointing with voluntary closing of the eyelid for interaction and propose it as a novel game mechanic.

This chapter aims to explore whether we can consciously and accurately direct our eyes at targets behind the eyelids. The proposed dynamic is based on predicting where a target is located with the eyes closed. Behind the eyelids, the user needs to roll their eyes towards the position of targets and open the eyelids to point at them with gaze. The concept is designed around three dimensions that can be explored for gameplay: *Not Looking*; *Eye Movements*; and *Duration*.

Not Looking:

The technique utilises the voluntary and explicit closing of the eyelids to encode the intention to use different game mechanics. We divide it into two steps: (1) *closing the eyelids* to indicate the start of the interaction; and (2) *opening the eyelids* to trigger the interaction and end it, e.g. aiming at targets.

Performing Eye Movements behind the Eyelid:

The technique relies on the ability to roll the eyeballs behind the lids. We refer to this dynamic as performing eye movements with the eyelids closed. We propose to investigate whether users can predict the positions of targets that would require to perform three different eye movements with closed eyes. Although other types of eye movements exist, we centre this research on: (1) fixations to focus on a static target because the eyes are known to move upwards when the eyelid closes [34, 117, 150]; (2) saccadic movements to travel to another position from where the eyes were looking at when they were closed; (3) smooth pursuits or the ability to follow with the eyes a target that is in motion.

Duration of the Eye Hold:

The technique leverages the down-hold of the eyelid. This allows us to explore different game dynamics that are dependent on how long the player keeps the eyelids closed. Some can be swift, e.g. to quickly aim at static targets; whereas others may be lengthened, e.g. waiting to be confident on the position of a moving target.

In what follows, we first present the game concept, then the user studies performed to gain insights on the feasibility of the technique. This structure aims to put the game design forward to support the proposed technique. Readers must note that the parameters reported in the following section (game design) are values based on the preliminary accuracy studies.

6.2.1 Game Design Process

We used the previous conceptual framework of *gaze interaction behind the Eyelids* to set the requirements for game design. We revised the state of the art literature to understand how general interaction gad used eye closure (e.g., confirmation blinks), and similarly for game interaction(e.g., [55]).

Moreover, we focused on finding metaphors that would contextualise the need to close the eyes, but that made gaze necessary in the game. We found the concept of "superpowers" inspiring and decided to embed the proposed gaze interaction as a superpower. Additionally, the game design was inspired by two popular superhero concepts: the quote "*with great power comes great responsibility*" (from the Marvel's Spiderman universe) and the idea of "*kriptonite*" (from the DC's Superman universe). These set the gaze design to include closing the eyes as a superpower and keeping them closed to avoid the character's weakness. With this criterion, we brainstormed a list of compatible game genres to explore. Additionally, we sketched different game interactions that focused on using different eye movements and duration of eye closure. Various ideas were considered and filtered to develop the final game design.

6.2.2 Implementation

The game *KryptonEyed* and the applications used in both user studies were developed with Unity Game Engine in 2D; with custom graphics and creative commons sounds. The applications require the use of an eye tracker and use Tobii Gaming SDK for Unity to enable gaze interaction. The calibration of the eye tracker is mandatory before playing the game.

To develop the proposed technique, we differentiate blinks from closing the eyes. Blinks are quick involuntary closing and opening of the eyelids that get filtered by the eye tracker's SDK (less than 200ms). On the other hand, closing the eyes is considered as the voluntary action of closing the eyelids for a period longer than a blink. This mechanic is detected as an absence of the user's presence by the hardware SDK.

To conduct the user studies, we used a *TobiiEyeX* eye tracker under a 27" monitor (Resolution: 1920x1080; Aspect Ratio: 16:9) at 40cm from the user.

6.3 Game Design: KryptonEyed

We designed and developed *KryptonEyed*, a mini-game prototype that uses gaze interaction controls only. We aimed to explore the opportunities for gaze-enabled game design by closing the eyelids to interact with gaze. We transformed the act of closing and opening the eyes for gaze pointing into the power of *teleporting*. It is used to transport the game character across the space instantly - See Figure 6.2. In the game, the player takes control of *WanderEye*, a superhero whose powers are activated by closing your eyes. After the player closes their eyelids, they can make *WanderEye teleport* to where they are

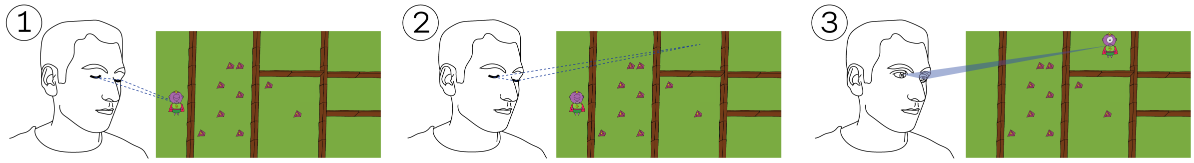


Figure 6.2: Illustration of Gaze teleportation in the game KryptonEyed. The proposed game mechanic requires the player to close their eyes (1) and look at the position where they want to make the game character teleport (2. Teleportation is confirmed when the eyes are opened (3).

Figure 6.3: KryptonEyed's title scene. To start, the player needs to make *WanderEye* teleport to hit the Krypo-Monsters.

looking once they open them. In the game, *WandeEye* closes her eye when the player does. The player needs to help *WanderEye* defeat the *Krypto-Monsters*. However, the monsters release *Kryptoneye*, a dangerous material, which is our hero's weakness and makes her lose power.

The game features three levels exploring the use of the interaction mechanic in different scenarios: Adventure/Exploration Puzzle, Shooter Game, and a Fast-Paced Obstacle Game. The scenarios were chosen (but are not limited to) as a sample of game dynamics commonly present in popular games such as Pokémon [69] and Zelda [86], e.g. adventure/exploration; battle events; and a boss battle. Accordingly, *KryptonEyed* presents three different ways to use the proposed technique to teleport to navigate; attack; or jump to avoid obstacles. The three levels are played in the order given above, proposing a gradual increase of the game challenge and pace. They frame the game adventure in three stages: Introduction, Main Task, and Boss Level.

The title scene of the game presents the players to the main character they are going

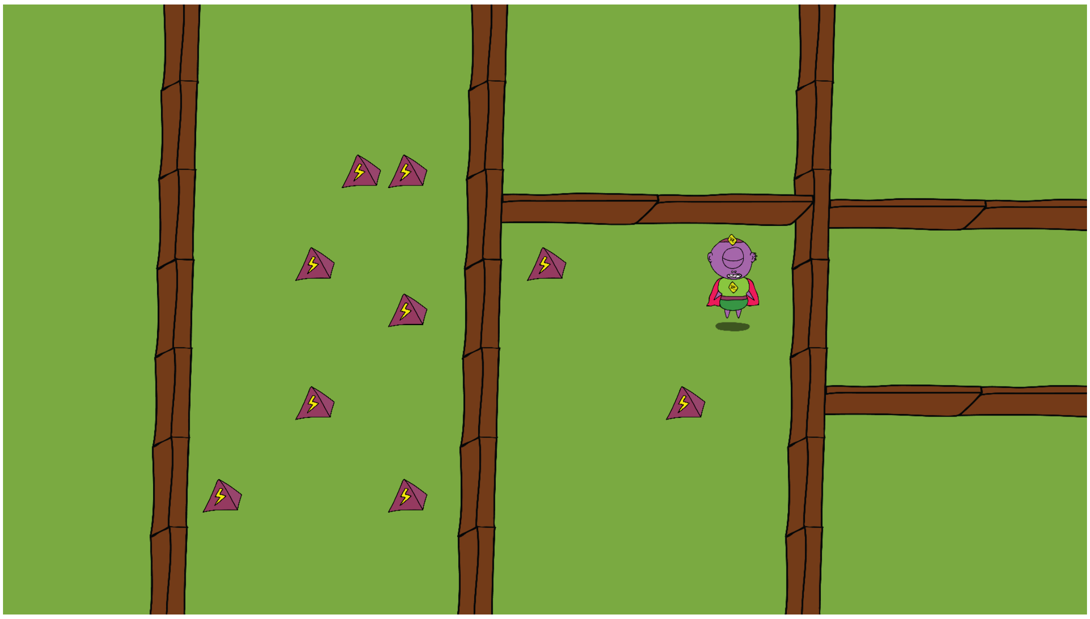


Figure 6.4: KryptonEyed Maze Level, Exploration Game Scene. Players control WanderEye with gaze and need to collect the energy boxes scattered around the maze.

to control (see *Figure 6.3*). This stage aims to introduce the gaze interaction technique to the player before starting the experience. To start the game, the user needs to make *WanderEye* teleport, so she hits the group of *Krypto-Monsters* on the other side of the scene. The game is designed to last between 2 and 3 minutes approximately if the player makes no mistakes. Gameplay videos available in Appendix B.

6.3.1 Adventure/Exploration Game

The first level is aimed to introduce the user to the game concept and gaze interaction mechanic, serving as a tutorial. The goal is to make *WanderEye* navigate the walled maze to collect the ten available energy boxes (see *Figure 6.4*). Once the task is completed, the game moves to the next level.

During this level, *WanderEye* automatically moves towards the player's gaze point. However, she cannot go through walls. Suitably, players can make her teleport to the other side by using her superpowers. We developed the interaction so players need to move their eyes by at least 2° of visual angle (Wall width: 150px) while the eyelids are closed, remembering the scene when they cannot see it.

The task is designed to contain no challenge and help the player learn how to use the "teleporting" gaze mechanic to navigate the maze. This aims to provide a relaxed short experience players cannot fail to allow them to get used to the gaze mechanic. Accordingly, we explored how the proposed interaction could be used with other gaze mechanics.

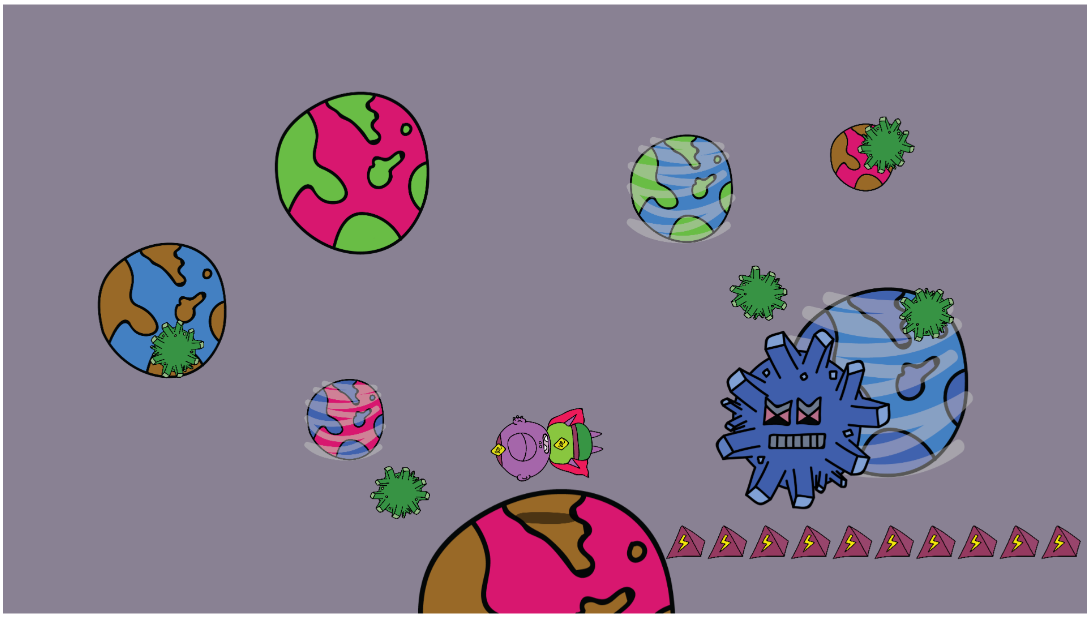


Figure 6.5: KryptonEyed's Shooter Game Level, Players need to make WanderEye teleport on top of the Kryptomonsters to attack them.

6.3.2 Shooter Game

The second level is aimed to showcase the potential of the proposed gaze interaction in a shooter game. The core concept explores how well we can point at objects based on different eye movements and duration. We overcame the challenge of introducing these complex concepts by introducing different rules, consequences, and rewards.

In the game, *WanderEye* is in outer space and needs to save the galaxy by neutralizing the different *Krypto-Monsters* (see *Figure 6.5*). To attack monsters, *WanderEye* needs to momentarily teleport herself to the monster's position (on top of it). Accordingly, the player needs to close their eyes and point at the monsters before they open them to attack. After the attack, the character automatically returns to her original position, making the action temporary.

We designed three types of monsters based on fixations; saccades and pursuits eye movements (see *Figure 6.6*). To make the player perform the targeted eye movement with the eyes closed, we created three "*Krypto-Monsters*" with different rules:

- ***Kryptoxations:*** The blue monster is based on fixations. It is a static target remaining at the same position. When looked at, they become smaller.
- ***Kryptoccades:*** The red monster is based on saccadic motion. It moves every time it is hit or when looked at, making them impossible to defeat unless the eyelids are closed before the attack.
- ***Kryptosuits:*** The yellow monster is based on smooth pursuit eye movements. It continuously moves in an orbital loop (400px diameter, 80°/s), making it difficult to track. When looked at, they speed up, and go back to the original speed when the player stops looking at them. This makes them challenging to defeat.

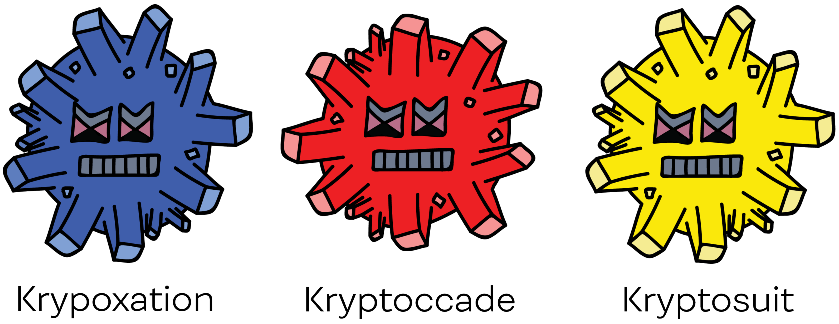


Figure 6.6: Krypto-Monsters custom graphics. Blue Kryptoxations remain static. Red Kryptoccades move when looked at. Yellow Kryptosuits are in constant motion.

Overall, the monsters' features aim to require players to perform the corresponding eye movement only with the eyes closed. For *Kryptoxations*, the rule demands the player closes the eyelids quickly maintaining the position of the target. In contrast, the other two monsters prevent the player from looking at the targets before performing the interaction.

Krypto-Monsters can appear anywhere in the scene and have between one and four lives (chosen randomly), requiring the player to attack them several times. Monsters randomly vary in size during the game, increasing the game challenge. They start with a diameter of 8° (200px), and can have a minimum size of 4° (100px). *WanderEye* size when shot is approximately 3x3° (80x80px).

Moreover, the scene is filled with *Kryptoneye* and will make *WanderEye* vulnerable; spin uncontrollably, and lose power by just looking around. Nevertheless, she can recover all strength by keeping her eyes closed. In the game, *WanderEye* has ten energy boxes, and each can be lost if the player looks at the galaxy for two consecutive seconds. Accordingly, every two successive seconds that the eyelids are closed, energy is recovered (up to a maximum of 10). If all power is lost, the game resumes from the previous level.

We introduce with this rule the metaphor of teleporting as a tiring event consuming energy, whereas closing the eyelids referred to "sleeping" and reloading power. This limited the time players can look at the scene, modulating the need to wait with their eyelids closed to recharge energy and plan the next action. The level ends when the player successfully hits monsters 20 times.

6.3.3 Fast-Paced Game

In the last level, the player needs to defeat the *KryptoBoss*. This level explores the use of the proposed gaze mechanic in a fast-paced obstacle jump game.

In the level, the *KryptoBoss* is constantly firing single *Kryptoneye* and walls made of the same dangerous material towards *WanderEye*. She needs to avoid the obstacles and wait to attack the monster (see *Figure 6.7*). Only when the *KryptoBoss* is spinning, it is vulnerable to attacks. When hit, the big monster changes its position to the other side of the screen and carries on throwing walls of *Kryptoneye*.

Accordingly, the player needs to make her teleport to perform quick jumps over the moving walls, by closing and opening their eyes. In this level, *WanderEye* is immune to

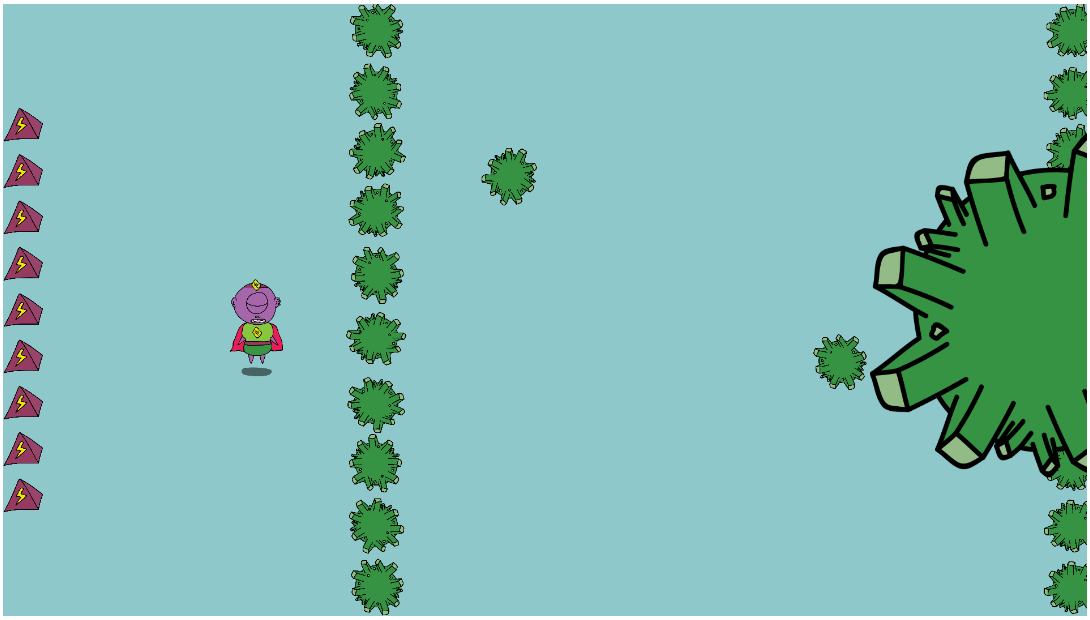


Figure 6.7: KryptonEyed's Final Boss Game, Fast-Paced Level. Players need to jump the obstacles and attack the big monster boss when it is spinning.

look at *Kryptoneye*, but if it hits her, she will lose power. Unfortunately, *WanderEye* cannot recharge energy under stress. The game ends once *WanderEye* hits the *Krypto-Boss* 5 times. *Kryptoneye* is 70px diameter, whereas the boss is approximately 13x16° (350x250px) size and half-hidden on the side of the scene.

We designed this level to add a challenge to the proposed gaze interaction. The game demands being very familiar with the technique. The main difficulty is that interaction needs to be quick to avoid the constant burst of moving obstacles.

6.4 Study 1: Feasibility and Performance

The presented gameplay technique relies on the user's ability to close their eyelids and roll their eyes, aiming at a target that they cannot see. This raises a fundamental research question on the feasibility of using the technique. The goal of the study is to understand how well participants can estimate the position of a target with closed eyelids.

We designed a task resembling the Fitts' Law task broadly used to evaluate gaze pointing usability [268, 218]. The task presents a set of 16 bullseye-like targets (130 px diameter ∼5°) placed in a circular shape centred on the screen at two possible distances: (A) *Long* distance between both the targets and screen centre, set at 250px (9.5°); and (B) *Short* distance at 130px (3°) - see *Figure* 6.8. During the task, participants need to close their eyes on the green square (75x75px, ∼5°) at the centre of the screen and aim at each target.

The task starts with only one target displayed at once, and it is completed when all the targets have been "hit". The order of the targets follow the Fitts' Law task structure, and it was completed after two loops. During the task, completion time and the distance

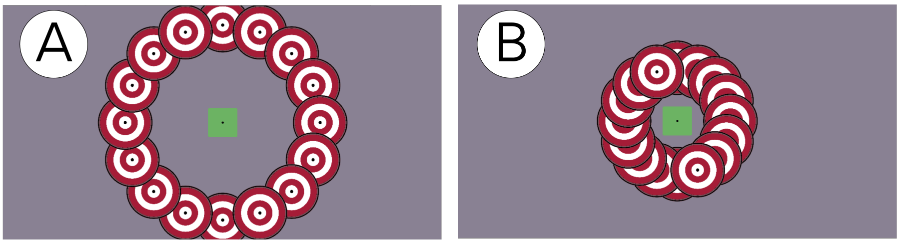


Figure 6.8: Study 1 Task Set-up. A) Long distance, B) Short distance.

between the target and the gaze point on eyelid opening were recorded. Moreover, we assessed the task workload using the NASA-TLX questionnaire [89] (Official App for Apple iOS).

6.4.1 Procedure

Upon arrival, participants filled in a demographic questionnaire. We gathered data about their gender; age; visual impairment (if applicable); and self-determination of experience with gaze interaction. Before the test, the eye tracker was calibrated for the participant using Tobii's native application; the accuracy was validated using the built-in tool for self-assessment, and the system was re-calibrated when necessary.

In the study, participants were asked to complete the task as fast as possible. They were instructed to (1) look at the green square at the centre of the screen and closed their eyes; (2) roll their eyeballs to the predicted target position aiming at their centre, and (3) open the eyelids to trigger a target "hit". From there, participants needed to repeat the action with the following target until no targets were left. They performed this task twice, one per distance condition. Task's conditions were counterbalanced.

After performing both task's conditions, participants were asked to answer the NASA-TLX questionnaire.

6.4.2 Results

Twelve participants volunteered in the study (4 female; 8 men), aged between 19 and 30 years old (mean: 25 $\pm$ 3 years old). Four participants wore glasses, two contact lenses, and six had uncorrected vision. Finally, four reported being experienced with gaze interaction. See Appendix C for further details about participant demographics.

The task results show how the accuracy when aiming at the targets from the centre of the screen at both distances was similar (Long: 52.57$\pm$27.45px, $\sim$1.99$\pm$1.04°; Short: 49.20$\pm$27.95px, $\sim$1.87$\pm$1.06°). *Figure 6.9* shows visual accuracy results of the different directions indicating how participants were less accurate, aiming at targets from the centre downwards in longer target distances. A Wilcoxon signed-rank test showed that target distance elicited a statistically significant change in gaze pointing accuracy with both eyes closed ($Z = -2.737$, $\rho = 0.006$).

In posthoc analysis, we calculated the success rate when aiming at targets. We considered an error when the gaze-point was further than the target's area. No statistically significant difference was found in the success rate between conditions ($Z = -1.229$, ρ

Table 6.1: NASA-TLX Scales Results (Mean ± SD)

NASA-TLX Scale	Weight	Score
Mental Demand	3.33 ± 1.17	64.58 ± 21.93
Physical Demand	2.33 ± 1.97	51.25 ± 29.79
Temporal Demand	1.50 ± 1.25	38.33 ± 19.18
Performance	2.58 ± 1.25	42.5 ± 16.00
Effort	4.05 ± 0.95	67.91 ± 26.01
Frustration	1.08 ± 0.75	39.16 ± 21.29
Overall Task Workload		58.97 ± 17.58

= 0.219): long (82.48±10.93%) and short (85.40±10.31%) target distance. Participants took an average of 77.36±25.68 seconds to complete the task with longer distance, whereas they took 72.87±24.60 seconds to complete the other condition. No statistical difference was found between them (Z = -1.143, $\rho = 0.253$).

Finally, *Table* 6.1 shows the weights and scores for the NASA-TLX questionnaire evaluating the perceived task workload, with an overall score: 58.97±17.58. Effort, Performance, and Mental Demand were the main contributors to the perceived task workload. This suggests that the technique is fatiguing, as it requires to think about explicitly closing the eyes and predict the target position, thus necessitating to introduce breaks when using it.

Overall, the results demonstrate the feasibility to use the technique for interaction in gameplay. However, in design game elements are restricted to meet a minimum size (>3°) to mitigate accuracy errors when opening the eyelids.

Figure 6.9: Mean accuracy when aiming at targets from the centre of the screen for long and short distances.

6.5 Study 2: Game Mechanic and Experience

In a second study, we aimed to investigate the performance of the proposed game mechanic and the related experience. To achieve this, we designed a task to understand how well we can aim at targets with the eyes closed based on (1) predicting the position of targets related to the different eye movement dynamics integrated into the game design, and (2) waiting before opening the eyelid to aim at the targets. Moreover, we included an eye tracking accuracy test task to use it as a baseline on how accurately gaze is estimated when both eyes are opened. Finally, we asked participants to play the game to evaluate the experience.

6.5.1 Eye tracking Accuracy

To get an insight into gaze input accuracy, we need to refer to eye tracking calibration literature. To test the accuracy of the eye tracker, the user needs to go through a similar procedure as to calibrate it. Generally, the user needs to fixate on a sequence of points on the screen [175], but alternatively, they could also assess the accuracy by following targets in motion [207]. To understand the accuracy of the eye tracker we designed a short task containing 9 targets scattered across the screen. In the task, participants had to look at the centre of each target and press the space key to make them disappear. When the key is pressed, the first five points sensed by the eye tracker are stored for offline computation of the accuracy. We understand accuracy as the distance between the gaze point and the centre of the target, reported in degrees of visual angle [61].

6.5.2 Performance

We investigated the accuracy of gaze pointing by predicting the position of targets with the eyes closed. The game introduces three types of targets that might require to perform different eye movements behind the eyelids: fixations; saccades; and pursuits. We developed an application to test the ability to aim at the centre of a target with gaze. The task presents one target (per each type of movement) at once that has to be hit ten times. After each hit, fixation-based targets remain static. Saccadic-based targets appear in randomised positions across the screen, and require the participant to look at the centre of the screen before closing their eyes.

In the task, participants had to (1) look at the centre of the screen; (2) close their eyes; (3) perform eye movements behind the eyelids when appropriate to predict the position of the target; (4) open their eyes aiming at the centre of the target. Participants are allowed to look at the target position beforehand. Then, they have to return to the centre of the screen (marked with a cross) before closing their eyes. Targets are round, bullseye style, with a diameter of 6° of visual angle (150px), decided arbitrarily. The smooth pursuit-based target follows an orbit with a diameter of 15° of visual angle (400px) and travels at a speed of 80°/s.

Further, to understand the influence of waiting with the eyelids closed on the gaze prediction accuracy, we designed two task's conditions: (1) performing the action *freely*, and (2) *counting* to 10 before opening the eyes. During the counting condition, participants have to count to 10, optionally out loud. The requirement is not to count in seconds but to think about the numbers, giving them a task to "disturb" the prediction. Similar to the accuracy test, only the five first detected points by the eye tracker (when opening the eyelids) are recorded for offline analysis. We consider as one group of data all the ten trials for each target set and condition.

To sum up, the test consisted of 2 factors (Free/Counting); 3 types of targets per task (Fixations, Saccades, Pursuits); and ten trials per target. During the test, the target conditions (related to eye movements) were not randomised because they are inherently different, and we did not intend to compare them. They were ordered by difficulty: keeping the eyes still with fixations; moving the eyes away with saccades, and predicting a target in motion with pursuits.

In total, the study contains 60 target hits and it could last between 10 and 15 minutes, dependant on performance.

6.5.3 Game Experience

We evaluated the proposed gaze dynamic in *KryptonEyed* and the game experience during a second part of the study. To assess it, participants played the game and answered a custom-made questionnaire comprised of 8 statements related to the game experience and the gaze mechanic: (Q1) "*I think the game was fun*"; (Q2) "*The gaze mechanic was easy to perform*"; (Q3) "*I felt competent playing the game*"; (Q4) "*The game was challenging*"; (Q5) "*I felt I had to think a lot (Cognitively tired)*"; (Q6) "*I felt eye tiredness and fatigue*"; (Q7) "*I enjoyed playing the game*"; and (Q8) "*I would play the game again*". They needed to be rated on a 5-point Likert scale (1 = 'Strongly Disagree', 2 = 'Disagree', 3 = 'Unsure', 4 = 'Agree', 5 = 'Strongly Agree'). Moreover, we asked participants to indicate which game level was their most preferred and explain why.

6.5.4 Procedure

In the user study, we asked participants to fill in a demographic questionnaire to gather data about their identified gender; age; visual impairment (if applicable); and experience with gaze interaction. This also included gaming acquaintance questions, including close-ended questions about how frequently they played video games; which genres; and their most played platform. Before the test, the eye tracker was calibrated for the individual participant, using Tobii's application. We controlled the accuracy of the calibration profile by using the built-in tool for self-assessment, and re-calibrated when necessary.

The procedure of the first part of the study is illustrated in *Figure 6.10*. At the start of the test, participants performed the calibration accuracy test. Subsequently, they were introduced to the performance task and had the opportunity to learn how to use the technique in a series of mock trials. Then, participants performed the real task.

During the test, for each set of targets, participants were instructed to first look at the target to be familiar with its position (*Figure 6.10, A*) and return to look at the centre of the screen. Second, they needed to close their eyelids and, when appropriate, roll them to the target's position (*Figure 6.10, B*). Lastly, they were instructed to open their eyelids, aiming their gaze at the centre of the target (*Figure 6.10, C*). The procedure was repeated until completing all the trials. Participants could ask for a break during the test to prevent eye fatigue.

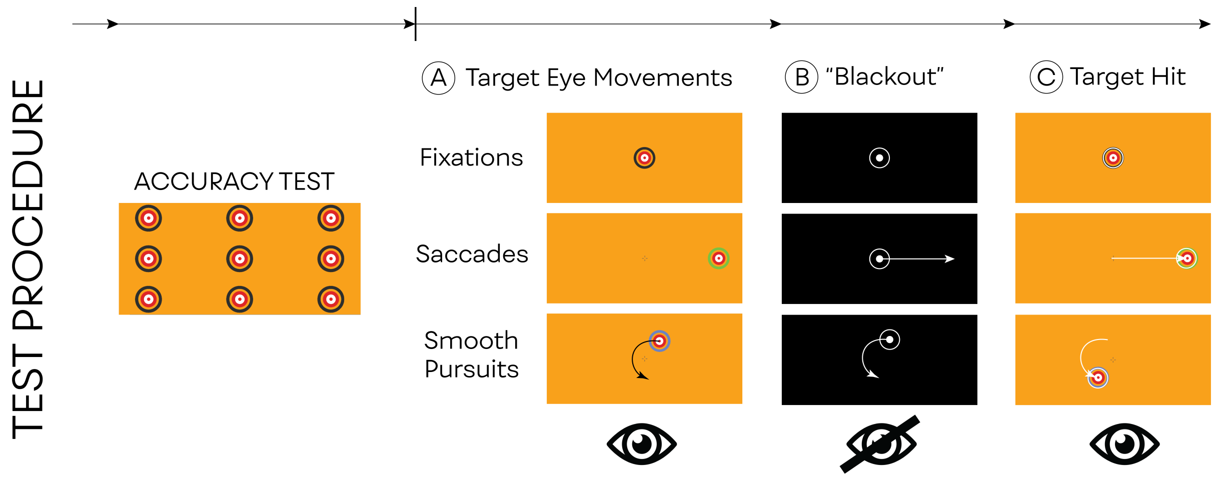


Figure 6.10: Test Procedure. First, participants performed the Accuracy test. Then, in each trial, they needed to look at the targets (A); look at the centre of the screen, close their eyes and roll them to predict the centre of the target (B); open the eyelids to aim gaze (C).

In the next section of the study, participants watched a short video showing them the instructions on how to play the game. Then, they were asked to play it as many times as necessary for them to experience all the levels at least once. However, participants could play as many times as they wished. Finally, they answered the game experience questionnaire and were invited to share their thoughts on the experience informally. Participants' opinion (informal interview data) was transcribed and analysed by the author of this thesis using an unstructured thematic analysis. Data was grouped according to similarities in themes and used to back up results and statements.

6.5.5 Participants

Twenty volunteer participants took part in the study, ten identified themselves as female, ten as male. Participants were aged between 20 and 50 years old (mean: 28 ± 7 years old). Ten of the participants wore glasses, two contact lenses, and eight had uncorrected vision. Finally, ten of them considered themselves experienced with gaze interaction. See Appendix C for further details about participant demographics.

6.5.6 Accuracy and Performance Results

The first section of the study aimed to understand the performance of the technique based on the prediction of different moving targets.

Gaze Accuracy:

Participants scored a mean accuracy of $1.38° \pm 1.04°$. This result is the baseline to understand how accurately participants can look at targets with both eyes open.

Performance Task:

Figure 6.11 shows visually the mean distance (offset) between the gaze point and the centre of the targets on eyelid opening, for each target type and condition. We explored the differences in accuracy for each set of targets (eye movements), comparing them between performance conditions (Freely, Counting).

A Wilcoxon signed-rank test showed that gaze pointing after eyelid opening performing a saccadic motion freely or counting did not elicit a statistically significant effect on the scored gaze accuracy (Z = -1.433, $\rho = 0.152$). Indeed, the mean accuracy when hitting the target based on saccades after opening the eyelids freely ($3.07° \pm 1.74°$) was very similar to the mean accuracy when opening the eyes after counting ($3.13° \pm 1.67°$). The other two pairs (fixations and pursuits) were found significantly statistically different between them ($\rho < 0.0005$).

Further, a Mann-Whitney U test showed that participants with glasses performed significantly worst ($\rho <$ 0.0005, M = $2.69° \pm 1.97°$) than other participants (M = $2.44° \pm 1.84°$). Moreover, participants with gaze interaction experience performed significantly better ($\rho < 0.0005$, M = $2.43° \pm 1.87°$) than the rest of them (M = $2.75° \pm 1.97°$). Six participants with gaze interaction experience wore glasses.

Overall, the results show the likelihood of missing a target. *Figure 6.11* shows how the technique scored a higher mean offset from the centre of the target than the baseline (with the eyes open). However, for most targets, participants successfully aimed inside the target area, except for the moving targets when counting. This further demonstrates the feasibility to use the technique for interaction in gameplay.

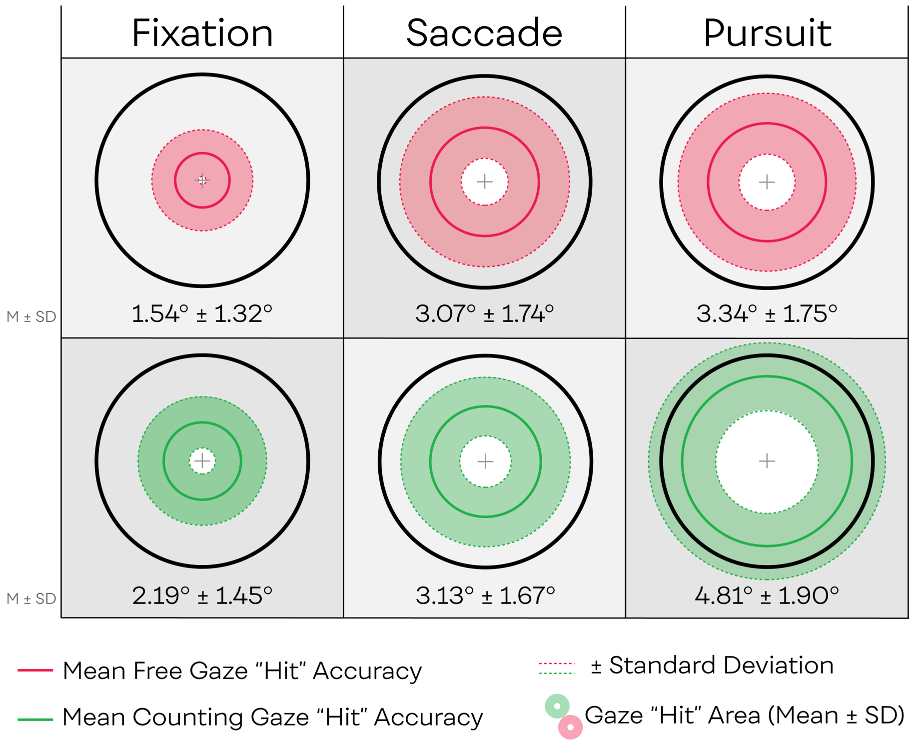


Figure 6.11: Gaze Mean Accuracy Results, in ° of visual angle, on each circular target type and condition (6° diameter).

6.5.7 Game Experience and Preferences Results

Six participants indicated being used to play games regularly (between 2-3 times a week and almost every day), during 2 hours or more. The rest of the participants (12) indicated playing sporadically. Two participants said they never play or like games. Overall, participants reported to play Action/Adventure games (11); followed by First or Third Person Shooter games (10), and Puzzle games (10). They played mainly on PC (7); Phone (7); and Consoles (5).

From twenty participants, only six were able to win at the game (four reported being experienced with gaze interaction). However, all the participants played all the levels during their first trial. They played twice on average. Only one participant decided to play just once. Five participants played between 3 and 4 times, and only two of them succeed at the game; one of them twice; the other after their last trial.

Figure 6.12 shows the results for the statements evaluating the game experience. Overall, the game was perceived as fun to play and challenging (Q1,4). Moreover, thirteen participants felt competent playing the game (Q3), and ten reported they found the gaze mechanic easy to perform (Q2 - six were experienced with gaze interaction). Further, the participants were divided on whereas the game demanded a high cognitive load (Q5), but the vast majority of them reported feeling eye tiredness (Q6) after the experience. Nevertheless, the experience was reported to be enjoyable (Q7), and most of the participants would play the game again (Q8). We did not find any statistically significant difference in the statements results between participants groups (gaming habits or experience with gaze interaction).

After playing the game, eight participants said the maze level was their preferred one. All of them enjoyed the lack of challenge, giving them the freedom to learn the technique.

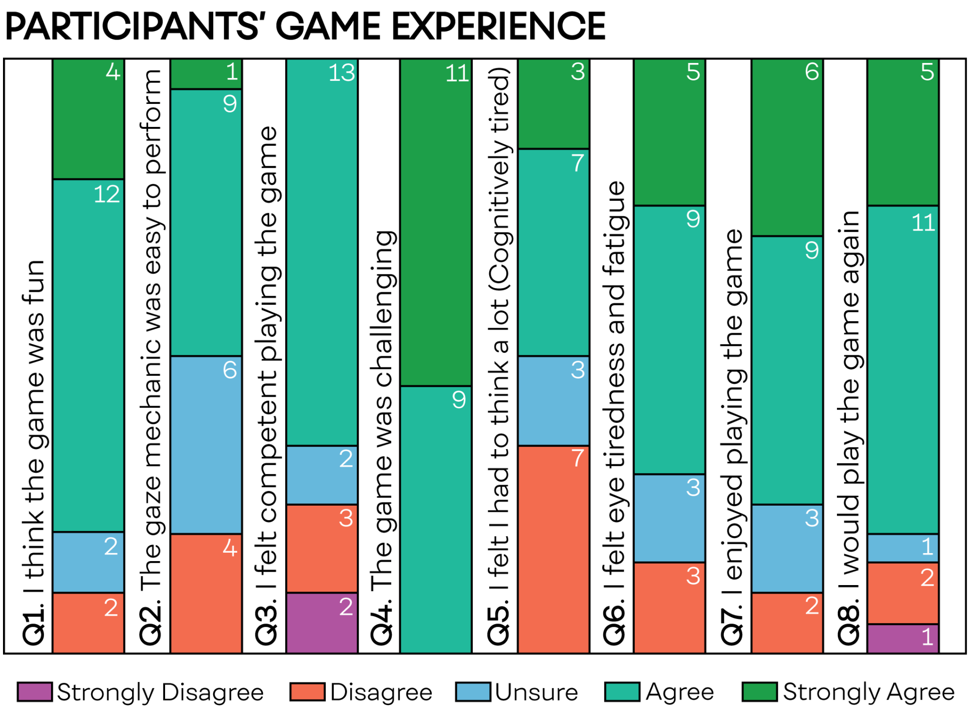


Figure 6.12: Game Experience questionnaire results.

Participant 9 (P9) pointed out that *"the Maze is a good tutorial to get to know the game"*. However, P10 felt that the level was too easy, and they felt like cheating. P5 said *"jumping through walls was very satisfying"*. Others thought that it was fun because it did not rely on closing your eyes only (P7).

Eight participants preferred the shooter level. The overall perception of this scenario was that it was swift and competitive (P8), and had a right balance of punishments and rewards represented by what they did with their eyes (P10). On the other hand, P18 said *"The level is quite fatiguing, but it is nice when you can just close your eyes and rest"*. Accordingly, P13 said *"I think the game allows you to improve, and if it gets too much you can just put the character to sleep"*.

The final level was the least popular. Some participants said it was because they lost the game on it (P13, P14). Four of them chose it as their preferred one because it was challenging, forcing them to *push themselves and be strategic with their planning* (P18). Others considered the challenge too much, and reported not having time to learn how to overcome it (P6).

In general, participants said they struggled with the number of different rules among the three levels of the game. P4 and P19 pointed out that it was confusing that the dynamic changed; e.g. you recharge energy in the second level when you close your eyes and makes you feel safe, but that does not apply to the last scenario. However, participants praised the lack of use of the hands to play (accessibility); and the novelty and enjoyment of having to close your eyes (P3), sometimes making you "*feel silly*" (P8).

6.6 Discussion

6.6.1 Design Implications

Based on the results from both user studies, it is necessary to discuss the implications to support a potential experience using the proposed gaze technique for interaction. Designers need to guarantee the successful use of the technique. If using a circle as a reference, the target needs to be at least 4° diameter for static targets (fixations); 5° diameter for targets that require saccadic eye motion; and 7° diameter for moving targets (pursuits). Nevertheless, this can be reduced if we increase the size of the represented area for gaze (e.g., rather than considering gaze as a single pixel, it could cover a bigger space). For instance, we could decrease the size of a target to 2° if the avatar (the gaze-point in the game scenario) is at least 2°. Moreover, we must note that if the tracker were inaccurate, the technique would not be unusable or it would compromise enjoyment. As gaze pointing happens behind the lid, the user has no visual reference on where they look at. On eye-opening, inaccuracies could be seen as a wrong prediction, and refinement would happen in the next try.

Further, static targets are more likely to be hit with gaze than moving ones. This insight does not suggest that moving objects should be avoided, but introduced with moderation in the game. Designers must consider the potential offset of the technique with this kind of target. Additionally, the accuracy when aiming at targets is improved when doing it freely rather than waiting to open the eyelids. That said, introducing both factors as dynamics in a game allows developing different levels of complexity and a window to explore players' strategies. The results confirmed our hypothesis that predicting the position of static objects based on fixations is easier than saccadic or targets in motion, the latter being the most challenging one.

Finally, as demonstrated in the game prototype design, the technique necessitates strategies to guarantee the use of eye movements with the eyelids closed (game rules), and mitigate the tiredness of performing it. Study 1 results reported that the mechanic is perceived as tiresome. However, the study task is tedious by design. Participants were asked to perform the technique repeatedly, fast and precisely. Therefore, the results are limited to insights on workload for a continuous, and probably stressful, use of the technique, which is mitigated in the game design (e.g. rules to rest sight by waiting with closed eyes, the sleeping metaphor to restore energy). The experience questionnaire's results support the technique is fatiguing but engaging and fun in the game. Moreover, the insights from qualitative data suggests participants appreciated the strategies for mitigation (P13, P18).

6.6.2 Challenging Gaze Interactions

Following what P10 said, the use of gaze interaction in games can sometimes feel like cheating. Gaze-enabled games leverage the natural attention of the eyes to trigger game interactions. These can improve the performance of the game or increase the feeling of immersion by using gaze to affect the camera rendering dynamically [96]; help the player to tag the characters (enemies) they look at, or support weapons to aim and shoot at gaze. Overall, gaze interaction can be perceived to give away too much because it is used to facilitate a better gameplay performance, with a chance to remove all challenge from the game [49].

The actions we can perform with the eyes are limited. However, there is a trend to introduce more challenging and playful gaze mechanics. In *Keyewai* [9] players need to control the character's movement with a controller, while gaze is used to direct the orientation of the avatar's torch. If the light aims at a cannibal, they will attack the player, requiring them to be aware of where they are looking at. Others, like in *Shynosaurs* [270], create an attention dilemma for the player to juggle between looking at their primary task or looking at the enemies to stop them. Overall, using gaze to make the game inherently more challenging does not seem like a bad idea, as it can provide a fun game experience.

With *KryptoneEyed*, we challenged the general use of gaze interaction for efficiency (looking at the game) and created a mechanic that plays with the opposite interaction (not looking), but still makes sense (it is meaningful). We mapped the action of closing your eyes to trigger gaze interaction and use it in three different game scenarios (instantiations): to attack; jump; move; or recharge. Our results show how the mechanic was perceived to be easy to perform, and players felt competent at it while maintaining the right balance in the challenge of the game. In the *Maze* level, participants reported perceiving the proposed gaze interaction as pleasing and satisfying to perform. Here, the game challenge is inherent in the learning of the new technique, whereas *the Shooter* and *the Boss* level challenge the use of the mechanic to meet a specific objective. As a guideline, the shooter game was challenging in handling the different events, and designers need to be careful not to overcrowd the list of tasks the player needs to take into account.

On the other hand, the challenge of the fast-paced game resided on mastering the technique. Given the short time that the participants played *KryptonEyed*, designers must not avoid using the mechanic in a similar scenario, but introduce strategies to mitigate the player's disengagement, e.g. a longer tutorial; allow retrying the level instead of starting the game.

6.6.3 Designing for the Unseen

One might ask why creating a game with beautiful aesthetics and make the player close their eyes, and in some cases keep their eyes shut. It might sound counterproductive and unexpected to not look at the game, using a sensing technology that relies on looking. This should not be seen as a drawback but an opportunity to emphasise play aesthetics that strengthen the use of gaze interaction beyond pointing.

In contrast to other games that rely on "not looking", *KryptonEyed* does not force the dynamic as a penalisation. *Virus Hunt* [266], for instance, punishes the player when they look at the viruses by spreading them. In the game *SuperVision* described in the previous chapter, the player is continuously penalised when looking at targets, so they have to play using their peripheral vision capabilities. Here, we introduced consequences to looking at the scene (by gradually losing energy) but also rewards by closing the eyes. We do not forbid looking, even though it is limited, and therefore grounding the challenge of using the gaze technique.

The rules introduced in the game helped to guarantee that the player performed eye movements behind the eyelids. We believe the presence of a researcher observing participants playing contributed to them not cheating - trying to fool the system by having the eyelids half open. However, if squinting as a trick were to happen, there would be two effects: unnecessary fatigue added (it takes more effort to squint than close the eyes), and there would be occasional unwanted hits with negative game effects, e.g. energy loss.

In the *Shooter* game, the player can look at the monsters, but it is challenging to attack them without performing the eye movements, e.g. closing the eyelids quickly on *Kryptoxations*, or they will go smaller; closing the eyes away from *Kryptoccades* or they move away. Overall, the player needs to rely on their visual field, but not explicitly aligned with the focus of their vision before closing their eyes for interaction.

Therefore, the game relies on the players' visual periphery awareness. Mostly present during the *Shooter* level, players are penalised if they look at the targets before shooting at them. Accordingly, they need to predict the target's position behind their eyelids based on what they've seen in their peripheral vision. We usually rely on peripheral vision to search for specific objects [213, 189]. Some players shared finding hitting the yellow monsters easier than the other ones because they had to look at it quickly without looking at it and relying on peripheral vision. We identify peripheral vision as an asset to explore in further gaze-enabled games research.

Accordingly, the *Boss* level played with spatial perception. The players were required to close their eyes to jump the obstacles, necessitating an estimation of the location of moving targets. On the whole, developing gaze interaction challenges like the one in *KryptonEyed* can deliver new approaches of not just playing with gaze but leverage our visual capabilities.

6.6.4 Gaze Metaphors

Gaze interaction metaphors offer the possibility to project an action from the real world into the game space, opening the space for novel design opportunities. In *KryptonEyed*, closing one's eyes is aligned with metaphors that contextualise the need to perform such action. We refer to the term *metaphors* to describe the gaze mechanic related to a narrative and a parallel human behaviour that users can connect with to perform the interaction. Although the action is presented to trigger teleportation; attacks or jumps, we could describe the mechanic with different behavioural metaphors describing *"not looking"* as an action.

First, *teleportation* could be considered as a metaphor to imagine where you want to go. In fiction, we have examples like in the 1939 "*The Wizard of Oz*" film [67]. During the iconic "*No place like home*" scene, Dorothy is asked to close her eyes and think about home, to be magically later transported back to Kansas. Similarly, in *KryptonEyed* closing one's eyes serves to make the player think about (and look towards) their next destination behind the eyelids.

Similarly, in the *shooter* level, this action is translated into teleporting to attack the enemies. One could see this action as a "*look that kills*" metaphor previously used in the game *SuperVision*. On the other hand, the presented interaction leverages the capability to roll the eyes behind the eyelids. This action could be used as a strategy to hide the intention to attack and catch the enemy by surprise. To an extent, moving your eyes while closed could be used as the metaphor to avoid *spoiling* one's intentions. Moreover, it could illustrate a *concentration* metaphor. When we need to think or focus, on something, we might tend to close our eyelids for a moment to settle our attention in the task. We use this behaviour in *KryptonEyed*, for instance, to jump an obstacle.

Finally, we introduced the closing of the eyes as the metaphor to make the character rest and restore powers. Accordingly, in the game *Nevermind* [171], the player can close their eyes to pause the game and relax when the experience gets too intense, regaining a moment of calm. The same action could be performed to signal trust, or a "*blind faith*" metaphor. We can close our eyes to indicate that we feel safe and rely on that when not looking, we will not experience any harm. In the same way, the action could be seen as a survival metaphor, making us close the eyes when in danger. In *Invisible Eni* [56], this is explored by making the player's character disappear when the eyes are closed to avoid the attack of the monsters. In a nutshell, this chapter showcases a broad list of metaphor examples that explain the same gaze mechanic, illustrating the opportunities to design interactions with narratives in mind.

6.6.5 The Price of Gaze Power

Participants performed the tedious performance test before playing the game, leading to a perceived cognitive and eye tiredness regardless of our efforts for mitigation. We consider this as a limitation. *KryptonEyed* is challenging and requires the players to push themselves to complete the different tasks. Looking extensively at a screen can cause frequent headaches; dry eyes; blurred vision; and eye fatigue, leading to Computer Vision Syndrome [38]. One solution to prevent this is to blink regularly. Ironically, even though the game requires players to close their eyes, we are not suggesting it is the solution. On the contrary, we cannot be sure, and there is not enough evidence to conclude gaze interaction alone creates eye tiredness.

On the other hand, as designers, we could modulate the amount of time the player spends looking at the screen, or in our case, the time the eyes are closed. In the *Shooter* level, by introducing the avatar weakness to *Kryptoneye*, we made the player necessitate to close their eyes for longer so they could restore their energy and keep playing. This could be useful to make the player rest from using the proposed mechanic and leverages "not looking" metaphors ("resting") to make the player pause the game. In other scenarios, not looking at the screen could make the game pause [171, 252], e.g. while playing with the phone and walking.

In *KryptonEyed*, we require players to perform something that, to some, can feel an unnatural and uncomfortable use of gaze in games. However, there is nothing natural about selecting objects with the eyes, even though it feels intuitive. Nevertheless, uncomfortable interactions, when designed carefully, can become a good asset to promote, for example, entertainment [15]. While some players felt the interaction was tiring, and even felt "embarrassed" or "silly" (P8); they generally liked the game experience and enjoyed the connection between the game avatar and the gaze interaction. This points out the game aesthetic value of the proposed technique. However, the mechanic might be more suitable to be used occasionally and during shorter periods, rather than as the primary game control.

6.6.6 Game Opportunities

In *KryptonEyed*, players thought the use of the metaphors for gaze interaction was meaningful. This refers to the relationship between what they were doing and the interaction in the game, e.g., closing your eyes to rest or to prepare an attack. In real life, not if we had powers, but when we need to concentrate, we could close our eyes for a moment and take a deep breath. Only then might we be ready.

Accordingly, gaze input has the potential to integrate a "natural" input for game control, mapping what the eyes can do in real life into actions happening in the game. This has been widely explored in the Natural User Interfaces research corpus with voice interaction emphasising the importance of the relationship between the users' game and real-world identity [26]. Let's take as an example, gaze interaction in the *Tomb Raider* games [172]. One of *Lara Croft*'s abilities is that she can climb and jump over dangerous and deadly space voids. She groans, but she does it without even blinking. In the gaze-enabled version, players can use gaze to aim at the direction of the jump and trigger it with the controller. However, would we feel more immersed in being the *Tomb Raider* if she, as we would do, took a moment to close her eyes and breathe? Would the interaction become more meaningful? This poses several questions on how to integrate the proposed gaze interaction in already established games but promises opportunities of augmented immersion worth further research.

Overall, in *KryptonEyed* we explored the diverse outcomes the proposed technique could offer for gameplay, for example, to prepare an attack; recharge energy; teleport; navigate; jump; disappear, or concentrate on using your superpower. This suggests that there are multiple opportunities to design gaze interactions based on these metaphors in games, including other genres and in combination with other input modalities.

6.6.7 Midas Touch and Double-Gaze Interaction

To some extent, we are proposing to leverage the Midas Touch problem by designing a two-way gaze mechanic. In gaze interaction, the Midas Touch [262] problem appears when we naturally look at objects of interest, but also use gaze for explicit interaction, triggering unwanted selections. The Midas Touch can be avoided by encoding gaze gestures for interaction, like eye movements to the sides [1]; or matching onscreen motion [272, 129]. Moreover, another solution to avoid unwanted selections is to use gaze with another input device: gaze signals interest, and other input modalities confirm, such as the mouse [289]; touch [198]; or voice [190, 257].

In contrast to multimodal mechanics using two different modalities, we use gaze only. First, gaze pointing is used as the primary mechanic, whereas explicitly closing the eyelids is the modulator. Gaze is used as both the sensing indicator and the input that confirms the command. In gaze interaction, *blinking* has been used in accessibility contexts to indicate a gaze selection [133]; or to model social behaviours in games when "charming" avatars [40]. In this chapter, we use a similar paradigm: the closing of both eyelids to leverage that we can perform eye movements while the eyelids are closed. Here, we expand the already limited list of actions we can do with our eyes for game control. This could create new opportunities to design accessible interfaces and new interaction mechanics using the eyes only. The principle could be extended and applied, for example with closing/opening of just one eye, which we explore in the next chapter.

However, our study is limited in providing an understanding of how quickly the technique can be performed or how robust the method can be. When playing games, the user can get excited and move around, compromising the eye tracker detection, sometimes necessitating re-calibration [61]. Nevertheless, this would only compromise the gaze accuracy for pointing, rather than the detection of whether the eyelids are closed. Whereas eye tracking robustness is an important matter for future improvement, the scope of this chapter is to provide the first step towards more meaningful gaze interactions in games that move away from traditional gaze pointing.

6.7 Conclusion

In this chapter, we presented the concept of *playing without looking*, introducing the explicit closure of the eyelids to trigger gaze interaction as a novel game mechanic. We developed a conceptual framework that explores three dimensions of the technique leveraging the physicality of the eyes, the eyelids, to use it for game interactions. We tested these dimensions in the game *KryptonEyed* including three game examples where the technique is instantiated and showcasing new gaze-based metaphors that contextualise the mechanic in the games.

The adoption of gaze interactions in games is broadly aligned with mechanics that rely on looking at the game scene. Not looking is unexpected because games are designed to be looked at with their beautiful aesthetics. In gaze interaction, not looking is even more unexpected, because eye trackers are designed to sense wherein the screen the user is looking at, and the absence of this signal is usually ignored in application's design. There are game examples that leverage this signal to auto-pause the game [171], or to integrate socio-cultural behaviours such as charming winks [40] or reflexes of protection [56]. However, these interactions are limited by only utilising the closure of the eyes as short events. Here, we suggest we can do much more when we do not look and leverage eye movements behind the lids. We investigated with *KryptonEyed* the feasibility of the technique, accuracy of pointing with gaze with the eyes closed, and the emerging experience introduced in the game. Results show how participants were able to overcome the pointing challenge and enjoyed the game experience. Players perceived the interaction to be easy to use; they felt competent at it, and although they reported the technique was tiring, they thought it had a meaningful purpose with the appreciation of the resting metaphors introduced in the game. We deem there are many opportunities to develop novel gaze interactions based on not looking in games. Briefly, we summarise the key takeaways:

- We explore a novel game mechanic leveraging what we can do with the eyes closed, contributing to advancing the use of gaze in games research. Beyond the presented technique, this chapter continues opening up the distinct design space of inquiry into interactions encouraging "looking" versus "*not looking*", and eye movements with our eyes open versus closed.

- Playing without looking opens up opportunities to use eye tracking playfully beyond gaze pointing by presenting the challenge of predicting the position of targets with the eyes closed. This contrast with the prevailing adoption of gaze input as a utility for efficiency, for example, to select targets faster.

- One of the central problems in using eye gaze for pointing is the Midas Touch, for which our work inspires the use of eye closing/opening as initiation and confirmation events. This enables hands-free interaction which can be of particular interest for accessibility.

- We discussed metaphors of gaze behaviours aligned with the concept of *playing without looking* that can inspire new opportunities in game design. These moves away from the widespread adoption of gaze interaction to follow the "what you look at is what to get" metaphor, and puts forward new gaze behaviours.

Overall, this chapter continues contributing new opportunities for gaze interaction in games by showcasing the use of eye movements without looking in a creative game prototype. In contrast with previous chapters that focus on concepts that make the user look away from the game, here, we explicitly required to play without looking by closing the eyes. We discussed the opportunities to use gaze playfully beyond the widespread adoption of gaze for efficiency, and "*not looking*" metaphors of gaze behaviours beyond gaze pointing with the presented technique. Based on our results, future work can explore the potential of integrating the proposed gaze dynamic with other mechanics and in different game genres. Finally, the concept presented in this chapter supports the emergence of a new space for inquiring interactions based on not looking, which is further discussed in the following chapters.

7 From Play to Interaction

In this chapter, we move away from our investigation of novel ways to adopt gaze input in games to showcase how thinking playfully about gaze can lead to the design of new techniques for eyes-only interaction. However, this chapter is connected with the previous games for two reasons. Firstly, although the interaction technique we will present is used for general interface interaction, it could also be used for in-game interaction. Secondly, the concept of "not looking" emerging from previous chapters draws us to investigate how closing the eyes can be further explored for interaction. The interaction technique discussed in the game *KryptonEyed* inspired the use of eye closing and opening as initiation and confirmation events. Nonetheless, it is limited by introducing tension to the interaction by requiring the user to close both their eyes. Although this tension has served as a design resource in play, it might not be desirable when using gaze input as a utility for eyes-only interaction with mainstream applications. For instance, closing both eyes to teleport the game character can be perceived as a fun action to perform in games, but it would have poor usability to drag and drop a file on a desktop interface. Accordingly, we propose using the closure of one single eye to indicate start and end events, whereas the open eye can be used for gaze pointing, and we propose using it to enable the drag-and-drop of virtual objects.

Here, we propose to leverage the eyes as two separate sources of input that can be combined to support continuous, direct manipulation. Even though we have two eyes, they are commonly treated as a single input channel. Eye trackers fuse input from both eyes to provide a continuous stream of gaze estimates in one single gaze point. However, humans can voluntarily open and close their eyes independently of each other, and keep either eye closed while still gazing with the other [124]. The eyes can therefore be considered as separate input channels, where the open/close state of either eye can be used to modulate gaze input observed from the open eye. We thus propose *Gaze+Hold* interactions that are initiated by closing of an eye, followed by continuous input, and completed when the eye is opened. We showcase and study the use of the technique for drag-and-drop interaction. The core concept of Gaze+Hold is to leverage the movement of the opened eye, whilst the closing of the other eye changes the interaction state. The *Gaze+Hold* technique raises four fundamental research questions:

- How accurately and precisely can user's gaze be detected when one eye is closed using a consumer-grade binocular eye tracker?
- How is the gaze point accuracy affected when transitioning between states, from both eyes open to one eye being closed?
- How well and fast are users with Gaze+Hold technique and if there a preferred eye (dominant or non-dominant) to perform the wink action?
- What type of interface and object manipulations can be enabled with Gaze+Hold interaction?

We describe the interaction technique Gaze+Hold to enable the user to grab an object of interest and move it to a different position in the interface with the eyes only, e.g. in a desktop interface with files and folders. The technique has a similar workflow to the

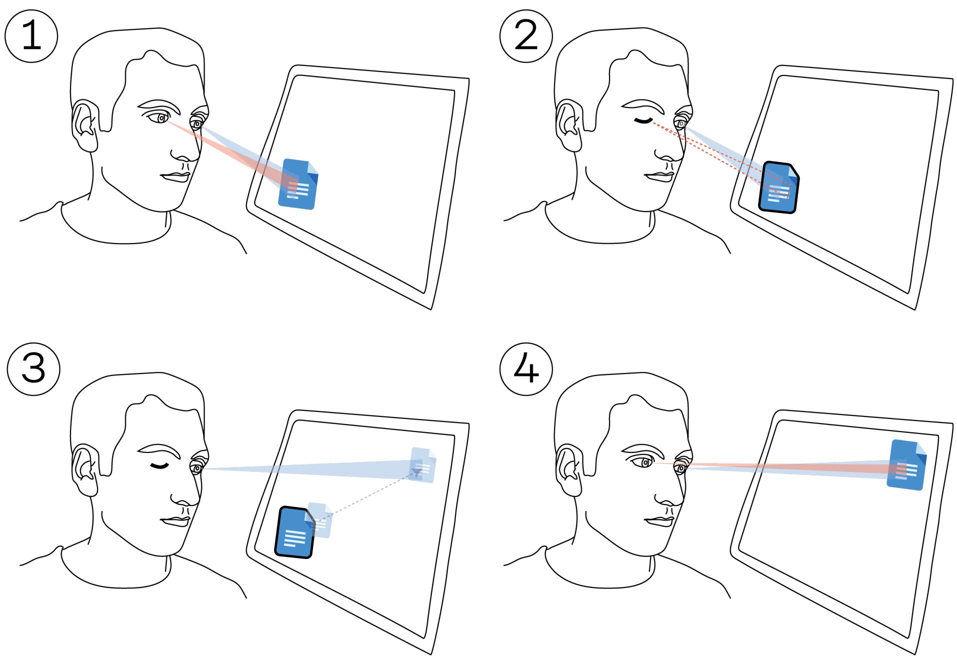


Figure 7.1: The use of Gaze+Hold to enable *Drag-and-Drop*. (1) The user looks at the object of interest; (2) The object is selected when one eye is closed; (3) The object can be dragged with the open eye as long as the closed one is held; (4) The object is dropped when the eye is opened.

traditional mouse interaction to drag and drop a file. With Gaze+Hold, the user can look at the file they want to drag and drop (*Figure* 7.1, 1). Further, the file is selected and attached to the gaze point on the closure of one eye (*Figure* 7.1, 2). As long as the state is held, the file can be moved. With the open eye, the user can look at the target position where they want to drag the file to, and a semi-transparent replica of this will follow the gaze point (*Figure* 7.1, 3). Finally, when the eyelid is opened (*Figure* 7.1, 4), the file will be dropped where the user is looking at.

In this chapter, we evaluate the precision, performance, and feasibility of Gaze+Hold for drag-and-drop interaction. Further, we present an exploration of the technique through the design of a range of novel eyes-only direct manipulation techniques. As we will show, it is not straightforward to map techniques that are well established with other modalities to input from only the eyes. The eyes function as both sensor and actuator necessitating careful consideration of input and feedback, and their movement is saccadic, and "restless" as fixations are short and jittery [118, 289]. The eyes are also distinct in that either eye can be used to gaze and point while the other is closed, although most people have a dominant eye [57]. We explore these issues through the design of techniques for common interface tasks including drag and drop; menu navigation and selection; selection of multiple objects; scrolling, zooming and panning; navigation, teleportation and view control.

7.1 Eyes-only Interactions

Interfaces that can be operated with just the eyes have been developed for accessibility [106, 84, 286], instant control [60, 267] and discreet input [44, 128]. As human vision is foveal, our eyes naturally shift to objects of interest for interaction. Their movement is faster than other body movement, and requires less energy and effort than input with head or hands [136, 289, 228]. Eyes-only control is therefore compelling for a wide range of contexts where other input is unavailable, not as ready to hand, or inconvenient.

Historically, much of the work on eyes-only interfaces is framed as mouse emulation [144]. Blinks and winks have been explored to mimic button events in order to make techniques designed for the mouse accessible [169, 132], whereas the focus of this chapter is on design for eyes-only direct manipulation. In analogy to mouse behaviour, Istance and colleagues discussed different modes for gaze input, including discrete selection (point and click), continuous manipulation (dragging) and disengagement from cursor movement and control to let the eyes freely look at the interface without unintended input [114]. In their work on Snap Clutch, the modes are activated by quickly glancing off-screen (up, down, left or right). Gaze+Hold is conceptually different in supporting a default state from which specific input modes are activated by closing an eye, and active only for the duration of eye closure. This lets users keep their gaze focus on the object they intend to manipulate, with default gaze behaviour instantly resumed once an input task is completed by opening the closed eye.

The key idea underpinning our work is to use closing and opening of one eye, to modulate gaze input performed with the other. The literature refers to the closing/opening of one eye as wink, contrasting blinks performed with both eyes [125, 169, 132]. A wink is a holistic gesture whereas we build specifically on eye-closing and eye-opening events to trigger and delimit direct manipulation. However, there is a large body of work on which we build. Some of the earliest eye control interfaces were based entirely on blinks and winks, highlighting the utility of eye closure as input [225]. Single-eye closure has the advantage that it rarely occurs involuntarily and is less prone to false positive input [132]. Most people can use either eye to wink but some tend to close both eyes when attempting to wink with the dominant eye [193]. Importantly for this work, movement of the eyelid is independent of movement of the eyeball [124], and people still have full gaze control when they close one eye. In manual targeting and manipulation tasks, closing of one eye tends to only minimally effect performance, with performance slightly better when the dominant as opposed to non-dominant eye guides the task [35, 158]. For this chapter, this prompts comparison of dominant versus non-dominant eye for "one-eyed pointing".

Prior work has also considered design of interaction techniques based on eye closure. Winks and blinks have been widely considered as a delimiter for gaze input [84, 169] as well as other modalities [275]. It has also been shown that winks and blinks can be effective as command gesture, for example as shortcut to smartphone functions [134], for switching between different views [94, 124], or as part of larger eye gesture vocabularies for users with severe motor impairment [291]. There is also interesting work on input with both eyes closed, for example to perform gaze gestures for password entry [63]. Jota and Wigdor provided a wider exploration of the design space of eyelid gestures, noting for example that duration of eye closure can also be used for input [124]. Hemmert and colleagues provided compelling use cases for closure of one eye to temporarily change the perspective of the user, for instance to zoom into a scene to see detail [94]. Gaze+Hold is likewise based on eye closure to control state, but extends beyond view control to modulation of input and eyes-only direct manipulation.

7.2 Gaze+Hold: Eyes-only Direct Manipulations

Several attempts have been made to understand how gaze can be used for object manipulation. Some used multimodal interaction with touch [200], multi-touch [196], or a pen [199]. These rely on using gaze to modulate the interaction, whereas another input triggers the action [197]. Moreover, gaze has been proposed to move content from one point to another with catch-and-release-like mechanics. Traditionally, this is performed by looking at a target that needs to be moved, and the target location while keeping a key pressed [120, 95]. Similar paradigms have been investigated to move content using gaze and voice [58], or gaze and touch [248, 235], focusing on the transfer of content supported by gaze [249] between devices. These mechanics rely on the user looking at a target, touching a multi-touch surface, and looking at the desired destination to "eye cut & paste" or "eye drag & drop" when the touch is released [250]. *Mistry et al.* [170] proposed a system to move a robot based on looking at the robot and its desired destination, confirming with blinks twice both activation and movement. Our work is related to these examples in providing a solution for drag-and-dropping using Gaze+Hold. However, we are in contrast in providing a hands-free solution using gaze only in two-steps. We combine the explicit closing of one eye to modulate gaze input from the open one.

7.2.1 Selecting and Moving Objects with Gaze+Hold

Selection and moving of objects are canonical tasks in graphical user interfaces. We implemented a set of Gaze+Hold techniques equivalent to basic mouse operations:

Selection. In Gaze+Hold, a selection is performed by gazing at an object, and closing and opening of one eye while gaze remains in position. This is effectively point-and-click with a wink gesture as click method [169]. However, selection can also be implemented as two-step with eye-closing to hover, gaze to evaluate feedback, and eye-opening to confirm.

Drag-and-drop. An object can be moved by gazing at it, eye-closing to select it, gaze pointing to a target location, and eye-opening to drop the object (Figure 7.1). Like selection, this is a basic technique where gaze input is purely positional. It can be performed quickly with a direct gaze shift to the target, but also allows for multiple gaze shifts, for the eye to search and evaluate target locations before committing to dropping. *Drag-and-drop* puts the focus of Gaze+Hold's state change on the content in the interface. The interaction is dependent upon the initial gaze point (e.g. a file) before the eyelid closes. Continuous eye pointing allows the object to be moved until the closed eyelid is opened again. The last gaze position recorded is used to drop the file in a new location. This technique can be integrated not only in the desktop environment but in editing tools and applications that include content manipulation methods - e.g. to move images in an editing workspace.

Cut/copy-paste. A Gaze+Hold version of copy-paste involves the same mechanics as drag-and-drop, but the object is copied rather than moved. As we have two eyes, related actions can be mapped as a pair. We designed a combined technique where left-eye selection is for cut/copy and right-eye selection for pasting. The left-eye selection cuts the object if it is performed with a quick wink, but takes a copy if the selection is performed with a brief gaze fixation between eye-closing and -opening. This uses a metaphor of fixating, illustrating how variation in gaze can select different actions. This need not involve actual detection of a fixation but is an example of time-dependent positional input (duration of eye closure).

7.3 Study 1: Accuracy & Precision During Wink

Te technique presented relies on the user's ability to look at points of interest with one eye closed, and the eye tracker's ability to detect this accurately. In addition, the technique relies on the gaze position prior to when the eye is closed, and subsequently, the gaze position of the opened eye. Accordingly, the use of Gaze+Hold raises questions on how accurately, and precisely the user's gaze is detected when one eye is closed and whether accuracy is affected when transitioning from two eyes open to one closed eye.

In binocular eye tracking, the estimated gaze position is traditionally the arithmetic mean from both eyes, which results in a lower error compared with measuring either eye separately [39]. Due to the physical requirement of the user to keep one eye shut, investigating the detected accuracy of a single opened eye is succinctly different from the conventionally defined monocular accuracy. In the latter, only one eye is being tracked by an eye tracker, yet the other eye is open [79].

7.3.1 Tasks

To investigate monocular accuracy and precision of the binocular eye tracker, we performed a 15-point test in which users were asked to focus their gaze on a number of stimuli. The targets were located in a 5×3 grid covering all the screen with distance $11.26°$ of visual angle ($\sim$370 px) horizontally and $12.17°$ ($\sim$400 px) vertically between them. Each target consisted of a grey circle on a black background, with a diameter of 36 pixels, and a centred black dot to focus on, as suggested in [122]. For each target, the users were asked to focus their gaze on the target for 2 seconds. The order in which targets were presented was randomised [122]. Users performed the test with both eyes open, and only one eye open (both left and right).

To investigate the effect of accuracy and precision during the state changes, i.e. between both eyes open and one eyelid closed (and vice versa), we performed a 1-point test using a target located in the centre of the screen. The task consisted of: (1) looking at a target located in the centre of the screen, (2) closing one eye when the target changes colour whilst maintaining gaze with the other eye, (3) opening both eyes when the target reverts to the original colour, (4) repeating steps 2 and 3 for the opposite eye. Each stage required the participant to maintain their gaze on the target for 2 seconds.

The accuracy is calculated as the mean offset between the gaze point and the centre of the target, over the duration the target is presented (2 s). The precision is calculated as the root mean square (RMS) distance between successive gaze data points [97]. Due to the small sample size, we provide descriptive statistics and do not run statistical comparisons.

7.3.2 Participants and Apparatus

Six participants (4 male, 2 female, age: M=26, SD=3.35) were recruited to take part in the study. Two participant's data had to be removed due to poor eye tracking quality. Of the remaining participants, three participants had uncorrected vision and one required glasses. See Appendix C for further details about participant demographics. Three participants' right eye was dominant. One participant had extensive experience using eye tracking technologies, one had a lot of previous experience, one had a little experience, and the remaining participant had never used an eye tracker before the study. One of the participants was the author of this thesis. We must note this does not influence the results, as the tasks are not skill-based but dependent on the capabilities of the sensing technology used. To conduct the user study, we used a *Tobii EyeX* eye tracker under a 24" monitor (resolution: 1920x1080; aspect ratio: 16:9), at 54cm from the user.

7.3.3 Procedure

Upon arrival, participants were presented with an information sheet and consent form, prior to filling in the demographics information. The eye tracker was then calibrated to each participant using Tobii's standard five-point procedure. All participants performed the accuracy test with both eyes open first. We then counter-balanced the order in which individual eyes were used. Gaze data was recorded for two seconds when the user pressed the space key whilst looking at each target. The key-press was included to remove eye movements between targets which could have impacted precision results. Following this,

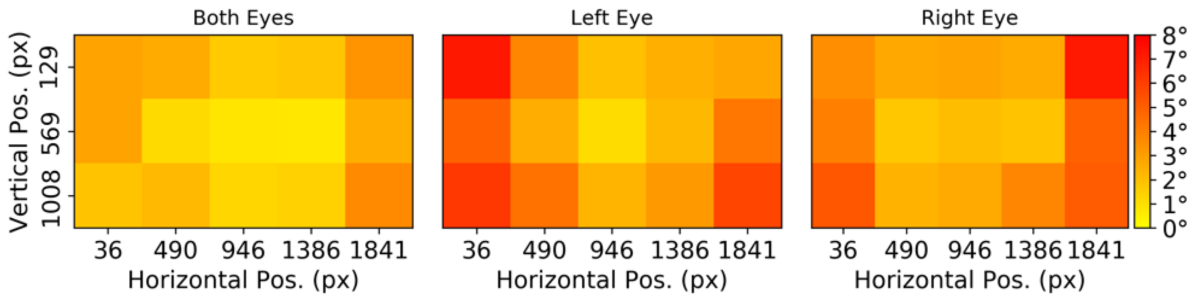


Figure 7.2: Accuracy heatmap results. Each cell represents a target's position on the screen showing the accuracy for each condition.

all participants performed the single, central target task twice. Once they closed their left eye, they followed by their right eye, and then in the opposite order.

7.3.4 Results

Results show the mean accuracy across all the screen for gazing with only the left eye ($3.70 \pm 2.32°$), or right eye ($3.58 \pm 1.24°$) was more inaccurate than gazing with both eyes open ($2.11 \pm 2.06°$). Similarly, gazing with only one eye open was less precise (Left: $0.77 \pm 0.46°$, Right: $0.91 \pm 0.60°$) than both eyes ($0.51 \pm 0.49°$). However, Figure 7.2 shows how the accuracy across all conditions is more inaccurate by the edges of the screen, noting that looking outwards causes more error, with a greater effect when using only one eye.

Moreover, the results from the centre test (Figure 7.3) showed that when opening or closing an eye, there is a brief spike in accuracy, indicating a short deterioration. This phenomenon occurs irrespective of which eye is being opened or closed. This effect could be caused by a readjustment from the eye tracker to adapt to only tracking one eye during the new state, or tracking issues when not able to compensate the partial loss of the gaze signal. The results showed that there might be some noise at the start of a state, in general, the first point of the state is only 0.5° less accurate than the overall state. As the Gaze+Hold technique utilises the gaze position when the eye tracker detects the opening

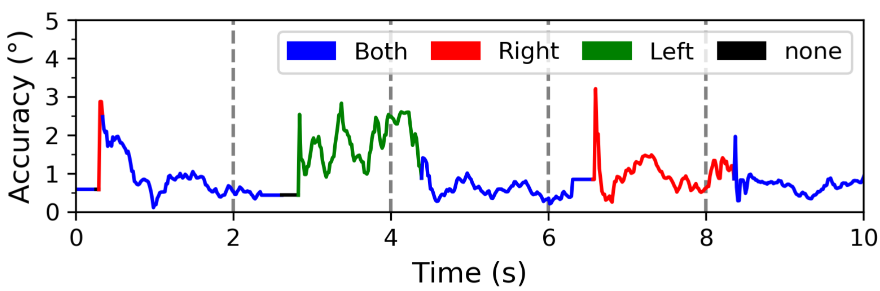


Figure 7.3: Example of eye tracking accuracy during the centre test trial for P3. The colour of the line indicates the open eye. The results shows clear spikes of accuracy error around the opening and closing of the eye.

or closing of an eye, we further investigated the difference between the first point of the new state compared to the overall accuracy of the state. The difference in the reported accuracy when closing the eye was $-0.12° \pm 0.54°$, and $-0.15° \pm 0.86°$ when opening the eye. Figure 7.3 shows an example of the centre test for participant 3 and showing there are spikes in the reported accuracy during the transitions. However, these do not have a significant effect on the initial and end gaze points. Therefore the last gaze point of the previous state during a transition should be used for determining the start and end points of a Gaze+Hold interaction.

7.4 Study 2: Performance and Usability

We conducted a second user study to evaluate the performance of Gaze+Hold. The study aimed at understanding how well and fast participants can use Gaze+Hold to drag-and-drop an object with either monocular vision (for dominant and non-dominant eyes) or looking with both eyes but pressing a key to confirm selection [95] as the baseline. Moreover, we tested the spontaneous users' choice to favour the closing of one eyelid against the other in a drag-and-drop task in a virtual desktop environment. Further, we measured the workload of Gaze+Hold in both tasks.

Performance:

We designed a task resembling the multi-directional Fitts' Law task used to evaluate gaze pointing usability [268, 218]. The task presents 16 targets in a circle with the origin at the centre of the screen (500px diameter, $\sim$19°). Participants were tasked with dragging and dropping a square-shaped object (75x75px, $\sim$5°) from one target to the next. The targets were circular with diameter: 5° ($\sim$130px) - see *Figure 7.4, A*. The goal of the task is to catch the object and drop it as close to the centre of each target as possible with Gaze+Hold or the baseline.

During the task, only one target appears at once. The square starts on the opposite side to the first target (*Figure 7.4, B_0*). This needs to be dragged from one target to the next. On "hit", the target disappears and the next one is displayed (*Figure 7.4, B_2*). The order of the targets follows the Fitts' Law task procedure. We measured the time it takes to perform two loops, dropping the objects on a total of 32 targets; and the distance between the centre of both target and square object on the drop.

Spontaneous Preference:

We designed a task resembling a computer OS desktop application using Gaze+Hold's drag and drop technique. We chose this application as it resembled the performance task in a real use scenario. A total of 16 different files (4 each: docs, sheets, slides and images) were scattered around the desktop. The task's goal was to move them to their corresponding folder. During the task, the completion time and which eye is closed when "grabbing" a file were recorded.

Usability and Workload:

For both tasks, we used a custom-made questionnaire comprised of five 5-point Likert scales to gain feedback on Gaze+Hold interactions: (1) "*I felt comfortable moving objects*"; (2) "*I felt confident moving objects*"; (3) "*I found it easy to grab objects*"; (4) "*I*

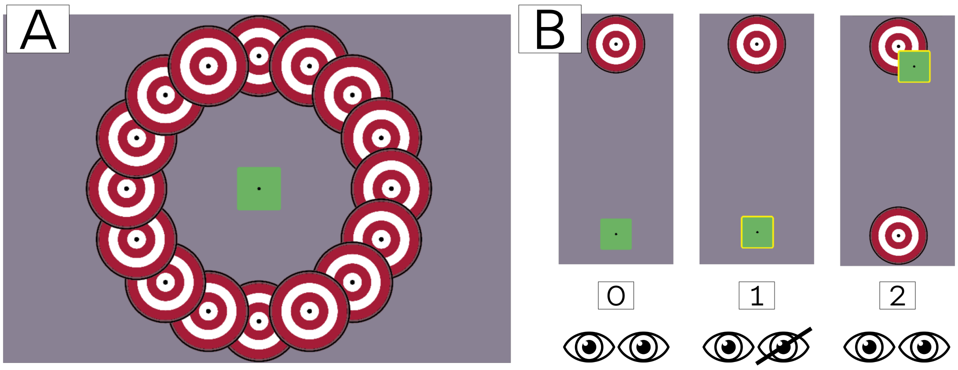


Figure 7.4: Gaze+Hold Performance Task: (A) Task set-up; (B) Task procedure schema: the user is required to drag-and-drop the square from target to target.

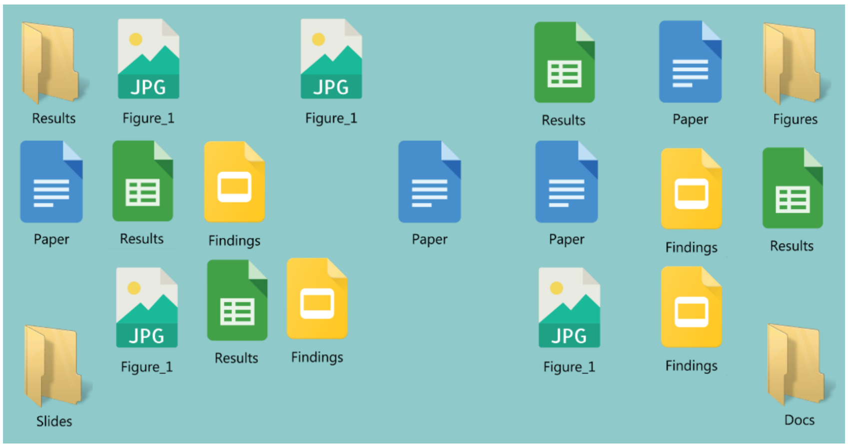


Figure 7.5: Gaze+Hold Desktop Files Task for Spontaneous Preference. The participants were required to drag-and-drop the files to their corresponding folders.

found it easy to decide the next position of the object";; and (4) "*I found it easy to release objects*". Each statement needed to be rated on a 5-point Likert scale (1 = 'Strongly Disagree', 2 = 'Disagree', 3 = 'Unsure', 4 = 'Agree', 5 = 'Strongly Agree'). Further, we used the NASA-TLX questionnaire to measure each task workload [89]. Every time the questionnaire was administered, both the pairwise comparison and the scale rating sections were answered.

7.4.1 Participants and Apparatus

Twelve participants took part in the study (8 male, 4 female, age: M=25, SD=3). Four of the participants wore glasses, two contact lenses, and six had uncorrected vision. Four of them were experienced with eye tracking or gaze interaction. From all the participants, ten had right-eye dominance, and two had left-eye dominance according to the eye-dominance test [273]. See Appendix C for further details about participant demographics. To conduct the user study, we used a *Tobii EyeX* eye tracker under a 27" monitor (Resolution: 1920x1080; Aspect Ratio: 16:9) located 40cm from the user.

7.4.2 Procedure

Upon arrival, participants were presented with an information sheet and consent form, prior to filling in the demographics information. They were then asked to wink at the researcher to note their spontaneous eye choice for winking. Finally, the eye tracker was calibrated for each participant using Tobii's standard five-point procedure. The resulting accuracy profile was controlled using the built-in tool for self-assessment, and the system was re-calibrated when necessary.

The performance task was repeated for three eye pointing conditions: dominant, non-dominant, and both eyes open. For the both open eyes condition, the participant was instructed to hold the key to pick up the object. The order of conditions was counterbalanced via *Latin Square*. Before the task, the participants had the opportunity to practice with the techniques. Participants performed the task four times (128 target hits) and were instructed to complete each task as quickly and as accurately as possible. After each condition participants answered both the custom-made questionnaire and the NASA-TLX.

Finally, participants were asked to complete the *desktop* task as fast as possible, using Gaze+Hold with whichever eye they prefered, and completed the NASA-TLX.

7.4.3 Results

We present the results from the performance task comparing the baseline (*Base*) to using Gaze+Hold with the dominant (*Dom*) and non-dominant (*NonD*) eye open. The accuracy results are reported in visual angle. For the accuracy, we only consider successful "drops" of the object on the target. We did not include manoeuvring during the task, e.g. dropping the object away from the target, catching it again and re-aim. We define an error as a target which requires more than one drag and drop movement. We compared the compared conditions using a Friedman test. Post-hoc tests were conducted using Wilcoxon signed-rank test.

7.4.3.1 Gaze+Hold Performance

There were statistically significant differences for performance accuracy ($\chi^2(2)$=440.13, ρ<0.001); completion time ($\chi^2(2)$=72.67, ρ<0.001), and error rate ($\chi^2(2)$=10.50, ρ=0.005), see Figure 7.6, A-C. In post-hoc analysis, *Base* was statistically significantly more accurate (*Dom*: Z = -18.903, *NonD*: Z=-19.93 , ρ<0.001); faster (*Dom*: Z=-21.87, *NonD*: Z=-27.09, ρ<0.001) and with less errors (*Dom*: Z=-2.51 ρ=0.01, *NonD*: Z=-0.63 ρ=0.53) than using Gaze+Hold.

There were no significant differences using Gaze+Hold with either eye for accuracy (Z=-1.75, ρ=0.079); completion time (Z=-0.53 ρ=0.59) or error (Z=-0.63 ρ=0.53). *Figure 7.7* shows the mean accuracy for each test condition during the performance task in a polar diagram representing all the direction/locations of the targets. Results show that using Gaze+Hold resulted in more accurate drag and drops when performing the drag upwards compared with dragging downwards. For the desktop dragging task, participants completed the task in 55.21 ± 22.18 seconds

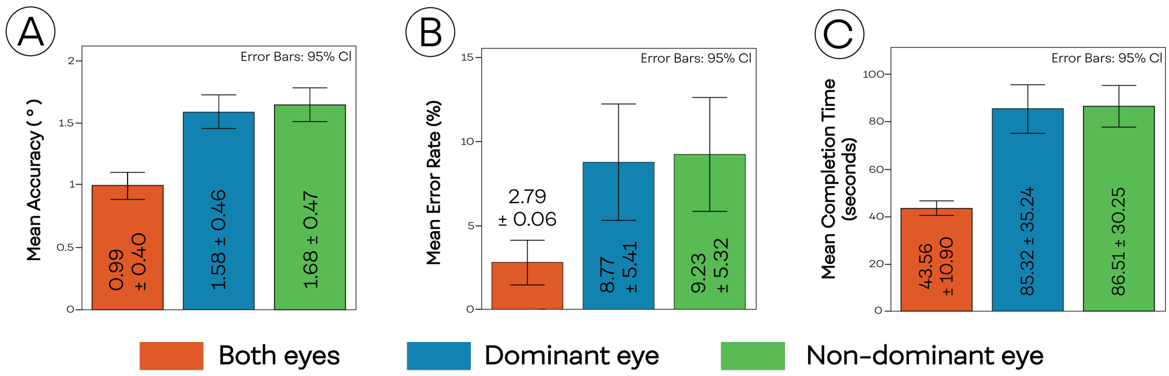


Figure 7.6: Gaze+Hold Performance Results, using either both, dominant, or non-dominant eye. A) Mean Accuracy; B) Error Rate; and C) Task Completion Time.

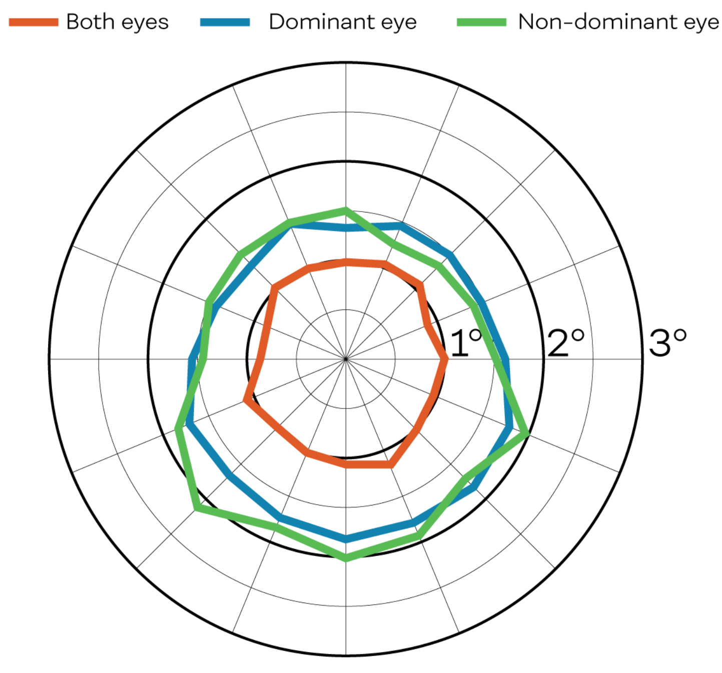


Figure 7.7: Gaze+Hold Accuracy Results for each target's direction.

7.4.3.2 Usability and Workload

Figure 7.8 shows the answers to the five statements related to the *performance* task. Overall, participants felt more confident and perceived the task easier using the baseline than with Gaze+Hold ($\chi^2(2)$=53.69, ρ<0.001). However, half of the participants agreed that both Gaze+Hold conditions were comfortable and straightforward to use, feeling confident when using them. Between one and three participants disagreed with the statements, the rest remained neutral.

During post-hoc analysis, using Wilcoxon signed-rank tests (with a Bonferroni correction adjusting ρ<0.017) we did not find any statistically significant difference in the perceived confidence (Statement_2) between the baseline and Gaze+Hold using either the non-dominant eye (Z=-2.31 ρ=0.021) or the dominant eye (Z=-1.40 ρ=0.16). Moreover, no significant difference was found on the perceived easiness to decide the object's position (S_4) with *Dom* (Z=-2.07 ρ=0.038), or to release the object (S_5) with *NonD* (Z=-2.36 ρ=0.018).

For the performance task, we found a statistically significant difference on the NASA-TLX workload ($\chi^2(2)$=15.50, ρ<0.001), however the task load was perceived equal between the two Gaze+Hold conditions (Z=-0.82 ρ=0.409), see Table 7.1. The Effort, Physical Demand, Mental Demand, and Performance dimensions were the main contributors to the workload of Gaze+Hold. The workload for the desktop task was 51.63±15.14, with Effort, Performance and Mental demand as the main contributors.

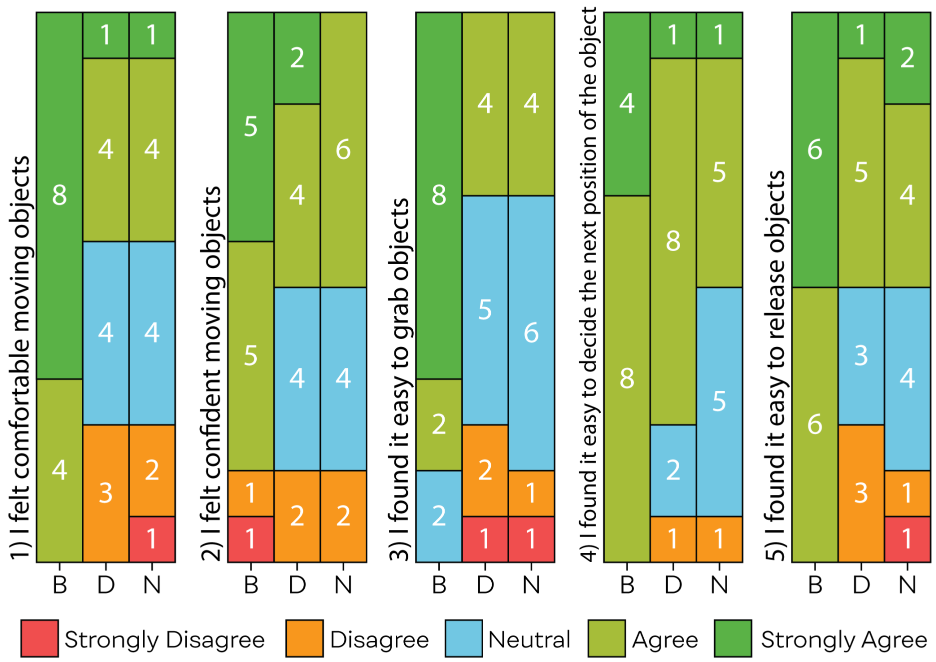


Figure 7.8: Gaze+Hold Usability Questionnaire Results, using either both (B), dominant (D), or non-dominant eye (N).

Table 7.1: NASA-TLX workload Results

NASA-TLX Scale	Both eyes		Dominant		Non-dominant		Desktop Task	
	Weight	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**	**Score**
Mental Demand	3.25±1.47	41.25±24.67	3.00±1.35	60.83±19.77	2.50±1.25	52.08±26.01	2.91±1.65	55.83±25.80
Physical Demand	1.50±1.55	20.83±22.71	3.00±1.77	62.08±27.72	3.08±1.93	59.58±30.98	2.00±1.95	41.17±27.80
Temporal Demand	2.75±1.01	43.33±23.83	1.50±1.19	40.00±21.88	1.33±1.17	37.50±19.41	1.75±1.23	41.17±21.90
Performance	3.83±1.21	23.75±21.71	2.91±1.38	40.00±18.25	3.08±1.25	38.75±20.82	3.41±1.49	37.91±19.52
Effort	2.91±0.95	34.58±22.77	3.75±0.82	69.58±19.73	4.00±1.00	68.75±18.72	3.67±1.24	61.25±18.04
Frustration	0.83±1.21	18.33±21.14	0.91±0.75	36.66±16.37	1.00±0.81	38.33±26.64	1.58±0.95	36.25±20.52
Overall Task Workload		35.30±15.55		**59.67±14.98**		**56.80±15.95**		**51.63±15.14**

7.4.3.3 User Preferences

At the start of the study, eleven participants winked at the researcher with their right eye, and one participant with their left. During the desktop files task, seven participants closed their dominant eye the most, whereas five predominantly used their non-dominant eye. Most participants' results were polarised favouring one eye versus the other one (>80%). However, three participants swapped between using each eye with an approximately 30% versus 70% use. Five participants reported that they preferred to close their dominant eye, whereas six the non-dominant, and one could not decide between them. This resulted in a preference dissonance for four participants that reported to prefer to close one eye but used the other (three dominant, one non-dominant). Accordingly, we found another dissonance between the spontaneous wink performed before the study and the out-loud choice (7 different) and between the wink and the eye closed during the task (5 different).

7.4.4 Summary of Findings

Both user studies demonstrate the feasibility and efficacy of using *Gaze+Hold* for eyes-only interaction, showing how participants can successfully use both eyes separately with the technique. Similar accuracy and precision were observed across either eye for Gaze+Hold interaction, and we observed no statistical differences between the eyes for performance, usability, or perceived workload. In addition, the dissonance between the participants' preferences suggests participants were unaware of which eye they spontaneously used with Gaze+Hold. Therefore, the eyes could be used interchangeably for interaction, providing the flexibility for different configurations or uses of the technique which leverage both eyes for interaction.

The results indicate that accuracy and precision of pointing with one eye closed are worse than when pointing with both eyes open, and the performance of *Gaze+Hold* is reduced compared with the multi-modal baseline technique of gaze and a button press. This could be attributed to the physiological nature of pointing with one eye closed, in addition to the binocular eye tracker being calibrated for both eyes. Study two also involved interaction using Gaze+Hold for an extended period. We would envisage real-life usage of the technique to be based on shorter interactions, as demonstrated in the described applications. Despite this, participants were effective with the technique with either eye closed.

In what follows, we explore the possibilities of using Gaze+Hold to enable direct manipulations with continuous gaze modulated by the closure of one eye. We dissect the concept to propose a framework for Gaze+Hold interactions. Finally, we present techniques and applications that leverage the use of Gaze+Hold to provide eyes-only interaction in mainstream applications.

7.5 Designing Gaze+Hold Interactions

Gaze+Hold defines a distinct style of eyes-only interaction. At a higher level, this is characterised by support of different states for gaze interaction that are controlled by eye closure; and at technique level by continuous gaze input with one eye, delimited by closing and opening of the other.

Gaze+Hold interactions are performed within specific input modes associated with left or right eye, and defined by:

1. Closing of one eye initiates input;

2. Movement of the other eye provides continuous input;

3. Opening of the eye to complete the interaction.

This framing opens up a design space for implementation of eyes-only direct manipulation techniques, for which the following are the key design considerations:

One- versus Two-State. Techniques can have a single top-level state mapped to either eye, or two states with left- and right-eye mappings. Two-state mappings lend themselves to support complementary or opposing actions (e.g. increase/decrease). One-state mappings provide for more flexibility, for instance for user choice of preferred eye, or configuration of the other eye for other functionality to be equally "ready to hand".

Positional versus Compound Input. Gaze input performed during eye closure can be purely positional for pointing. Eye-closing selects a start point, and input is continually tracked for selection of an endpoint by eye-opening. Input can also involve distinct events extracted from the eye (fixations, dwell time, or any form of eye gesture) for compound input. Examples are combination of point and dwell for selection, and multi-step navigation of menus. Purely positional input supports fast interaction for basic tasks (e.g., moving an object) while compound input enables richer interaction and is unbounded with regards to forms of eye expression that can be leveraged.

Input Granularity. Positional input can be leveraged at different levels of granularity, fine-grained for selection of points, or coarse-grained for selection of regions. Eye tracking has well known accuracy limitations that need to be considered in techniques that are based on fine-grained input, while techniques can be designed to operate on coarse-grained input to be more robust against gaze tracking error.

Position-dependence. Techniques may depend on the position at which they are invoked by closing of an eye, for example if this is used to select an object for manipulation, but can also be designed to be invoked anywhere on the interface.

Absolute versus Relative Input. Gaze input can be absolute in terms of positions in the interface, or relative in terms of offset from an anchor point. This can be a reference point in the interface, for example the centre of the display, or the gaze position at the start of the interaction (if the interaction is position-dependent).

Discrete versus Continuous Feedback. During the interaction, feedback may be continuous, e.g. with a gaze cursor or gaze trail; or discrete, e.g. highlighting objects crossed by gaze, or providing feedback only at the endpoint of the interaction.

7.5.1 Control and Configuration of Gaze Behaviours

Gaze+Hold is designed to facilitate gaze input dependent on state. Gaze with both eyes open defines a default state, and gaze with left or right eye closed each define a specific input state. The direct association of different states with eye closure allows for fast switching between gaze behaviours while avoiding a moded approach. There is no presumption on the type of gaze behaviour in the different states, and in any of the states the behaviour can additionally depend on object, location or region of gaze, or other context. The key design considerations within this framework are:

Default Behaviour. Gaze+Hold lends itself to managing Midas Touch, by separating default behaviour from explicitly triggered input states. A default state could be chosen accordingly, for example using gaze only for looking, only for passive feedback, or only for conservative forms of input that are not prone to unintended activation.

Configuration of Input States. Input states associated with left and right can be statically or dynamically configured. Where an application requires only one or two forms of manipulation, these can be mapped for direct access to either eye. If more functionality needs to be supported, the mapping can be dynamic. For example, if an action is to be used repeatedly, it could be presented as a tool in default mode that users can pick with either left or right eye. If there are multiple possible actions within a given context, these can be provided via contextual menu triggered by one eye and navigated by the other. If a manipulation itself involves variants for execution, the choice may also be built into the technique and triggered by variation in the eye movement performed.

Figure 7.9 illustrates how the Gaze+Hold concept supports continuous direct manipulation. In this example, gaze with both eyes open has no effect on objects the user looks at, whereas gaze with one eye closed can be used for multi-selection and moving of objects. Both eyes open defines a default state from which users can switch temporarily into specific input states by closing either left or right eye to explicitly signal intent to manipulate. Gaze input performed with one eye closed has its analogy in mouse input performed while a button is held down. The temporary switching of a pointer by discrete

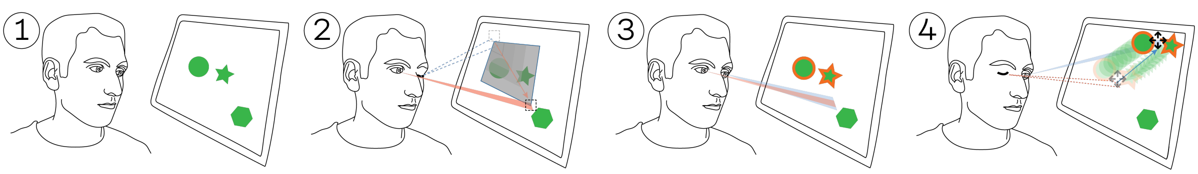


Figure 7.9: Gaze+Hold techniques ecology example: (1) The user looks at the interface without triggering any effects; (2) On left eye closure, continuous multi-selection is enabled via continuous gaze input from the open eye; (3) The interaction stops and objects are selected when opening the left eye; (4) Gaze+Hold allows for multiple techniques mapped to the two eyes, e.g. right eye closing is used to move the selected objects.

input is pervasive in state of the art interfaces for dragging, panning, zooming and other forms of continuous manipulation. Gaze+Hold opens up a design space for such tasks to be performed with just the eyes.

7.6 Exploring Gaze+Hold Interaction Techniques

We explore Gaze+Hold through the design of concrete interaction techniques for general user interface tasks. The focus is on continuous manipulation but we also consider how discrete selection is supported within the framework, and how the eyes can be dynamically configured for different tasks. Techniques' video demonstration available in Appendix B.

The following techniques emerge from a brainstorming session within the research team. We initiated the session by associating the technique with a metaphor. Using the example of drag-and-drop, we found similarities between gaze pointing during the closure of one eye with a mouse button press and drag/motion. The computer "mouse" metaphor set the starting point to discover the richness and expressiveness of the Gaze+Hold technique. First, we listed all the applications and techniques using a mouse button press and motion. Then, we focused on similar actions in platforms or interfaces that do not use a mouse but rely on another type of input, e.g., touch. After exploring the mouse's use, we used the conceptual framework presented in the previous section to narrow down the list of potential applications. The following techniques are the result of this process.

All techniques, as well as some application examples, were developed using Unity Game Engine in C# in 2D with both custom and creative commons graphics. We used the Tobii Gaming SDK for Unity to get the position of the gaze point and the Tobii EyeX Framework to separately detect eye-closing and eye-opening events, based on absence versus presence of left or right eye from visual tracking. The system automatically filters involuntary blinks, during which both eyes become absent from tracking for a short duration (∼250ms).

7.6.1 Multiple Object Selection

Closure of one eye can be used to frame selection of multiple objects. We designed four different Gaze+Hold techniques for this task to illustrate alternative design choices.

Multiselect-Crossing. Once activated by eye-closure, this technique selects all objects crossed by gaze during eye closure (Figure 7.10, A). The technique is not position-dependent; it can be initiated on the first object to select, but also in any neutral part of the interface. Input is positional and can be fast as users do not need to fixate on individual objects, for instance selecting a row of objects by gazing across. However, crossing can be prone to unintended selection of other objects (Midas Touch).

Multiselect-Dwell. In this technique, objects are selected by point and dwell during eye closure, to ensure that selections are intentional. This constitutes compound input, combining gaze position with dwell time. In conventional gaze pointing, dwell times are usually 500ms or longer to avoid Midas Touch. For this technique, dwell can be optimised as eye closure pre-selects a state in which users are focused on a specific task (e.g., other constrained selection tasks such as gaze typing have been implemented with dwell as short as 250-300ms [154]).

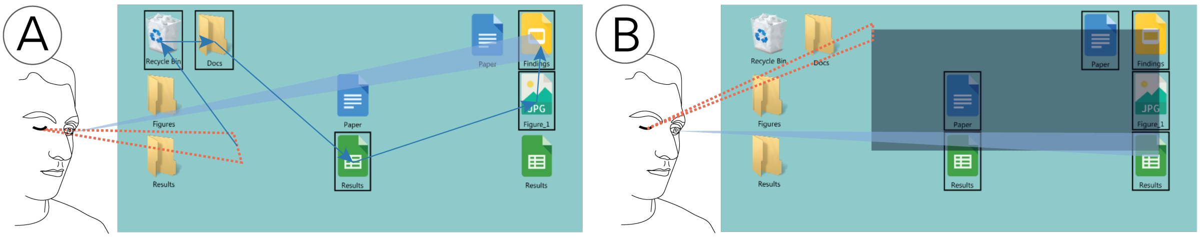


Figure 7.10: Selection of multiple objects. A) *Multiselect-Crossing* is initiated by eye-closure and selects all objects crossed by gaze until eye-opening. B) *Multiselect-Box* uses gaze to draw a selection box.

Multiselect-Blink. This is a variant of the previous technique, and also based on point and click selections during eye closure. However, instead of using dwell, the pointing eye is briefly closed to confirm selection. This illustrates how we can draw on different eye expressions within Gaze+Hold. A wink with a second eye, while the first one is already closed is not natural and as such effective against Midas Touch. However, users may also find it difficult to perform.

Multiselect-Box. This technique is based on a selection box, as also commonly used in mouse interaction. The gaze position at eye-closing defines one corner of the box. Gaze during eye closure controls the opposite corner of the box, such that it can be pulled out over the set of objects intended for selection, finally confirmed by eye-opening (Figure 7.10, B). Gaze input is positional only and can be fast as selection can be completed with a single gaze saccade from the start to the endpoint.

7.6.2 Selection of Text

Selection of text is conceptually like selection of objects with a box, as it involves selection of a start point and dragging to an endpoint. However we describe two Gaze+Hold techniques that illustrate different opportunities of eye-based design.

Text-markup. This is designed as two-state technique, where the left eye is used to mark up a text in yellow, and the right eye in green. With either eye, the initial gaze position selects a start point in the text, and gaze becomes the handle for an endpoint of the text selection that can be dragged over the text and finally committed by eye-opening. This illustrates how the eyes afford variation of input by choice of left versus right eye, while the gaze manipulation is the same with either eye. Gaze input is positional and needs to be fine-grained for text selection. In practice, this is a problem as eye tracking has inherent accuracy limitations.

Text-nudge. This technique is designed to facilitate fine-grained text selection when pointing is not sufficiently accurate. Initiated by eye-closing, a cursor is inserted in the text based on the initial gaze position. The user can now perform quick glances to left, right, up, or down to nudge the cursor, where each glance is a distinct eye gesture away from and back to the current position without any intermittent fixation. Once the cursor is in the desired position, a gaze shift can be performed to an endpoint which likewise can be nudged by glances before the selection is committed by eye-opening. The gaze input is positional for the shift from start to endpoint, and gestural for nudging. The two forms

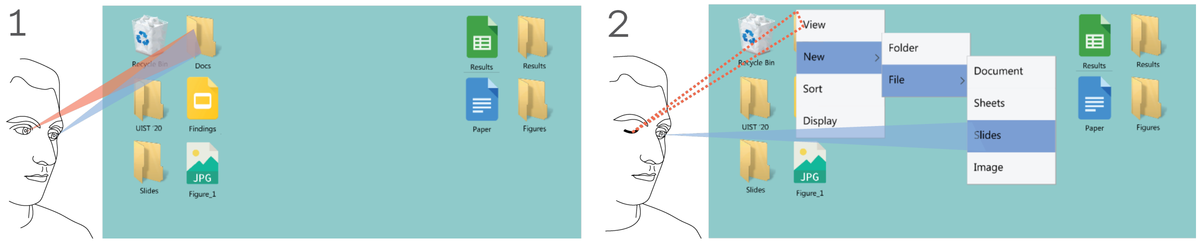


Figure 7.11: *Context Menu.* (1) On closure of one eye, a menu opens and (2) can be freely explored and navigated by gaze, with final selection of an item committed by eye-opening.

of input are distinguished as gaze shift ends in fixation at a new position, whereas glances are eye movements in one direction directly followed by return movement. Note that the use of nudging gestures is optional, and a gaze shift can be performed straightaway if the initial cursor position is already correctly placed.

7.6.3 Menu Navigation and Selection

Design for eyes-only menu interaction is challenging as it requires mechanisms for menu opening, navigation, and item selection. This involves particular Midas Touch problems as users may dwell longer on specific items when they consider choices, without intent to select. In the literature, this is addressed with longer dwell times or additional interaction steps [118, 233, 62]. Gaze+Hold provides an alternative, which we explore with a context menu, see Figure 7.11:

Context menu. The menu is context-dependent on the initial position, where it is opened by eye-closing. Items can be visually explored with hover feedback. If an item has a sub-menu associated, this also opens in response to hover, but closes when gaze moves to another item at parent-level. A final selection is made by eye-opening on an item, but selection can also be abandoned by gazing off-menu prior to eye-opening. The design illustrates how separate input from the eyes is utilised to avoid Midas Touch. One eye looks and points without risk of unintended selection, while the other performs discrete input to trigger a menu, and to confirm a selection.

7.6.4 Zooming or Scaling

We designed two Gaze+Hold techniques for zooming, to explore different mappings of gaze input to control the zoom versus the focus point:

Zoom-Discrete. Initiated by eye-closing, the focus of the zoom is fixed to the initial gaze point. The continuous input of the open eye control the zoom (in/out) by performing discrete gaze gestures relative to the focus point (looking up/downwards) and guided by visual indicators (Figure 7.12, A). The technique is robust as it relies only on direction of gaze movement up or down, but the design implies that the user has to look away from an initially selected focus.

Zoom-and-Point. This technique has separate states mapped to left and right eye, one to zoom in, the other to zoom out. During eye closure, gaze controls the focus point (Figure 7.12, B). This mapping makes it possible, for example, to adjust the focus based

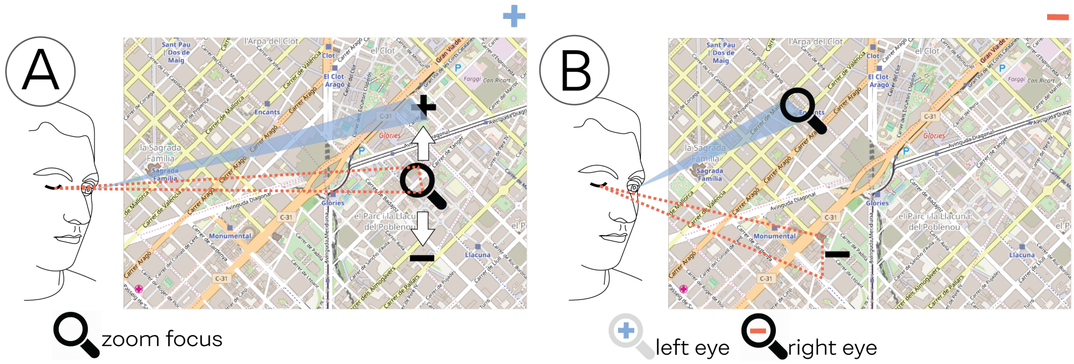


Figure 7.12: Zooming with Gaze+Hold. A) *Zoom-Discrete* uses gaze gestures up or down, to zoom in/out from a focus point at which the technique was invoked; B) *Zoom-and-Point* uses closing of one eye to zoom in, and closing of the other to zoom out, while the eye that remains open determines the focus point.

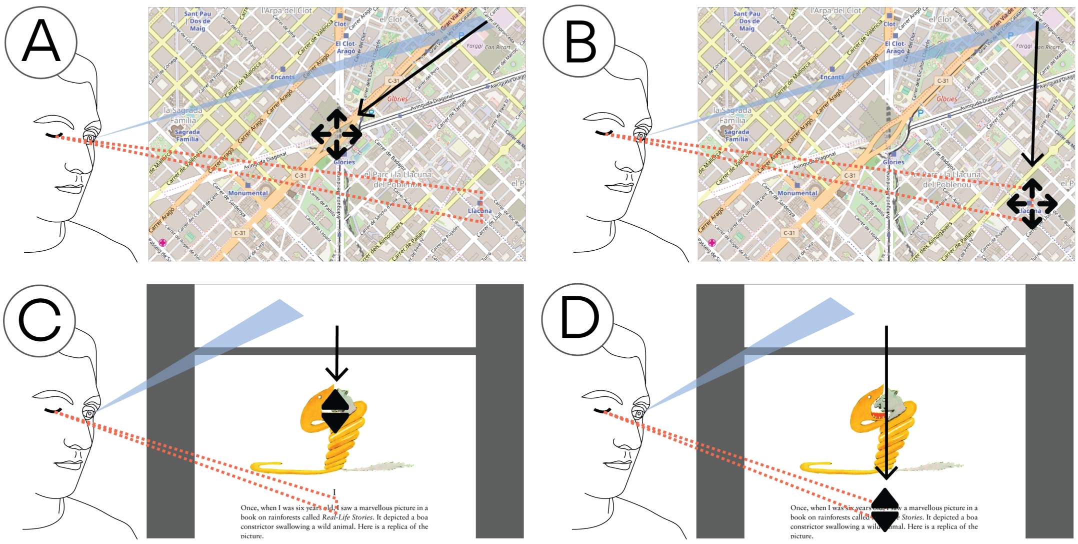


Figure 7.13: Panning/Scrolling. The canvas is shifted in the direction from gaze position to (A/C) Pan/Scroll-to-Centre: the centre of the screen; (B/D) Pan/Scroll-to-Anchor: the anchor point.

on detail that is gradually revealed by zoom. The amount of zoom is time-dependent on duration of eye closure.

7.6.5 Panning and Scrolling

Panning and scrolling are operations to adjust the viewport over a larger space or document. We considered that gaze lends itself to shifting the view over shorter distances where gaze is natural in selecting content to which the view should be adapted. We designed two relative input techniques with Gaze+Hold, both for scrolling in 1D as well as panning in 2D:

Pan-to-Centre. After triggering by eye-closure, the canvas is shifted in the direction from gaze position to display centre, which is marked as reference point (Figure 7.13, A). If users keep their gaze on the same content during panning, the viewport will become centred around the content. Gaze can also be shifted to content gradually revealed, to pan further. Eye-opening completes the interaction. The gaze input is positional but used relative to the display centre. The technique is intuitive for example for map navigation, and centering the map around a point of interest that is naturally selected by gaze.

Pan-to-Anchor. The gaze position at eye-closing is used to define an anchor point in the viewport, marked as reference point. Panning starts when gaze shifts from the anchor point to another position, in the direction from the gaze position to the anchor (Figure 7.13, B). The technique is more versatile than Pan-to-Centre as it allows users to identify other parts of the viewport than the centre as reference for adjusting the view. In map viewing, for example, it allows selection of the left edge of the view as anchor, followed by gaze to the western edge of a landmass to view so that this becomes aligned.

Scroll-to-Centre / Scroll-to-Anchor. These techniques behave accordingly for scrolling in 1D. In Scroll-to-Centre, gaze at the top results in scrolling up to earlier pages in a document, and gaze at the bottom below the centre in scrolling down (Figure 7.13, C). In contrast, Scroll-to-Anchor, starts with placing an anchor point, for example near the top of the view so that any content than looked is scrolled to the top (Figure 7.13, D). Scroll-to-Centre lends itself more to search in a document, whereas Scroll-to-Anchor supports adjustment of the view.

7.6.6 Navigation and Teleportation

Panning and scrolling with Gaze+Hold is effective for view adjustment over shorter distance but less so for navigation of larger spaces or documents, as holding an eye closed for longer may induce fatigue. We therefore considered techniques specifically for navigation:

Navigate-Select. Closing of an eye triggers a change in view, to an overview of the interaction space, such as a zoomed out document. The overview can be navigated by gaze to select a different part of the document, at which detailed viewing is resumed after completion of the interaction by eye-opening (Figure 7.14). The navigation is over

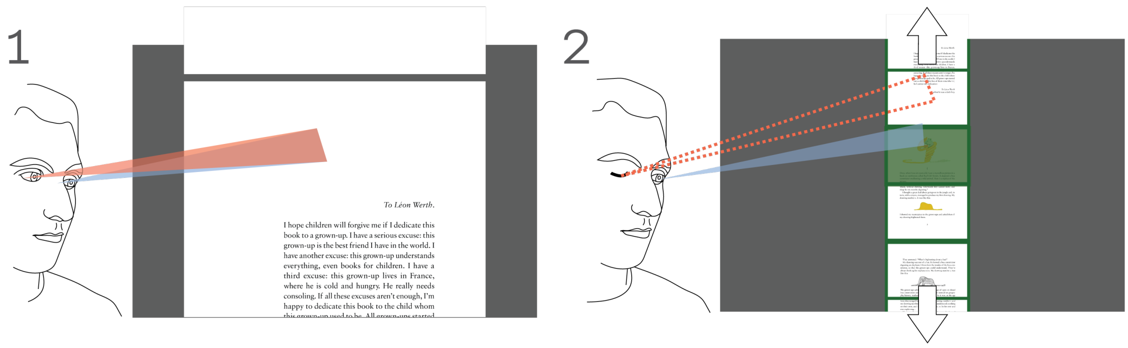


Figure 7.14: *Navigate-Select*. (1) On eye-closing, Gaze+Hold zooms out the document so (2) the user can look at a position in the document to navigate to when opening the closed eye (Navigate-Select).

discrete parts of the interface, and lends itself to moving for example between pages in a document, images in a gallery, tabs in a web browser, or applications in the OS.

Navigate-Point. This is a variation of the technique. Eye-closing triggers a “world in miniature” view of the interaction space, and gaze controls a window to select the part of the world that will be in view after completion of the navigation. This lends itself to navigation of interactive worlds, and for example teleportation in games.

7.6.7 Temporary View Control

The presented navigation techniques are based on temporary switching to an overview. Eye closure can more generally be used to provide the user with a different view or perspective, as previously explored e.g. in sniper zoom [94]. A quick change in view can be useful for cross-referencing information from another document or screen when inputting data, or temporarily overlaying additional information, e.g. textures in 3D modeling.

View-Control. A change in view is triggered by eye-closing. During eye closure, gaze can manipulate the new view, and eye-opening switches the interface back to the original view. Figure 7.15 illustrate the technique in a games context, inspired by changes in perspective such as eagle vision in Assassin’s Creed. Consider a user playing in a first person point of view where their aim is controlled by their gaze (Figure 7.15, 1). When the eyelid is closed, Gaze+Hold changes the camera view perspective so the user can see their position from a bird’s eye view, whilst still controlling the camera with their gaze (Figure 7.15, 2). Once the eyelid is opened again, the camera returns to the first person perspective.

7.6.8 Line Drawing and Measuring Tape

By leveraging the saccadic nature of the eyes to define start and end-points, Gaze+Hold can be used for line drawing in sketching applications or as a measuring instrument. More complex paths can be created using anchor points, defined by closing and opening the open eye during the hold (line drawing). However, drawing more complicated paths may cause fatigue if holding the eye closed for prolonged periods. Information can be added to the drawn line to provide additional utility, such as the distance between points. This

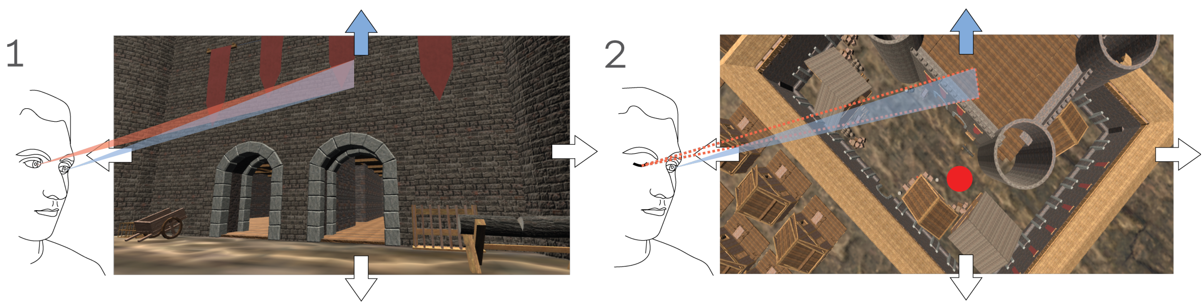


Figure 7.15: Temporary View Control. (1) The user’s gaze moves the camera with both eyes open. (2) Gaze+Hold changes the perspective to birds-eye when one eye is closed whilst still controlling the camera with gaze.

creates the opportunity for compelling applications using only the eyes, e.g. a measuring tape in AR. The measuring Tape application utilises the input of the open eye during the hold for continuous feedback.

7.6.9 Configuration: Toolbar and Menu

The configuration of each eyelid with Gaze+Hold opens up the usability of the concept in a wide array of applications:

Toolbar: The user could dynamically change the configuration of the eyelids in real-time with a toolbar, see Figure 7.16, A, using copy/cut-paste, increase/decrease size and remove. This allows the user to use multiple techniques in a single application that can be dynamically configured, e.g. zooming, panning, navigation, change the view to satellite, or drag-and-drop the street view icon in a map application.

Eye-Menu: One eye is assigned to open a pop-up menu to choose which technique is assigned to Gaze+Hold when closing the other eye, see Figure 7.16, B.

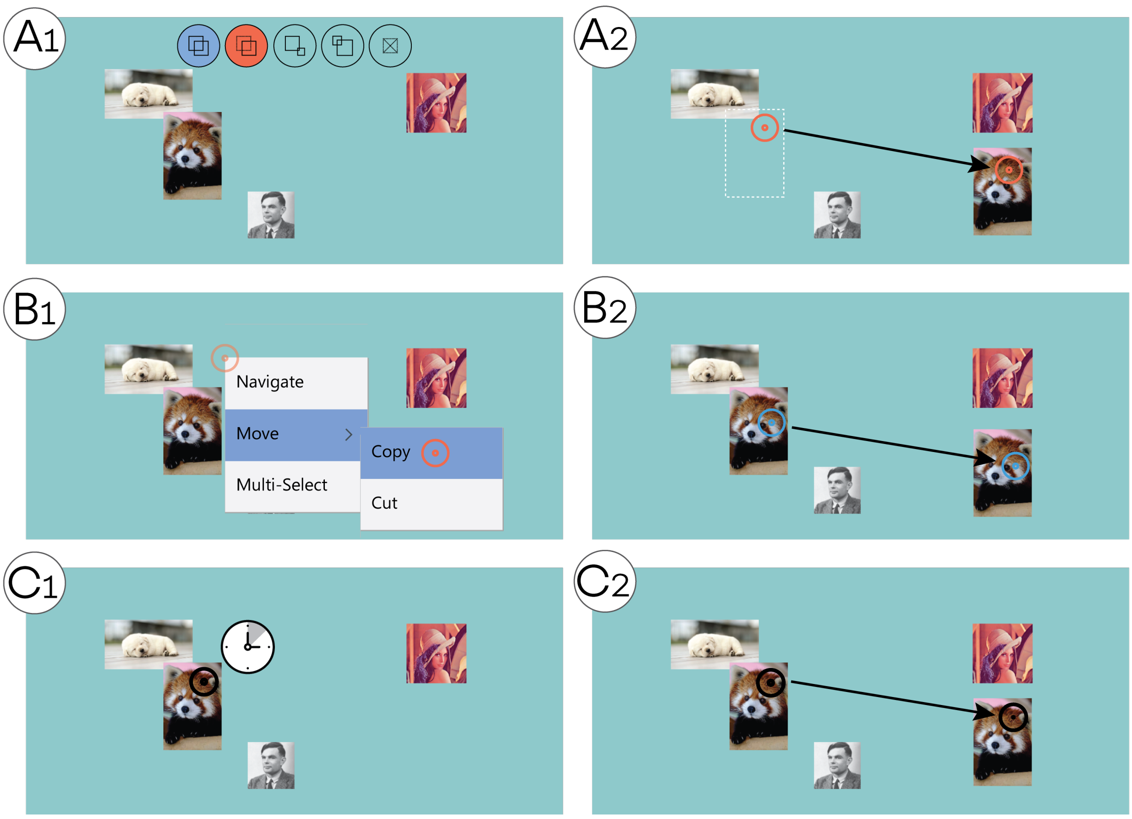


Figure 7.16: Gaze+Hold variants for configuration: (A) Using a Toolbar to dynamically set the action each eye closing performs (left=blue, right=red) to cut-paste with the right eye; (B) The right eye controls a pop-up Menu to assign copy-paste to the left eye; (C) Combining Gaze Mechanics: A dwell on an image after eye closing to copy-and-paste it.

7.6.10 Configuration: Combining Gaze Mechanics

Gaze+Hold can invoke different actions depending on the type of eye movements performed, which can be configurable and allow a wide variety of actions to be performed at any time. In previous techniques we have proposed the use of dwell or blinks during the interaction state (e.g. selection techniques and complex line drawing). Beyond this, Gaze+Hold can be combined with other gaze-based interaction mechanics.

Saccades and Dwell. The eye movement following the closing of the eye determines which action is invoked on an object. In the immediate period after the eye closes, we look to see whether a fixation or saccadic eye movement occurs, and assign different actions to each. If the user looks at a picture when closing one eyelid and look away during the hold (saccadic movement), the image is *cut-pasted*. In contrast, if the user fixates on the image for a dwell time (800ms), this will get copied for *copy-paste*, see Figure 7.16, C. We explored this configuration in an *Image Workspace* application which displays images that can either be resized after dwelling with a gesture or moved across the workspace with a saccadic movement. The application is context-aware, and the same concepts apply to the workspace, for panning and zooming respectively.

Smooth Pursuits. Gaze+Hold can be used to signify intent to interact for other gaze-based mechanics. Smooth pursuit eye movements can be used to select moving targets [272], or objects with movement added [227]. Pursuits interactions requires movement on the interface, which can be visually distracting. We can use Gaze+Hold to only show moving targets when one eye is closed, whilst the other can follow the motion for selection.

VOR. The vestibulo-ocular reflex (VOR) stabilises the eye in the presence of head movement and can be used for target disambiguation of occluded objects in 3D environments, whilst requiring only monocular eye tracking [157]. Gaze+Hold can be used to delineate selection using VOR.

7.7 Discussion

Common input modalities (e.g. mouse, touch, pen) enable seamless transitions between pointing and manipulation states, such as mouse clicks versus button holds; fingers to tap versus drag and pinch; and pen to tap versus drawing. This is non-trivial for eyes-only interactions, where the eyes are traditionally viewed as a single source of input.

Existing eyes-only interfaces are based on continuous gaze tracking for pointing, complemented by primitives for discrete selection which include dwell time [276, 118], long blinks [84], saccadic gestures [51, 286, 93], and smooth pursuit [272, 264]. This has two principal limitations. First, the pointer moves with every eye movement, with no distinction of whether the movement was intended as pointing action, incidental to viewing, or caused by a visual distraction. Moreover, it can create problems of feedback (whether and when to display a cursor [203]) and unintended input (Midas touch [118, 114]). Secondly, use of the eyes is exclusive for either pointing or click-equivalent action, unlike with conventional pointing where positional input can concur with discrete input (e.g., mouse movement while pressing a button). As a consequence, continuous direct manipulations (e.g., moving an object) are not well supported, as they have to be mapped to successive discrete interactions (selection of command, object and target position).

The work presented in this chapter is innovative in treating the eyes as two input channels to support seamless transitions between interaction states for direct manipulation. Winks consider input from both eyes separately but are limited to discrete actions [134, 94, 124, 291]. Gaze+Hold's framework presents compelling design opportunities for eyes-only interaction, inviting exploration of the possibilities created when considering input from both eyes separately. The techniques and applications presented demonstrate the versatility of Gaze+Hold interaction, showing how it can be seamlessly combined with other gaze mechanics for both selection and continuous manipulation.

Moreover, Gaze+Hold presents a novel solution to the gaze Midas touch problem because a discrete action modulates continuous gaze pointing. Traditionally, the Midas touch is solved with either multimodal interaction, e.g. combining gaze with voice [190] or touch [198], or by joining discrete gaze interactions, e.g. look and blink [169, 133] or wink [230] to confirm. Gaze+Hold provides an eyes-only solution that contrasts other gaze-only techniques by complementing discrete interactions with continuous, direct manipulation. Being able to suppress accidental input, combined with the ability to configure Gaze+Hold interaction presents the opportunity for the creation of eyes-only interfaces for accessibility. In addition, Gaze+Hold interaction can be used where traditional binocular eye tracking is not suitable, for example, users with a glass or lazy eye, because during the manipulation phase only continuous input from one eye (the open one) is required.

Finally, we note that not everybody can wink with both eyes, which may limit the usability and configurability of Gaze+Hold interactions. However, the eyelid muscles, like any other, can be trained. From a technical perspective, the eye tracker's accuracy and precision also affect usability. Our results are based on the use of a consumer-grade remote binocular eye tracker for desktop usage (the Tobii EyeX). The techniques presented could be equally applicable in other environments where eye tracking is readily available, such as mixed reality head-mounted displays. However, further study is necessary due to differences in the characteristics of eye trackers. Study one has a small sample size; however, it provides indicative insights on the accuracy and precision of pointing with one eye closed, and grounds our understanding of the second study results. Nevertheless, the techniques presented in this chapter invite future study of the usability of Gaze+Hold to support interaction in specific applications, or as a part of a holistic eyes-only interface, especially for accessibility.

7.8 Conclusion

In this chapter, we presented the Gaze+Hold interaction technique, which enables direct manipulation by leveraging the input from both eyes separately. Gaze+Hold defines a distinct style of eyes-only interaction based on the continuous input of a single eye modulated by holding down the eyelid of the other. We described a design framework to create Gaze+Hold interactions and explored the proposed concept to develop a constellation of techniques and applications that use Gaze+Hold for eyes-only direct manipulation.

Tracking of just one eye is sufficient for gaze estimation, and effective gaze-based interactions have been demonstrated with monocular eye trackers [60, 267]. However, interaction with graphical user interfaces is more commonly based on binocular tracking with eye trackers mounted or integrated with the display. This configuration brings other challenges to gaze interaction, such as the need for calibration or the Midas Touch. Accordingly, gaze interaction is often used in combination with other input modalities. Here, we propose Gaze+Hold to use the eyes only by modulating gaze pointing with the closure and hold of one eyelid down, thus proposing an alternative solution to the Midas Touch. Gaze+Hold relies on one-eyed gaze as continuous input, and we therefore investigated the effect of closing an eye on eye tracking accuracy and pointing performance. Moreover, we studied the usability and feasibility of using Gaze+Hold for interaction. In the small-scale accuracy test study, we observed robust performance at about half of binocular accuracy with asymmetric effects toward the left and right display edges. Moreover, in the follow-up user study, we assessed Gaze+Hold on a drag-and-drop task. Although slower than with both eyes open, participants were effective with the technique. Notably, all users were able to use Gaze+Hold with either eye closed, and the use of dominant versus non-dominant eye for manipulation had no significant effect on performance, usability and perceived workload. Briefly, we summarise the key takeaways:

- Gaze+Hold is innovative in utilising the eyes as two input channels to support seamless transitions between interaction states for direct manipulations.
- Although Gaze+Hold is less accurate and efficient than interacting with open eyes, it enables eye-only interaction in a wide variety of applications.
- Similar accuracy and precision were observed across either eye for Gaze+Hold interaction, and we found no difference in performance or perceived task workload between the use of either eye.
- Results reveal how Gaze+Hold is not limited to a single-eye configuration, and both eyes could be used for either modulation and pointing, opening up the design space of Gaze+Hold interactions, which can be of interest for accessibility.
- We described a set of applications that explore the technique's design space. These showcase the potential of Gaze+Hold to temporarily use continuous gaze pointing via discrete input and provide eyes-only interaction for different forms of continuous manipulation.

Overall, this chapter on Gaze+Hold moved away from the core objectives of this thesis by not exploring the interaction in play; yet it is not limited to be adopted as a control mechanic in games. Gaze+Hold was inspired by the previously presented concept of *playing without looking*, and it conceptually follows our exploration of playful ways to adopt gaze for interaction. Accordingly, Gaze+Hold contributes to demonstrating how ideas that are tested playfully, or in our case through game design, can lead to concepts and techniques that are useful in mainstream applications beyond play.

8 Emerging Frameworks

In previous chapters, we have discussed individual contributions for each game concept we explored. Here, we take a step back to reflect on the work as one piece and discuss the lessons learned. However, our reflection goes further and beyond the discussion of game outcomes, and we continue exploring new opportunities for gaze input in games by describing frameworks that emerged from ideas surfacing from the game chapters and user studies. Readers must note this discussion reflects only on the game concepts, and it does not explicitly include the work described in chapter 7 (the Gaze+Hold technique), although it is implicit in talking about the "*playing without looking*" game concept.

In the introduction, we proposed that gaze interaction is more than pointing, more than looking. The work we described through each chapter is evidence on our efforts to open up a new, and distinct, space of inquiry: "not looking" for gaze interaction. In this chapter, we describe three frameworks that discuss state of the art gaze-enabled games with concepts that emerged from our playful explorations and their evaluation. Figure 8.1 represents the underlying structure of the frameworks presented in this chapter. Each game game is key in identifying behaviours that move out from the prevailing focus on adopting gaze pointing in games. Each framework discusses concepts picked up from each game chapter aiming to advance the gaze-enabled game research corpus, inspire new gaze interactions, and highlight new opportunities.

The first framework addresses the core of this thesis to analyse how "not looking" behaviours have been integrated into play. We illustrate the use of "*not looking*" as an interaction dynamic with examples of gaze-enabled games. The framework proposes five discrete categories to design for this unexpected use of gaze input. For each category, we analyse game examples that require to not look at the game scene. The framework

Figure 8.1: The underlying structure of the Emerging Frameworks and the concepts associated to each chapter.

dimensions describe whether specific game events mean the player *might not*; *cannot*; *should not*; *must not*; or *does not* look. Finally, we discuss the outcomes of adopting not looking behaviours and the potential opportunities for interaction design.

The second framework proposes the concept of game diegesis to integrate the adoption of gaze input in the game narrative by introducing gaze interaction roles and gaze metaphors. Gaze roles describe the use of gaze in the game, whereas metaphors serve as the narrative figures that symbolise, illustrate, and are applied to the interaction in design. Here, we seek game examples from state of the art that integrate gaze input in the game narrative, including different gaze roles and metaphors. Based on our analysis, we describe three roles: *Social*, *Hurdle*, and *Power*; and provide a list of metaphors employed to contextualise each role. This framework aims at reflecting on the meaning of gaze input in games. Through an integrative approach with other frameworks, players are anticipated to develop a deeper connection to the game narrative via gaze input, resulting in a stronger experience concerning presence, i.e. being in the game world.

The third framework reflects on ideas discussed in each chapter which contribute to understanding gaze input in the game as the attention relationship between the user (the subject) and the game (the object). The frameworks describes four dimensions: *Identity*; *Mapping*; *Attention*; and *Direction*. The framework serves as a design and inquiry toolbox to guide research questions, analyse and communicate gaze mechanics in play. We visualise the design space, highlighting opportunities for gaze interaction design and future HCI gaze research through the framework's lens. We describe design guidelines and propose new directions to create novel gaze interactions for gameplay.

8.1 Exploring Not Looking in Gaze Interaction

The immediate definition of "not looking" for gaze interaction is to require users to close their eyes. However, the chapters presented in this thesis demonstrate how *not looking* could take many forms in play. The *Twileyed* game introduced tension to gaze interaction to make the player look elsewhere from the game action and posing different control challenges. Additionally, *SuperVision* required the player to rely on their peripheral vision by pushing them to look away from game objects. Finally, *KryptonEyed* explored that not looking is more than closing the eyes, and we are capable of performing eye movements behind the lids. Accordingly, each game presents playful designs that are engaging and thought-provoking and go beyond adopting gaze input for pointing. They describe new concepts that "unfold" looking and propose to adopt gaze with new challenging behaviours such as tension; to consider the active use of the broader vision and peripheral vision, and to leverage the physical function of the eyes to play with closed eyelids.

To better understand the design space for *not looking* interactions, we created a framework illustrated by state of the art game applications that make the player 'not look' at the interface. We utilised our survey on gaze-enabled games to find game applications that showcase this unexpected use of gaze input. We analyse the novel playful experiences they provide and discuss potential outcomes. In the following sections, we propose a spectrum of gaze interactions that move away from directly looking to interact with the game. Rather than considering this spectrum as binary states with open eyes against closed, we try to understand *not looking* as a concept in several steps because it can mean different things: not being able to look because it is physically impossible; looking away or elsewhere; blinking, or keeping your eyes shut. We illustrate in the following framework five discrete categories based on interactive gaze-enabled game designs. They demonstrate a range of potential interaction dynamics to adopt in play with this unexpected use of the eye tracking input - see *Figure* 8.2. In the framework, we define each step based on the players' decision not to look and how this changes their gaze behaviour.

8.1.1 First: Gaze Effects (Might not look)

Some gaze-enabled games introduce effects the players do not expect, and which could make them decide they might not look at the game scene. This is in line with our description of the concept of *playing with tension* as side effects to gaze interaction. For instance, in *Twileyed's Jekyll and Hyde* game, both characters are connected so one will always move when the other moves. This is a side effect the player does not expect, as traditionally in games, they are only capable of controlling one character at once. As a reminder, the game introduced a biased mapping to the gaze point, so Hyde moves towards the direction Jekyll (the player's gaze around the character) is looking. This side effect requires the player to understand the challenge of moving a character towards the gaze point without looking at the location where they want to go. Accordingly, the player is forced to set their gaze attention elsewhere, and they might not look where they would without the additional tension.

We can find examples with less restrictive challenges. For instance, *The Royal Corgi* [271] is a first-person perspective game in which the player needs to network and talk to the king's counsellors to win their favour and become the next royal corgi instructor. The

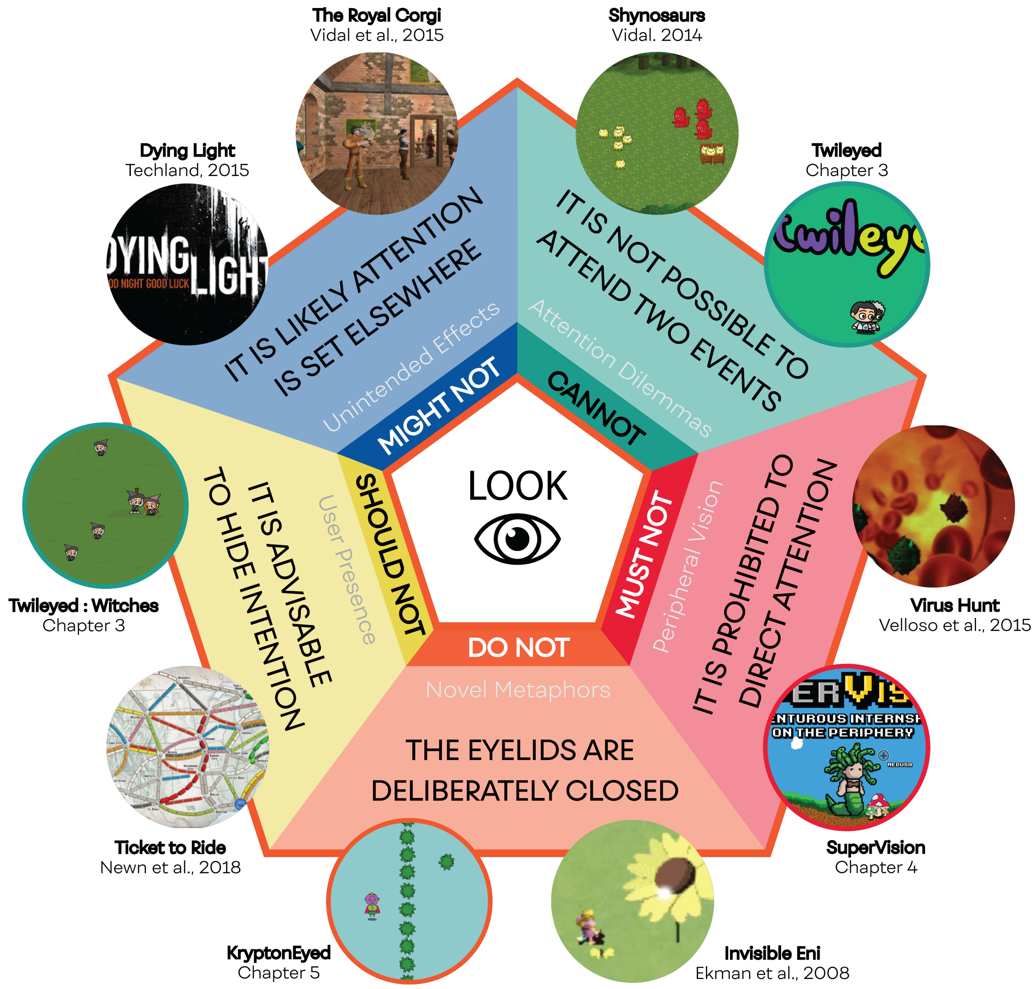


Figure 8.2: Unexpected Gaze Interaction Framework defining in 5 categories the spectrum from looking to "*not looking*". Each step is illustrated by game examples showcasing the use of not looking, the rationale behind the behaviour and the potential outcome.

game uses the keyboard to navigate through the different dialogue options; however, where the player looks at in the game scene influences the character's reactions. Therefore, the player needs to be careful and pay attention to where they look not to upset the character with whom they interact. For instance, when talking to the *Military Advisor*, players need to show respect by maintaining eye contact. Moreover, when talking to the *Budget Advisor*, they need to be careful and not glance at his wife, or he will get offended.

We can find a similar dynamic in the mainstream game *Dying Light* [243]. This example is a survival horror and adventure game set in a dystopian post-apocalyptic world. The player needs to infiltrate a quarantine zone while battling human enemies but also zombies they will encounter. In the gaze-enabled version of the game, the player can aim firearms at gaze; automatically climb where they look and control a flashlight with gaze. However, zombies will notice the players' presence when they are looked at, making them responsive to gaze interaction.

These examples demonstrate that looking can create unintended outcomes. We look to explore the scene, and we also use gaze input for interaction (*Dying Light*). However, characters can react to our attention to them triggering what could be unwanted and unintended consequences. Accordingly, we might decide to stop gazing at the scene and stop looking around not to promote these undesired gaze effects. In *The Royal Corgi*, we might decide to only look at the character we are talking to when we notice they get upset when we do not pay attention to them if looking elsewhere. Similarly, in *Dying Light*, we might choose not to glance around in a space full of zombies, and keep our gaze low, not to draw the dying's attention.

8.1.2 Second: Gaze Attention (Cannot look)

Some games introduce multiple events the players cannot look at because they happen at once. The fundamental feature of these games is to leverage it is physically impossible to attend two events at the same time, posing an attention dilemma. Games usually contain sub-tasks and multiple events that the player needs to solve at the same time, e.g. retrieving an artefact while sorting obstacles and defeating enemies. However, the adoption of gaze input in the game mechanics adds the challenge that we need to use our eyes for interaction as much as we need them to look at the game. This is known to create tension (e.g. the Midas Touch), which we leveraged in the design of the game *Twileyed*. In this collection of three games, we included a main collection task that was disturbed by enemies' attacks. For instance, in *Dorian*'s game, the player needs to look at Dorian to move him and collect his frames. However, when the Assassin attacks, players need to juggle between looking at the scene, and the other characters to protect Dorian. They cannot look at all of them at once, leading to mistakes and failing the game challenge.

We can find a similar dynamic in the game *Shynosaurs* [270]. In Shynosaurs, the player needs to save the *cuties* by dragging and dropping them into safety with the mouse. During the task, the *shynosaurs* (dinosaur-like enemies) come from the woods to take the *cuties* away. However, if the player glances at the *shynosaurs*, they will feel intimidated and act like a shy naughty kid. They will stop and pretend they are not doing anything wrong. The longer the player looks at them, the shyer they become, until they cannot stand being looked at and run away crying.

In *Limus and the eyes of the Beholders* [140], the hero (*Limus*) needs to escape a dark cellar by using a magic portal. The challenge is that the enemies called *Spikees* will try to catch *Limus* when they see him, going towards his position. However, if *Limus* looks at the *Spikees*, they will freeze and stop moving. In the game, the player controls *Limus* with a gamepad, whereas gaze interaction is used for the player to look at the *Spikees*. To make this chasing enemies stop, both the avatar (*Limus*) and the player need to look at them, disrupting the task of getting to the end of the level.

These examples illustrate how looking can be challenging because we cannot look at two things simultaneously, introducing playing with "attention dilemmas". Both in *Shynosaurs* and *Limus*' games, the player faces a challenge in gaze attention and a constant dilemma. They need to either solve the main task: saving cuties or reaching the end of the level; or looking at the enemies to freeze them. This "*not looking*" dynamic makes the users stop looking at the game scene and focus their attention on the enemies. Although this dynamic might be difficult to extrapolate to other less playful domains, it offers an insight into how playing with this level of not being able to look can create greater awareness of the user's gaze attention and how to balance it.

8.1.3 Third: Gaze Awareness (Should not look)

Other games have introduced challenges by accounting for the user presence in the game world. Gaze signals our intention because we look at the objects we want to interact with. We can find game examples utilising the information on where in the game the players are looking at to make the experience more challenging. Accordingly, sometimes it is advisable to hide intention, and the player should not look at the game to avoid spoiling their strategy. For instance, in *Twileyed's The Witches* game, the player will look at the little witches they want to collect. However, enemies move towards their gaze point, and they should not look at the witches, thus looking away, to complete the task if they want to succeed.

We can find similar dynamics in the gaze-enabled digital version of the game *Ticket to Ride* [182]. In the game, the gaze point is visualised to the opponent, spoiling the player's strategy. Ticket to Ride is a board game in which players need to build train routes between cities across countries to gain points. Target routes are only visible for the corresponding player, and if incomplete will make the players lose points. The challenge becomes planning train networks carefully to minimise the risk that the opponent will block the path and take over the route. Therefore, when gaze input is exposed, the player needs to juggle between looking at their objective or not to hide their intention.

The game *Screencheat* [139] is a competitive split-screen First-Person Shooter multiplayer game in which players are invisible and need to look at each other's screens to find the other and kill them first to win. To do this, they are encouraged to look at the half of the screen where the other player is playing. In the scene, they can see where the player is but also where they are looking, and predict the opponents' future direction.

In *Screencheat* the player is forced to look somewhere else to figure out where the other player is and win. However, the opponent player knows where you look in the game and might react accordingly. In *Ticket to Ride*, if the player is aware that the other player can see where they are looking at, they might decide to fool and deceive the opponent by looking somewhere else. Both examples show how the player knows that the opponents are aware of where they are looking. As players, we might decide that we *should not* look at the scene, not to spoil our strategy. Therefore, we might choose to look away deliberately to trick the opponent.

8.1.4 Fourth: Gaze Aversion (Must not look)

In our definition for this spectrum for not looking, we have seen how games are designed to make the players modify their behaviour as they play. In contrast, some examples prohibit direct attention to the game scene to make the player not look from the start.

In our exploration of *playing with peripheral vision* we leveraged gaze aversion game dynamics to force the player to look away from game objects in a collection of three mini-games. *SuperVision* explores the challenge of actively using peripheral vision. In the games, players need to overcome mouse manipulation tasks and perceptual challenges in peripheral vision of objects with different size; colour; and form. When players look at the game objects, they are penalised, and they are forced to look away and work only with what they can see in their broader field of view. Similarly, *Virus Hunt* [266] is an arcade game in which players win points by removing viruses when tapping them on the screen. However, if the player looks at the virus, it duplicates, spreading the infection.

These game examples are designed to explore two main concepts: touch or mouse manipulation, and the use of peripheral vision with gaze interaction. Further, *SuperVision* expands on just playing with what can be seen in the periphery, and the three mini-games leverage perception capabilities by proposing visual challenges in peripheral vision. Both *SuperVision* and *Virus Hunt* establish rules that make the players stop looking or looking away. The player is penalised when looking at the objects in the scene that need to be sorted by using gaze aversion dynamics. In other words, looking is not permitted, but it is still possible as it is not required to close the eyes. Through the games, players are unsuccessful at overcoming the challenges, because the eyes are attracted to objects that pop up. They might look and fail, making them understand that to succeed, they must not look but need to figure out how to do things by not looking directly at the game.

8.1.5 Fifth: Gaze Absence (Eyes Closed)

The final step illustrates the extreme of not looking when the player does not look, the eyelids are deliberately closed, and the eye tracker loses the gaze input information. The fundamental principle of this dimension is that looking is not physically possible because we cannot see with our eyes closed. Given how atypical and somewhat unexpected, closing one's eyes is for gaze interaction, there are not many game examples in the state of the art.

We can find examples that utilise blinks for interaction. For instance, the game *Blink Blink Boom* [6] uses blinks to reload the game gun. This introduces a short and swift closing and opening of both eyes to trigger specific events for game control rather than exploring playing without looking. In contrast, some games such as *Nevermind* [171] pauses the game experience when both eyes are closed. However, closing the eyelids is not used for explicit interaction during gameplay. The game *Invisible Eni* [56] uses gaze absence, to affect different game states. The goal of the game is to move *Eni* close to butterflies so she can guide them to flowers and feed them with nectar to be free. *Eni* must complete this task avoiding the *nightmare monsters* that chase her. However, when the players close their eyes, *Eni* does too and disappears into a puff of smoke to evade the monsters and protect herself.

Our work on *playing without looking* and *KryptonEyed* follows in this spirit the closure of the eyelids for interaction. However, it goes beyond the concept of gaze absence to pose a gaze pointing challenge behind the eyelids. As discussed in the previous chapter, interactions such as closing the eyes open up the space for the design of games that incorporate new metaphors for gaze in games beyond looking. Moreover, integrating not looking behaviours into the game interaction can augment the feeling of presence to make players more involved in the game and map their actions as if it was the real world.

8.1.6 Lessons learned Beyond Play

Exploring “not looking” through playful experiences has helped to shape opportunities that could be extrapolated in other genres and applications within the HCI field.

8.1.6.1 Social Gaze and Awareness

The games using *gaze effects*, introduce to some extent the *Midas Touch* [262] during gaze pointing. This is related to the trigger or selection of objects when we look at them without the intention to interact with them. In HCI, the *Midas Touch* is a problem and it is often avoided. For example, in desktop applications, we would use the eyes to indicate the object of interest and another input, such as the keyboard, to confirm the selection. In games, it can be leveraged, not only to introduce dynamics for not looking but also to introduce the use of *Social Gaze*. *The Royal Corgi* [271] uses social gaze behaviours in a virtual world leading to greater immersion in the playful experience. However, *Social Gaze* is not unique to the gaming context. For instance, in 3D virtual world online communities, or meeting spaces of the future, gaze behaviour could be useful to recreate real-life situations. For instance, users could know if they are looked at to call their attention; where another user is looking at to support following a discussion’s bullet-points; or avoiding to make eye contact not to engage in starting a conversation in a crowded virtual meeting room, e.g. Mozilla Hubs.

On the other hand, in both *Screencheat* [139] and *Ticket to Ride* [182], gaze visualisation is presented as a way to share the opponent’s experience, and it has been demonstrated to have a positive effect in social presence [139], the feeling you are in the virtual space with someone else. Moreover, although the examples are set in a competitive context, this visualisation could also be used to add a new layer of non-verbal communication between two parties. This showcases that gaze could be used in the digital space, e.g. in remote collaborative work-spaces. Further, this category in the ”*not looking*” framework allowed players to predict and try to understand their opponent’s strategy and behaviour. Gaze patterns are a good asset for systems to predict intentions [103]. However, systems need to be aware that such intentions might not always be real, and the user could also try to “fool” when aware that they are being observed. This presents opportunities, not only to explore the decision not to look at the game space but also to consider this behaviour to train future intelligent ubiquitous systems, e.g. for healthcare.

8.1.6.2 Peripheral Vision and Metaphors

The use of gaze aversion allowed the exploration of peripheral vision perception in games, leading to potential applications to train peripheral awareness (SuperVision). Greater peripheral awareness can be useful, for example, to pick up notifications without looking at them. In a way, this paradigm could also solve the *Attention Dilemma* posed in *Shynosaurs* [270], as the player might be able to focus their attention on the enemies while performing the task in peripheral vision. Moreover, using gaze aversion to leverage “*not looking*” behaviours requires users to resist the impulse of looking at things that pop up. Accordingly, playing “without directly looking” could train inhibition control. In turn, this could guide the design of future applications and interfaces that do not disturb the user from the main task. For example, GPS and navigation systems that do not need to be looked at, creating safer driving environments.

On the other hand, "*not looking*" introduced the use of metaphors to support the gaze interaction in the game's narrative. In *Invisible Eni* [56], when the tracker loses the eyes once they are closed, the player character disappears. This example uses blinks as a means or the metaphor to escape dangerous situations, closing the eyes as the reflex to protect ourselves from intimidating events. This created new design opportunities to explore gaze metaphors. For instance, *closing one's eyes to avoid danger* as we would do in real life; or a *"blind faith"* that with our eyes shut, nothing wrong can happen, and we need to trust the system. Other examples could use closing the eyes as a sign for concentration; resting, or to disappear from the scene for a moment. New metaphors could guide the design of future applications, for instance, for meditation. In meditation apps, the user is guided to close their eyes, but detecting the action could signal that the user is ready to trust the system to guide them, and wait for further instructions. On the other hand, opening one's eyes could signal the system that we need to do something else and have a break. Overall, novel metaphors can inform future systems to customise the experience based on the users' gaze behaviour.

Moreover, metaphors are not exclusive of the fifth category of the framework but present throughout the different examples of the spectrum. In games we can find *looks that challenge or defy* or looks with a social meaning [271]; *looks that intimidate* [270]; *looks that freeze* [140]; and *looks that could petrify, kill or charm.* This showcases the potential of exploring the spectrum of the proposed framework for interaction design, which we will discuss in the following section.

8.1.7 Understanding Looking Away

We could understand the defined spectrum as a framework based on the users' decision to change their gaze behaviour to not look. Each category of the spectrum must not be treated in chronological order but as a set of dynamics that move towards the complete absence of gaze input. Nevertheless, we identify a consistent pattern drawn between dimensions: the user is in control of looking away, while the game engine controls the challenge that influences the user's decision not to look. Accordingly, we define two sets of behaviours: (A) when the users realise through reflection on the gameplay outcomes that they *might not*, *cannot* and *should not* look at the game scene; and (B) the scenarios in which the game system pushes the users to look away, either with rules that they *must* obey or mechanics that make them *stop* looking.

One take of the first group (A) is to consider them closer to the space of gaze interactions aligned with "looking". It is the game engine that introduces an effect or a challenge to gaze interaction. On the other hand, the user decides that looking is no longer suitable in the game context, and therefore falls on the "*not looking*" spectrum. Although in the second dimension (*cannot look*), the system is designed so the users cannot attend to simultaneous tasks, it is still the user who decides to look away and balance the attention to the different challenges of the game. In all three dimensions, the user could decide to ignore the game effects and continue looking at the game. For instance, the player could seek to attract zombies in *Dying Light* because they enjoy killing them, or they might decide to upset characters in *The Royal Corgi* because they are not enjoying the game and want to fail at it as fast as possible.

On the other hand, the second behaviour (B) introduces less flexible rules, posing challenging gaze interactions that present looking away as a "must" to be successful in the experience. Moreover, the users are also introduced to metaphors that require them to stop looking and to close their eyes. Both actions are the users' will, but the game engine challenge can influence them. They no longer offer an open space for reflection and decision but set the behaviour as a rule.

Both can guide designers to consider adopting new behaviours for gaze interaction in contrast to the definition of looking as the expected action."*Not looking*" could either be a decision of the player based on the experience outcomes to using gaze input, or a direct consequence of the application's rules pushed by the system itself. We deem the proposed framework could be used as an asset for design.

8.1.8 Designing Unexpected Interactions

Although the different categories of the presented framework are centred around applications of gaze interaction in games, they could be generalised to define unexpected interactions for other HCI genres. Nevertheless, whether the proposed dimensions are suitable to design applications and interfaces with sensors beyond eye tracking could shape the research agenda for this new approach. We can only hypothesise how the framework can illustrate new opportunities for interactive systems.

Firstly, we could think of unexpected interactions with sensing technologies. For instance, not moving or shaking a device with an accelerometer; not pressing a button; not speaking into a microphone; not touching a touchscreen with your fingers or a pen. Secondly, each stage of the spectrum could be different to each sensor, and it is up to the designer to introduce the effects to trigger the associated behaviours.

We can take as an example pressing a button. *Not* pressing it might be applied in an interface that requires pushing it consistently and then a release for interaction (e.g. Dead man's switch). This system could also be considered a somehow switched input binary state, where pressing is the null signal. The button could also be inside a box, making it physically impossible to be pressed. Further, a red button with an alarm sign might suggest to the user that they *must not* press it. On the other hand, another one with a "please do not press" sign could be an instance of a button that *should not* be pressed. Moreover, the designer can think of situations in which the user *might not* press the button (when it is required). Maybe it is because it makes an uncomfortable noise, or because it gives you a low and not dangerous static shock. Another example could tackle a button that *cannot* be pressed. It might be a broken button; one that moves away; or one that pushes itself when the hand approaches.

Similarly, the lack of pen input in a tablet could lead to the design of mid-air gestures that might indicate the users' intention when they *might not* touch the surface, such as in a sorting task or an option selection. Moreover, we could also think of voice sensing systems that you need to whisper or even be silent to activate them. More pragmatically, silence could be the indicator of written spaces in speech-to-text systems. These examples could illustrate, for instance, learning opportunities for interfaces using buttons that fail;

or novel pen and touch gestures on touchscreens. However, the framework and defined spectrum might also need to be fine-tuned for each technology.

Although this approach could be useful when designing gaze-enabled interfaces, further research is needed to validate and generalise the model for other sensing technologies. Overall, we discussed the framework as an outcome of the work presented in this thesis, and we encourage designers to think about the "not looking" interaction space as an opportunity for gaze design.

8.2 Diegetic Gaze: The use of Roles and Metaphors

Although the number of gaze-enabled games has continuously risen over the years [245] and its potentials are indicated in other game domains such as Virtual Reality (VR) [102]; it is still a niche research activity [100]. One reason for this can be seen in the fact that in many cases, the integration of gaze appears to be superficial. Gaze, in this regard, is considered as being an add-on that is built on top of a fully functional game, leaving it as an optional element. We have challenged this approach to propose more creative ways to adopt gaze input in games. In doing so, we have discussed new concepts for playing with gaze and the introduction of new metaphors to embed gaze in the game world.

Gaze-based game taxonomies such as the EyePlay [263] highlight the use of gaze in games from a feature-driven perspective with a focus on the "formal elements" of a game (e.g., game rules, goals, procedures, controls) [70]. Velloso et al.'s EyePlay puts forward categories that describe how gaze input has been mapped into traditional game control mechanics, such as moving characters or shooting guns. In the game experiences presented in this thesis, we partly challenge the EyePlay framework by moving away from its non-diegetic and mechanics-centred perspective. Here, we refer to the term "diegesis" to indicate a distinction between things that belong to the game story and elements that do not [137].

Accordingly, all three games (*Twileyed*, *SuperVision* and *KryptonEyed*) have followed a consistent design: the use of metaphors to support the integration of gaze input and the associated play concept into the game narrative. This is in contrast with the prevailing adoption of gaze in games as a utility for game efficiency, for instance, using gaze as a tool for highlighting and selecting game entities [254] or for camera control [255]. Upon reflection, as discussed in each game's chapter, we believe the metaphors used to contextualise the interaction in the games were key in the design process to find new ways of giving relevance to gaze input in games. We have been inspired by fiction and stories of gaze challenges to reflect that the eyes are more than looking. We deem thinking about new metaphors could serve designers as a starting point for envisioning gaze-based games.

The concept of "metaphors", as we have used it in this thesis, introduces the concept of diegesis in the design of gaze-based interactions in games. We can see such metaphors as "dramatic elements" (e.g. story, characters and context) [70] that are strongly related to the players and their interpretations of the game world. In using this dramatisation of gaze, we believe we have added a new dimension to gaze interaction that gives players a role in the game. For instance, rather than adopting gaze input to control a weapon, the player assumes the gaze of Medusa and their gaze is converted into the eyes of this mythological character. This is in contrast with the EyePlay framework that only puts the game, and not the player, in the centre of attention. For example, the category "Navigation" deals with gaze as a means to an end to reach a specified location within the game. The players' perspective (i.e., their interpretation of the gaze embedded in the game world) plays only a minor role.

A well-known game design model, the "Mechanics, Dynamics, and Aesthetics" (MDA) Framework [104], resembles the integrative character of our approach. After Leblanc et al. [104], the mechanics comprise the formal elements of a game (e.g., resources and winning conditions) that lead to specific player behaviour (i.e., the dynamics of a game). From this behaviour emerges a particular experience, such as having a feeling of being a powerful hero in a fantasy world. It is deemed that dramatic elements also have a significant impact on the players' behaviour and their interpretations of the game world. We argue for considering dramatic elements in the design of gaze-based games. Specifically, we have been interested in making gaze something that is part of the game world/story and using metaphorical figures (i.e., rhetorical concepts of gaze integrated into the game world), thus introducing the interaction as a diegetic element. This could contribute to the player's feeling of presence in the game world - the sensation of being there.

Beyond the explicit list of metaphors discussed within the chapter dedicated to the game *KryptonEyed* which frames gaze as a power, *Twileyed* and *SuperVision* include popular characters from fiction that serve as the first step in thinking about gaze diegesis.

Twileyed's *Dorian's Pictures* game showcases the use of metaphors inspired by social behaviours. For instance, looking at Dorian to select him promotes "looks of attention" which complies with Dorian's narcissism, whereas looking at other characters is translated to metaphors of Dorian looking at them with "looks that intimidate" to make them "paralyse" or "freeze". In *Jekyll and Hyde*'s game, the player is empowered to move two characters at once by moving Hyde "through Jekyll's eyes". Although this is presented as a "side effect", it could also be described with a "looks that draw attention" metaphor as one character will move towards the direction the other is looking. Finally, *The Witches* game challenges the player to solve the task with a gaze hurdle, "magic" (gaze to cast water spells) "has a price" and enemies will move towards wherever the player looks. This narrative can also be explained with "looks that draw attention", "looks that inform" and "spoil", or even giving the villagers the power of "the third eye", as metaphors.

Both *SuperVision* and *KryptonEyed* introduce metaphors to give the player gaze powers: "looks that kill", "looks that turn into stone", "looks that charm" and "teleportation". However, *SuperVision* poses challenges so the player must not look, and powers turn into a hurdle. On the other hand, *KryptonEyed* reflects the metaphor about the "price" of gaze interaction by introducing the same gaze behaviour (closing the eyes) to make the character "teleport" and "rest".

In a nutshell, all the games showcase how the diegesis of gaze input is possible in games opening up design opportunities. However, although it has not been formalised, this approach has been previously used in state of the art gaze-enabled games. We analyse the current literature seeking examples of gaze diegesis. We are interested in the cases that are based on the role of gaze inside the game and the use of gaze-based metaphors to integrate it into the game narrative.

8.2.1 Gaze Roles

There are fewer examples of gaze mechanics in games that blend into the gameplay narrative. These follow a diegetic approach, and gaze interaction is part of the game, the means to an end and the artefact that allows the player to trigger specific actions that are in-line with the game narrative. Within the game, gaze has a role and is integrated into the game narrative, making the player necessitate the eye tracker to guarantee a successful gameplay experience.

Therefore, gaze affects not only the game experience, the narrative or the player experience, but creates a link between both that benefits the overall gameplay. One of the main characteristics of this approach is that if the eye tracker is removed from the game, the player cannot play and the experience makes no sense. Sometimes the game can be impossible to use or control. When it does, for example, by replacing gaze pointing with mouse pointing or other input devices, the interaction is no longer suitable nor aligned with the game narrative - the mouse-point cannot "intimidate" as gaze does.

In the game "The Royal Corgi" [271], gaze influences the reaction of the characters the player communicates with. For instance, they can upset a character if they do not look at them or look distracted by looking somewhere else. Therefore, the game is built to explore the social use of gaze, so wherever the player gaze is pointing, the other characters will modify their answers. Accordingly, if we remove the eye tracker, the game has no thrill and probably no difficulty as it would be a plain conversation with avatars. If we were to substitute gaze by another pointing input, such as the mouse, mouse-pointing would not fit the interaction effects. The characters would refer to the player visual attention, which would be modelled by the position of the mouse. This would create an ambiguity between the input type and the content or narration of the game for the player.

Thereby, whereas the diegetic gaze mechanics are integrated into the game narrative with more considerable influence, one could consider that gaze has a role within the interaction dynamics and the game narrative. We identified in the literature three typical roles: (1) Social; (2) Power; and (3) Hurdle. These are based on the assumed function or part that gaze interaction plays in the game. Roles can be considered not only the purpose but also the effect or consequences it triggers.

8.2.1.1 Social Gaze

Social Gaze describes the use of gaze related to trigger social constructs, behaviours and those events related to human relationships of attention. This role illustrates the gaze mechanics used to interact with characters, e.g., greeting or show attention socially. Similar to a live (real) environment, our eyes can indicate social cues inside games. For instance, we can look at people we want to interact with or avoid looking at people that we are not interested in talking to. Generally, the social role of gaze for gameplay interaction is leveraged to provide character awareness. It allows the player, for example, to greet other characters on eye contact [254, 172, 229, 74], fostering greater immersion and emotional bonding between characters [166].

However, more complex social behaviours could be performed with gaze. For instance, in Royal Corgi [271], the player's gaze can show disinterest, distraction, respect, interest or even draw the attention of those characters. On the other extreme of social interaction, gaze interaction with a social role could serve to indicate submission by avoiding to look at threatening characters or even use eye winks as a seduction tool [40].

8.2.1.2 Gaze Power and Player Empowerment

Gaze Power describes when gaze is used to trigger actions that would be considered fictional or not possible in real-life. This role represents the gaze mechanics that allow the player to use special features that belong to the game avatar just by looking. This role uses gaze as a fantasy or make-believe artefact. Gaze interaction is leveraged to provide the player with powers and special abilities that would not be possible to perform outside the game environment. Examples showcase being able to petrify opponents [98], freeze enemies [179, 140] or hack other characters in the game [253], just by looking. Others use pupil dilation to control power within the game and to close the eyes to disappear [56] or explicit gaze pointing to discover hidden pieces of the game story [143].

"Power" as a gaze role allows providing players' empowerment in the gameplay. Games illustrating this interaction mechanic offer the player game control beyond the traditional gamepad or other controllers, and gives them the ability to highlight objects of interest by having special psychic powers [191], or showcasing the avatar survival skills [172, 167]. Unmistakably, we could perform those actions with a different pointing input device, such as the mouse. However, the eyes are a natural attention sensor, and the use of gaze as input for interaction can integrate this power more intrinsically and smoothly.

Moreover, gaze interaction has served not only to give power to the player but also secondary users. Maurer et al. [159] created a version of Super Mario Bros in which half of the game scene was made black (and hidden). In the game, a second player can control with their gaze the position of a hole to see through the hidden part of the screen, which allows the primary player to see what is coming next. The described approach used gaze to empower a new player that previously, and without eye-based input in the game, was a mere spectator of the gameplay.

8.2.1.3 Gaze Hurdles

Gaze Hurdles describes the function of gaze when it assumes a curse or difficulty and becomes a problem to the player, posing a game challenge. This role illustrates the gaze mechanics that penalise the player for looking. This role uses gaze interaction as an obstacle, flaw or impediment, making it a challenging artefact. Games using gaze interaction as a burden use rules that penalise the player during gameplay just by looking. The main characteristic of this role is to use gaze pointing against the player and trigger unwanted outcomes. This has been generally exploited in implicit gaze interaction games where the player could trigger sound effects when looking at objects in the scene [73], making the experience more immersing and sometimes scarier [108]. We identified these examples as "hurdles" because the gaze effects are unexpected to the player, and they are created to provide them with an "unsettling" and immersive feeling during gameplay.

Others, like "Screencheat" [139] or "Ticket to Ride" [182], play with spoiling the players' gaze behaviour by showing a visualisation of the gaze point to the opponent. Although these dynamics represent a passive and implicit use of gaze interaction, they indeed illustrate the extents of this gaze role. Explicitly, a gaze hurdle is aligned with dynamics that make the players aware that when they look something terrible can happen, and they need to deal with the consequences. Examples like “VirusHunt” [266] and “SuperVision” present game mechanics that use gaze interaction against the players, making them necessitate to look away from the screen and rely on peripheral vision to be successful in gameplay.

8.2.2 Defining Gaze Roles through Metaphors

Gaze interaction roles can be perceived as ambiguous mechanics in gaze. It might not be evident to the player, for example, that they can look at someone to intimidate them (*Social*), petrify enemies by staring at them (*Power*) or not looking at objects if they want to succeed in the game (*Hurdle*). These three examples could be translated as gaze aiming or selection mechanics from the perspective of the game control, but their effects within the game might be considered confusing.

Take as an example the game *SuperVision*, in which the player needs to rely on peripheral vision because they will be penalised if they look. This mechanic can be confusing to the player given that the game is gaze-enabled and relies on eye tracking technology. We have already discussed that gaze interaction is coupled with looking, and not looking or looking away is perceived as an uncommon interaction. In the game, this ambiguity is solved by contextualising gaze aversion with pop culture and Greek mythology characters. Therefore, these references or metaphors serve as a figure of narration that symbolises, represents and is applied to the interaction dynamics, helping the player understand the gaze role.

Research on metaphors in the context of gaze is carried out in various fields: it ranges from linguistics [151], to intercultural research [216], film studies [22] and game studies [279]). For instance, in linguistics, the notion of metaphor describes how the world is understood and interpreted by humans. This can be seen in expressions referring to gaze and seeing, such as “seeing is touching” or “the eyes are a container for emotion” (Li [148]). In agreement with Begy [14], we see the term “metaphor” not from the perspective of linguistics, but rather in the cognitive sense. Specifically, we are interested in the metaphorical projection, where knowledge obtained from one domain is transferred to another one. In the context of games, this means that metaphors outside the games domain are translated into the game’s diegesis. Gaze metaphors in games offer the possibility to do something that is not possible with traditional scenarios for design, opening the space for novel opportunities.

For example, the concept of the “Midas touch” is based on the well-known story of King Midas and his curse: Everything he touches turns into gold (even his family is transformed into golden statues). Traditionally, the metaphor conveys the concept of being greedy. In the interaction design domain, it describes the issue that in gaze-based interactions, the perception and the user’s actions are not decoupled from the interaction process [262]. In games, the metaphor is employed as either a power or as a curse of the player’s avatar. In one case, players might look at objects to turn them into gold and get rich. In another game, the player could take the role of the Midas character whose goal is to avoid looking at specific game entities. The notion of the “Midas’ touch” metaphor could also be translated into the social domain: The player has to avoid looking at the other characters; otherwise, they will experience social fear and cannot move.

Table 8.1: List of Surveyed Gaze Metaphors related to each Gaze Role.

Metaphor	Gaze Role	Game Examples
Looking Distracted	Social	The Royal Corgi [271]
Looks of Respect	Social	The Royal Corgi [271]
Submissive Looks	Social	The Royal Corgi [271], La Rochelle Lab [40]
Avoiding to Look	Social	The Royal Corgi [271], La Rochelle Lab [40], SOMA [72]
Looks of Interest	Social	The Royal Corgi [271]
Look to Greet	Social	Assassins' Creed [254], Tomb Raider [172],
Looks that Calm	Social	Wayla [30], Spectrophobia [205]
Narcissism	Social	**Twileyed** [208]
Eye Contact	Social	Agents of Mayhem [229], Shelter 2 [166], Reflections [237], Knee Deep [74]
Looks that Freeze	Power	Limus and the Eyes of the Beholders [140], Biofeedback [179]
Not Looking for Safety	Power	Invisible Eni [56], Nevermind [171]
Having the Third Eye	Power	The Channeler [191]
Having an Eye for Detail	Power	Amphora [173]
Look to reveal	Power	Fractile [143], Mario Bros [159], Tomb Raider [172], Paws [167]
Hack at Gaze	Power	Watch Dogs 2 [253]
Survival Instinct	Power	Tomb Raider [172], Paws [167]
Teleportation	Power	**KryptonEyed** [210]
Looks that Charm	Social, Power	La Rochelle Lab [40], **SuperVision** [209], The Royal Corgi [271]
Starring Competition	Social, Power	The Revenge of the Killer Penguins [282]
Looks that Intimidate	Social, Power	The Royal Corgi [271], Shynosaurs [270], Spectrophobia [205], **Twileyed** [208]
Blind Faith	Social, Power	Invisible Eni [56]
Through someone's eyes	Social, Power	**Twileyed** [208]
Looks that Infect	Hurdle	VirusHunt [266]
Looks of Fear	Hurdle	La Rochelle Lab [40], Glimpse of Fear [108], Medusa's Labyrinth [73]
Disrespectful Looks	Social, Hurdle	The Royal Corgi [271]
Looks that Defy	Social, Hurdle	Spectrophobia [205], SOMA [72]
Looks draw Attention	Social, Hurdle	Keyewai [9], Dying Light [243], Screencheat [139], Ticket to Ride [182], Mills [139], **Twileyed** [208]
Looks that Kill	Power, Hurdle	**SuperVision** [209]
Looks that Petrify	Power, Hurdle	**SuperVision** [209], Medusa's Lair [98]
Medusa's Gaze	Power, Hurdle	**SuperVision** [209], Biofeedback [179], Medusa's Lair [98]
The price of Magic	Power, Hurdle	**Twileyed** [208]

Sometimes metaphors can help to explain ambiguous or challenging interactions, such as having to close one's eyes for interaction in *KryptonEyed*. Furthermore, mechanics can change throughout a play session (e.g., the gaze-based interaction could start as a curse and turn into a superpower in *Twileyed's The Witches* game). This ambiguity cannot only be introduced by the game through mechanics, but the meaning of gaze could also be defined by the players and/or diegetic elements. For instance, in Lankes et al. [141], gaze was utilised as a tool to augment playful collaborative activities. By introducing various forms of social gaze-based behaviours, a player could renegotiate the meaning of their counterpart's gaze guided by psychological concepts (e.g., joint attention).

We can find examples of different eye-based metaphors used in gaze-enabled games throughout the related work (see Table 8.1). These metaphors define the gaze mechanic, so it makes sense to the user to demonstrate that it is necessary and integrated into the game narrative. Not using a metaphor to strengthen the gaze role, could make the interaction or game dynamic to be perceived as ambiguous.

For instance, we could justify a *social* use of gaze, such as to make characters aware that we are looking at them, by using metaphors of "looking to greet" [254], or "Eye

Contact" [166]. Other games ("The Royal Corgi" [271]) can explain the fact that gaze is a social pointer and will trigger a possibly unexpected reaction from the other characters in the scene by using gaze metaphors related to social behaviour, such as "looking distracted", "looks of interest", "disrespectful looks" or "avoiding to look". In the game, the character with whom the player interacts with explains that the user is disrespectful or that they are looking distracted.

Gaze *powers* are easily integrated into the game narrative with metaphors. Designers can illustrate a gaze selection could "freeze" the enemies [179, 140], or even "looks can petrify" [98]. Without a metaphor, gaze powers would be aligned with gaze pointing for aiming and selection, and thus representative of the game control that affects the gameplay experience. When using a metaphor, gaze becomes an artefact of the game narrative to explain that objects highlight when looked at because you, as the main character in the game, have a "third eye" power [191]; events appear because you can "unravel stories" with your vision when looking around [143]. Moreover, a gaze power metaphor could explain unusual gaze interactions, such as closing one's eyes. In "Invisible Eni" [56], the player can make Eni (main avatar) disappear into smoke to protect herself from the monsters. These could be "Closing your eyes for safety", but also could be described with metaphors of "blind faith", "concentration" or "fear".

Finally, gaze *hurdles* metaphors justify why gaze is posing a challenge to the player. When the player gets penalised during gameplay for looking at game objects, like in *SuperVision*, the player might find it ambiguous that they cannot look at the scene. However, when using metaphors like "looks that infect" [266] or "looks that kill/petrify/charm" (*SuperVision*), it is then understandable for the user, and it makes sense, that when they look, bad things could happen.

Metaphors are usually aligned with a particular use of a gaze interaction "Role" but are not bonded to a unique one. For example, in the "La Rochelle Lab" game [40], a "look that charm" is used to make the player wink at an enemy to get their homework back, hence using gaze with a social role. In the "Narcissus" game in *SuperVision*, the same metaphor is used as a gaze hurdle, as the player needs to sort frames without looking directly or they will fall in love with him.

Similarly, in *SuperVision*, "looks that petrify" are used as a gaze hurdle when Medusa, one of the game characters, look at mushrooms she needs to remove, turning them into stones. In "Medusa's Lair" [98], the same metaphor is used as a power in a multiplayer scenario. In the game, one player acts as Medusa and can petrify the opponents by looking at them while they run around trying to escape her. Moreover, but not specifically in a computer game, "Medusa's gaze" could act as a social gaze metaphor, like in the children game "Red Light, Green Light". In the game, all players must stop and pretend they are statues (petrified) when the leading player (opponent) turns around to look at them, or they will be disqualified. Whereas this could be considered as a power or a hurdle for the players, they choose to be immobile, and it is the intimidating look of the opponent that makes them stop.

In effect, gaze roles and metaphors form a complex relationship between them, influencing each other retrospectively and allowing the creation of different game dynamics.

8.2.2.1 Social Powers

Some social gaze behaviours can be perceived as powers. In "Amphora" [173], the player needs to solve puzzles and unfold the character story through connected tales. In the game, the player with "an eye for detail" can make butterflies fly away. Later, players can see them on the menu screen where they show the player's progress in the game. In this case, gaze could have a social role because the butterflies are aware of the player's attention on them. However, it could be a power because they sense the player's gaze and magically fly away to another scene. Accordingly, a "Staring Competition", in "The Revenge of the Killer Penguins" [282] can represent a social gaze metaphor to require the player to continually look to win, but also could be considered the power of submission.

In "Shynosaurs" [270], players need to save the "cuties" by looking at the enemies to intimidate them, and they become shyer the more you look at them until they leave crying. This game illustrates using a social metaphor to represent both a social and power gaze interaction. Gaze is used to make the enemies stop, freezing them on the spot by staring at them (power). Nevertheless, as the player keeps their gaze on the target, the social gaze intimidation is adopted.

8.2.2.2 Social Hurdles and Powerful Hurdles

Social metaphors of gaze attention are usually presented in games for characters awareness. In gameplay, when the player stares at another character, they will generally look or even wave [254]. However, in "SOMA" [72] and "Dying Light" [243] this social role is turned against the player. In both games, enemies (robots and zombies respectively) will become aware of the player's gaze and attack them, creating a social gaze hurdle.

A "Look that kills" might be considered a gaze power metaphor, because it is not realistic, makes no sense and only works with its metaphorical meaning. However, depending on the game narrative, this gaze mechanic could also be considered a *Gaze Hurdle* because it has deadly consequences. In the "Cyclops" game in *SuperVision*, this metaphor is used as a gaze dynamic. The player needs to sort balloons by manipulating them with the mouse in their peripheral vision. If they look at the balloons, they will explode and fall, making gaze a hurdle and posing the challenge. On the other hand, in the game, there are also bad balloons the player needs to destroy; therefore, gaze turns into power and continuously switches between the two roles.

8.2.2.3 Socially Powerful Hurdles

In a two-player game like "Keyewai" [9], gaze is used to steer the avatars' torch direction. During the game, players need to explore a forest inhabited by cannibals. If the torch is pointed at the cannibals, they will become aware of the player and attack them. However, if both players light-point at them, the cannibals will get confused and do not know whom to attack. The social gaze metaphor "looks draw attention" is used in this game as a hurdle. When the cannibal detects the players' attention, it creates an unwanted event, the attack. Nevertheless, the collaboration between players can transform this gaze mechanic into a gaze power, when "drawing somebody's attention" turns into a distraction or confusion strategy.

“Spectrophobia” [205] showcases the use of a gaze metaphor that is transformed depending on the gaze role determined by the game narrative. In the game, the player acts as a young man who attempts to find his wife in an abandoned mansion. He is haunted by invisible and sanguinary monsters who can only be seen through his reflection in mirrors. The monsters have different behaviours that the player affects through “Eye Contact”. Some monsters attack when looked at (Hurdle: *“Looks that Defy”*), other are pacified (Power: “Looks that Calm”), whereas spiders will run away when aware that they are aware of being gazed (Social: “Looks that Intimidate”).

These examples showcase how the combination of different roles and metaphors create a constellation of examples broadening the opportunities to develop novel eye-based interaction mechanics in gaze-enabled games.

8.2.3 Towards Diegetic Gaze Design

Thinking about the diegesis of gaze in games introduces a novel perspective for game design. We propose the adoption of gaze through metaphors and roles that are embedded in the narrative of the game, rather than implementing gaze input as an additional game feature. In doing so, we could extend existing frameworks, such as the EyePlay framework, by focusing on how gaze is embedded in games. Metaphorical projections have the potential to help players develop a deeper connection to the game by transferring gaze actions from one domain to another. Games in this regard are relevant because they could not only depict everyday-life situations but also grant players to explore environments and (social) situations that would not be possible in reality. Thus, games could be regarded as opportunities for innovative designs, where established metaphors could be modified, or new ones be introduced.

Designers can use the proposed taxonomy of roles and metaphors to guide new designs in gaze-enabled games. However, we do not claim completion as other dimensions might emerge from innovative ideas. In this regard, we discussed the analysis of sate of the art gaze-enabled games with concepts surfacing from our game design process. We identified the adoption of gaze in games can allow players to reflect the innate social function of the eyes, provide them with powers that they could not experience in real life or challenge them in creative and groundbreaking experiences. Moreover, we deem that the inclusion of narrative elements driven by playful concepts could provide insights for novel interaction designs. Games and playful environments are especially suitable. They allow physical activities through various in- and output devices (i.e., Kinect [165], Leap Motion [256]), and they often facilitate the introduction of different interaction roles embedded in metaphors. Furthermore, games are a useful instrument in the context of nonverbal interactions: For instance, games have been employed to investigate the impact of facial expressions on subjects [138].

There is another opportunity to connect metaphors in the context of gaze-enabled play with the concept of “Embodied Interaction”. Following Maurer et al. [162], Embodied Interaction deals with designing systems that are meaningful for users, which are interpreted as social beings with sentient bodies. Through their physical attributes and their senses, people experience their surroundings [50], guiding their actions and cognitive processes [259]. By including gaze as a narrative element in the form of metaphors, players could interpret and influence a given game situation through their bodily senses.

The term "Embodied Interaction" also implies nonverbal communication in general (e.g., body postures, facial expressions, hand gestures and gaze) as well as the aspect of uni- and multi-modality in interaction design. Consequently, diegesis through dramatisation could be applied to other modalities, such as gestures, facial expressions, etc. For instance, our taxonomy could contribute to the work of Djordjevic [46]. The researcher investigated established HCI metaphors and created guidelines for identifying metaphors that aimed at maximising the clarity and reducing the users' mental workload. By addressing the aspects of narrative elements and story, we could extend the framework as it exclusively focuses on functionality and visualisation (i.e., aesthetics and consistency). Furthermore, diegesis could also be applied to multi-modal configurations, as gaze has been studied in combination with gestures [31], facial expressions [53], or voice [258], opening the design space for novel uses of gaze in play.

8.3 Understanding Gaze in Play

The objective of this thesis has been to explore how designers can adopt gaze differently and more creatively in games. What is characteristic of the game concepts described in previous chapters is that they showcase new ways to use gaze input to provide playful experiences. Accordingly, "not looking" behaviours and metaphors inspiring gaze-enabled games highlight opportunities to think about gaze interaction as an *experience*. Concretely, we have discussed the properties of mapping real-life behaviours into the game world, either by engaging what players can do with their eyes (attention, perception or actions) or via the integration of dramatisation in the adoption of gaze for interaction.

This is very much in-line with the concept of "game aesthetics". Although there is no consensus on the definition of the concept, we are interested in Niedenthal's take on *game aesthetics* as an expression of the game experienced [187]. In his view, the aesthetic meaning of games emerges at the intersection of the use of our senses and embodiment with the tangible qualities of games when we play. We can translate this back to gaze interaction and consider gaze as an experience because when the eyes are used within the game context, it has the potential to make the player feel more involved in different ways. For instance, in *SuperVision*, the player adopts the characters' gaze hurdles, and this could lead to them feeling powerful. In *KryptonEyed*, mapping the player's actions into the game (eye closing) could lead to greater presence.

However, when using gaze input as a utility for efficiency, we believe it might lose the richness of gaze and the potential meaning it could take in the game. In this regard, we are interested in referring to Sicart's definition of game mechanics in which he proposes that the best way to describe mechanics is to formalise them as verbs [226]; e.g. "to move", "to climb", etc. If we look at gaze interaction from a mechanics-driven perspective (such as the EyePlay framework [263]), the experience of using gaze input is not different from a gamepad, which removes any aesthetic value. Using gaze to "move" the game avatar makes no sense because gaze cannot create motion - unless the game grants the player the power of telekinesis. Here, we should note the need to use a metaphor to add the aesthetic experience to the interaction. On the other hand, when gaze is used "to intimidate", "to charm" or "to freeze", we are describing mechanics in line with how gaze is used in the real world or supporting new experiences, thus using gaze behaviour as a game aesthetic.

As such, we deem there is a need to understand how gaze is used for eye-based interaction in games to formalise the aesthetic properties of gaze input. We must clarify, all gaze interactions are based on using the eyes as a pointing device (even for not looking) because eye trackers transform the input from both eyes into a single point in the screen. However, there could be different conceptual differences in how gaze is adopted in the game. Most notably in our work, we have been interested in moving the gaze point away from the focus of attention or the absence of such when not looking. This calls for a taxonomy that explores how gaze has been used in games highlighting its aesthetic value.

We have discussed in previous chapters different aesthetic experiences that emerged from each game concept. For instance, the three games showcase how not looking behaviours can describe different actions, from looking away to closing the eyelids. *KryptonEyed* shows how actions we perform with the eyes can be mapped to different game entities, e.g. closing the eyes to move the game character's body or to close their eyes to rest. *SuperVision* draws the attention to *what* you are looking to propose not to look at objects in the scene. Finally, in *Twileyed*, we discussed the concept of "identity" which explains that gaze input in the game could be adopted to be the gaze of either the user or the game character they are controlling. These experiences make us think about gaze interaction not just as input but as different ways to look at the game.

Therefore, we could define gaze interaction as *attention*, or the *action* that sets a relationship between the user (*the subject*), and the game (*the object*). In what follows, we want to describe gaze interaction in games considering: (1) *Who* is the actor looking at the scene; (2) *How* gaze is embedded in the game; (3) *What* the user's behaviour is, and (4) *towards What/Whom* is gaze attention directed in the game scene. Accordingly, we propose four dimensions: (1) *Identity*; (2) *Mapping*; (3) *Attention Type*; and (4) *Direction (Object)*. *Figure 8.3* represents the hierarchy of the dimensions, whereas *Figure* 8.4 adds visual details. These dimensions emerged from the analysis of the 221 games surveyed in our presented literature review. We compiled a total of 406 single gaze mechanics across all the games. To summarise them, we grouped them by similar look-alike dynamics. For grouping, we considered the different options that appeared based on each step in the initial description of the dimensions (1-4) following the subject-action-object metaphor. We performed this process several times as different groups emerged, leading to the four proposed dimensions.

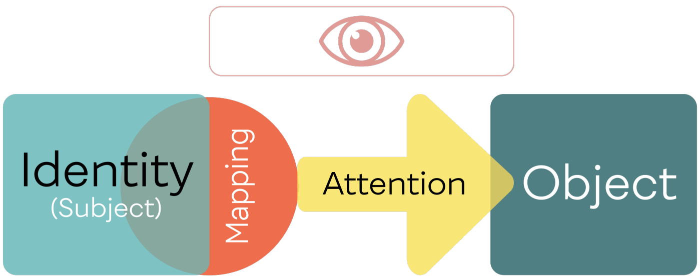


Figure 8.3: Gaze in Play Framework dimensions.

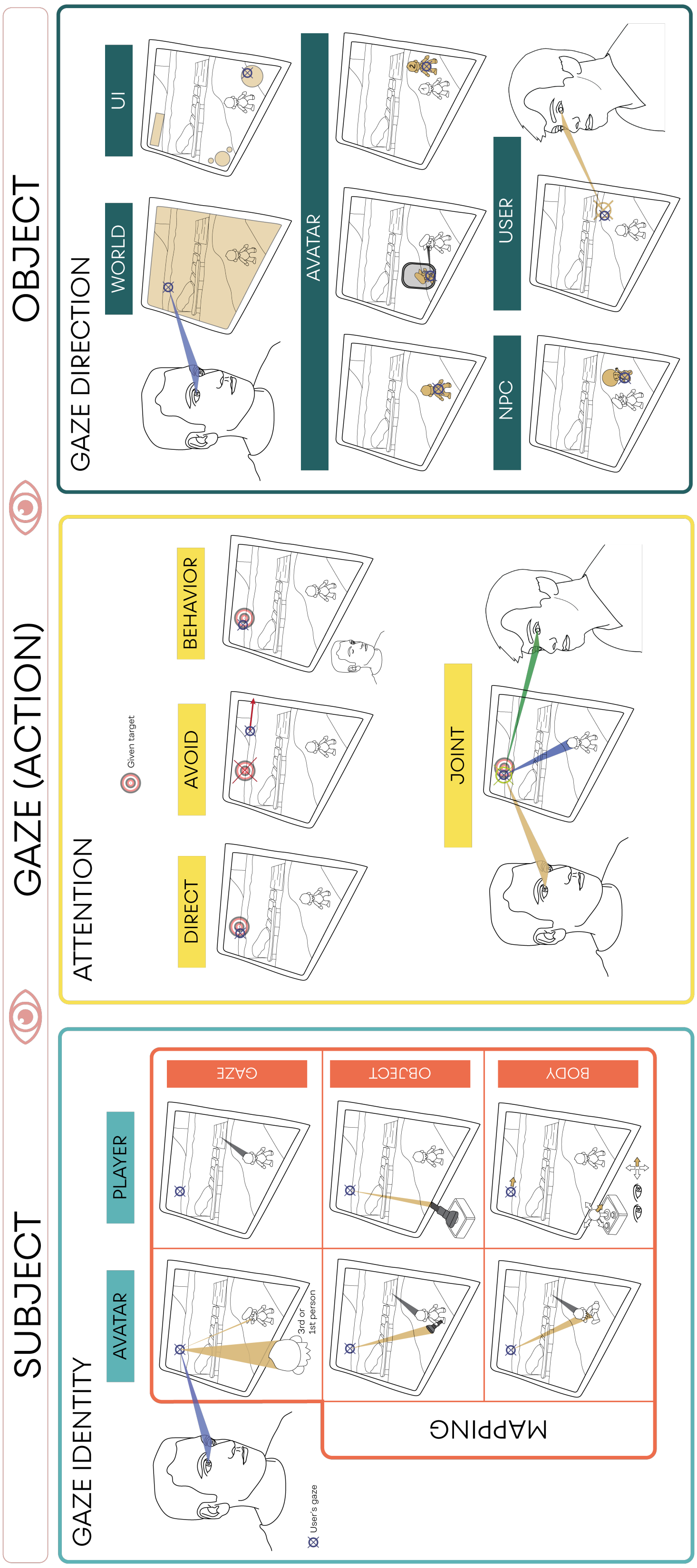


Figure 8.4: Gaze in Play Framework diagram unfolding each Dimension of the "*Subject - Gaze Interaction (Action) - Object*" model.

8.3.1 Gaze Identity: The Player and the Avatar

In non-gaze-enabled games, the *player* controls the game *avatar* in the virtual world. In gaze-enabled games, there is an opportunity to extend this paradigm and have both of them co-exist at the same time. In contrast with traditional gamepads that transform the players' operations into game actions, gaze has the potential to map the eyes' natural pointing into the game world and give the user an active role. In *Twileyed*'s Dorian game, we used this to require the player to look at a narcissistic character that needs attention to move. Accordingly, the player becomes the subject of the interaction, whereas Dorian is the object of attention. On the other hand, when the player looks at other characters, the game story established that is Dorian (the game avatar) who is intimidating at gaze. In this case, the users' gaze adopts the identity of the avatar in the game world. Here, we refer to the concept of *gaze identity* to describe *who* looks inside the game.

In games research, identity can refer to the user-character relationship defining the game avatar as the player's agency (the feeling of control over actions and their consequences [149, 174]) [178]. Accordingly, gaze could be considered a device to construct such agency. We do not refer to identity as the sociological notion of self, but the role the user assumes during the game through the use of gaze. Notably, gaze interaction takes input from the player's eyes; however, in the game world, this can have different interpretations. In some games, the user's gaze-point is transformed into where the main *avatar* looks at in the game world. Therefore the user assumes the role of the character and their gaze becomes the avatar's gaze in the game. In other examples, although it might seem redundant, the user looking at the screen transforms into the *player* (the game actor) looking at the game scenario. Therefore, we identify two identities in games: (1) the *player* and (2) the *avatar*.

The Player: Gaze interaction allows the user to become an actor co-existing with the avatar and interacting with the game space at the same time. Here, we refer to the *player* identity to describe the active role that allows the user to influence the game context with gaze independently from the avatar. Needless to say, users are players, but we refer to this identity as the role they are assigned inside the game mechanics, representing different conceptual dimensions outside and inside the game. For instance, the user looking at the screen is the input for interaction, whereas the gaze-point embedded in the game mechanics gives the player agency inside the game world. For example, the player looks at enemies to intimidate them in *Shynosaurs* [270]; influence the opponent by looking at the digital game board while playing *Ticket to Ride* [182], or collaborate with the avatar to freeze the enemy at gaze in *Limus and the eyes of the Beholders* [140]. Similarly, in more abstract games like the *Pursuits Frog* game [272] or *Simon Says* game [45], gaze is utilised into commands inside the game.

The Avatar: The player's gaze can control the main character in the game, e.g. where the user looks at is where the avatar is looking at. The *avatar* identity describes when the user assumes the role of the avatar in the game. Therefore, the user looks at the game as if it is the avatar's gaze interacting with it. For instance, when the user looks at a passerby in *Assassin's Creed* [254], they wave at the avatar and not the game camera. The user could understand that when they look, it is the *avatar* looking at the game scene. We believe adopting the avatar's gaze could be seen as user empowerment because the players can sometimes assume powers that are not possible in the real world. For instance, in *SuperVision*, players can petrify at gaze because they are Medusa. Similarly, in *The Royal Corgi* [271], the user assumes the role of the dog-trainer candidate.

During game design, one could integrate either a single or both identities at a time, because they are compatible and related to isolated gaze interactions. For instance, in *Tom Clancy's The Division 2* [59] the *player* interacts with gaze with the overlayed UI map (non-diegetic game element), whereas the *avatar* looks at the enemies to aim a firearm at them. In *Twileyed*'s Dorian game, players could assume two different identity roles during the game, thus gaze could allow the user to switch between mindsets. Moreover, we do not claim completeness on this dimension, and we invite designers to think about integrating gaze to give other identities to the users. In *Maurer*'s *Mario Bros.* [159], gaze is used to empower an audience user giving them an active role to support the primary player. In *Twileyed*'s Witches game, participants perceived they were controlling both the water spells but also the enemies (Non-Player Characters, NPCs). Accordingly, future research could explore creating gaze interactions that support the control of NPCs in the game.

8.3.2 Mapping: Embedding Gaze

Another characteristic in gaze design that contributes to providing a different experience is how gaze input is embedded inside the game. For instance, in *Twileyed* gaze input is transformed in Dorian, Jekyll or the Witch's gaze; *SuperVision* requires the players to adopt the character's gaze hurdles; whereas in *KryptonEyed* by closing the eyelids, gaze input is mapped to the teleportation of the avatar's body. In other games, gaze can control virtual objects, such as torches or weapons, becoming a pointer device. Therefore we refer to the concept of *gaze mapping* to describe how gaze input is integrated within the game environment. We identify in games three types of gaze mapping: (1) *gaze*, (2) *body*, and (3) *object*.

Gaze mapping describes the fact the gaze-point is used to control where, indeed, the eyes point at in the game. For instance, in games like *Ibb & Obb* [161], or *Ticket to Ride* [183], the player's gaze point is displayed to the partner/opponent player, so they have a reference to where the other player is looking at in the game. In contrast, in *Limus and the eyes of the Beholders* [140], both avatar and player's gazes are mapped in the game world, and they need to look together at the enemies to stop their attack.

Body mapping describes that gaze input controls the movement of game objects. For instance, gaze can move the avatar's physical body (a butterfly) in a 1:1 mapping in *Schau Genau!* [220], direct a plane's orientation in *GazePilot* [188], or move virtual characters' eyeballs [141, 222]. In contrast, *body mapping* can describe gaze interactions that take input from the movement of the eyes, or the eyelids, rather than the exact position of the gaze point. For example, in *KryptonEyed*, eye movements with closed lids are mapped into game actions. In *TrackMaze* [1], the player controls the direction of a ball with eye gestures. The eyes simulate joystick actions, and the player needs to roll their eyes side to side to move a ball in the maze.

Object mapping refers to gaze controlling something operated by the "body". In some game examples, gaze input can direct tools (carried by either the avatar or the player) at the scene. For example, in *Keyewai* [9] and *StarGazing* [266], gaze controls the direction of a torch. In *GazeArchers* [198], gaze is mapped into the direction of weapons. On the other hand, gaze could control something that the user holds or carries. For instance, in *LaserViz: Cup game* [261], the player wears a head-mounted eye tracker holding a laser pointer. This points where the player looks at in the space. In *Maurer et al.*'s *Mario Bros.* version [159], a secondary player can use their gaze to move a "virtual" *object* to help the main player see through a pinhole what comes next in the game.

Embedding different gaze mappings in the game could affect how the game is experienced. Firstly, the *gaze* mapping is linked to the sensory input of the eyes, and it allows game aesthetics that play with gaze behaviours, e.g. social gaze [271] or adopting gaze "powers" that would not be possible in real life [179]. These could help increase game immersion. On the other hand, both *object* and *body* mappings could influence the user's perception of control in the game, e.g. feeling empowered with tools controlled by gaze [261, 9, 159]; or moving a paddle with the eyes as if it was magic [220, 49]. Both mappings are correlated with *gaze* because we usually rotate/direct our body/head towards where we look at in the world; thus, mappings could be combined. Moreover, the *body* mapping allows the exploration of not just the gaze point but the physical function of the eyes, e.g. the muscles to perform different eye movements or control the eyelids.

8.3.3 Gaze Attention

One of the main contributions of this thesis has been the description of gaze behaviours that move away from traditional, and direct, gaze pointing. Notably, by exploring not looking, we have identified that, in games, gaze does not have to be used to look at things, e.g. to select them. Accordingly, players could collaborate with other characters to look together at games, look at where the opponent is looking or even avoid to look at the scene. These behaviours could provide different experiences in gameplay. We refer to the concept of *gaze attention* to describe how the user looks at the game in games. We identify four attention types: (1) *direct*, (2) *avoidance*, (3) *joint*, and (4) *behavioural*.

Direct attention describes the traditional use of gaze as a pointing device enabling the explicit selection, aiming of tools and other commands by aligning gaze with objects of interest. For example, in *The Royal Corgi* [271], the player walks around the room directly looking at the virtual world and the different characters. Moreover, in *Vidal et al.'s Pursuits Frog* game [272], the user follows with gaze the motion of the flies to select them so the frog can feed.

Avoidance attention describes the fact that direct attention can be averted. As demonstrated in the game concepts explored in this thesis, avoidance can happen when the player is required to avoid looking at game elements or to close their eyes for interaction [6, 56]. In design, *avoidance* is set in the game rules to require the user to move their gaze away from the object of interest. For example, in *Ejdemyr's Maze game* [54] and *Keyewai* [9], the user needs to avoid looking at enemies to avert their attack. In other cases, the user must avoid looking at the game to win, e.g. avoiding the spread of viruses when you look at them in *VirusHunt* [266]. Finally, we could think of *avoidance* as the user's physical presence, and not just looking away from the scene. For instance, in *Assassin's Creed: Rogue* [252] and *Nevermind* [171], the user can automatically pause the game when they are not in front of the screen.

Joint attention happens when two entities in the game (e.g. two players) look (or not) at the same object *together*. For example, in *GazeArchers* [198], two players need to look at gaze-aware enemies jointly to distract and defeat them. Moreover, one could think of the player *joining* their gaze with the game avatar. In *Limus and the eyes of the Beholders* [140], the enemy gets frozen when both *Limus* (the avatar) and the player look at them. Furthermore, two avatars can jointly look at game elements. In the multiplayer game *Keyewai* [9], the users can avoid being attacked by cannibals if both steer the avatar's torches towards them to dazzle and confuse them.

Behavioural attention describes behaviours that are atypical and not entirely explained by other dimensions. In design, *behavioural* attention includes different ways to look at the game, e.g. a wink of one eye to charm characters [40]; or saccadic eye gestures to move a ball in a maze [1]. Other non-conventional gaze interactions aligned with this category are present in *Invisible Eni* [56]. In the game, the user can open magic flowers by staring at them with dilated pupils. Moreover, we do not include in this dimension gaze dwells (the ability to fixate on the same location for a specific duration), or smooth pursuits (the ability to match with gaze the motion of a target) because they are better described by *direct* attention.

Accordingly, the definition of attention types includes restrictions. *Direct* and *avoidance* are absolute types that cannot happen at once, but one can transform into the other one; e.g. in *SuperVision* the Cyclops looks at bad balloons but avoids looking at good ones. On the other hand, *joint* and *behavioural* are flexible types because they can be combined with all the others; e.g. players can wink at a character, or avoid them together. Moreover, we must note that even though *joint* attention mainly relates to multiplayer scenarios, it could also be introduced to build a connection between the user and the avatar as two different actors in the game with different roles [140].

8.3.4 Gaze Direction (Object)

We have already discussed how the integration of gaze input and behaviour in games contributes to providing different experiences. However, depending on where the player looks at, different interaction effects and gameplay experiences might emerge. This is relevant in our games; for example, in *SuperVision*, the player must look at the objects in the world, but they could still look at the game scene. In *Twileyed* different gaze metaphors were introduced depending on whether the player looks at specific characters, the avatar they control or the game world. Similarly, in *KryptonEyed* player should only look at the monsters in the shooter game after closing the eyelids, but they can look at the monster boss in the next level with no consequences. Therefore, it is important to consider where the player looks at to provide different game experiences. We identify that, generally, the player interacts with (1) the game *world*; (2) user interface elements (*UI*); (3) the *avatar* they control; (4) *NPCs* or (5) other *users* in multiplayer environments.

The World direction describes how gaze can interact with the space where the game develops. In digital games, it corresponds to the 2D/3D virtual world, whereas, for physical or analogical games, it could be the board or space where the game takes place. We consider the *world* to be both the ground; and materials that shape the environment, but also the objects that inhabit it, excluding avatars and NPCs. Looking to the game world can be used to adapt the narrative of the experience, by guiding players through the story-paths they are more interested in, e.g. in *Rapture of the Deep* [204] or the game *Fractile* [143]. Moreover, the player can look at the game world to use tools or powers, e.g. telekinesis to rearrange the sand in a dessert [239]. In *StarGazing* [266], the player can aim an eye-controlled torch to illuminate the game world. In other examples, the player looks at the world to direct the position of the avatar [188] and a paddle [49]; or to control the position of a gaze-point marker they can use to communicate with another player, e.g. in the game *Ibb & Obb* [161].

The player can also look at *User Interface Elements (UI)* which are non-diegetic GUI elements such as overlaid buttons and menus for interaction. For instance, in *World of Warcraft* [115] or *Second Life* [12] the player navigates at overlayed buttons to enable eyes-only accessible game control. In design, thinking explicitly about the user looking at the *UI* against the game *world* could allow, for instance, cleaner UIs. In mainstream games such as *Tom Clancy's The Division 2* [59], or *Hitman* [109] UI items only appear when looking at them so when they look a the game world player has a less crowded field of view.

The Non-Player Character (NPC) direction describes gaze interaction with the characters that populate the game world that is not the main *avatar*. According to *Warpefelt* [277], NPCs are characters within a computer game that are mainly controlled by the computer and not the player. NPCs can be of different types: *Providers* (storytellers or loot providers); *Functions* (vendors, services and quest-givers); *Adversaries* (enemies and opponents); or *Friends* (sidekicks, allies, companions, pets and minions). Accordingly, looking at characters can augment social behaviours, e.g. in *The Royal Corgi* [271] or when passersby NPCs wave back when gazed in *Assassin's Creed: Odyssey* [254]. In other examples, the player looks at NPC to use their "powers"; for instance, to intimidate them [270], freeze [140, 179] and attack them [198].

The Avatar direction describes looking at the game character the player controls. This could be the player's avatar; the avatar's reflection in a mirror or their hands when looking down in a First-Person Perspective; and another player's avatar in a multiplayer game. Looking at the *avatar* can be used to activate different game modes depending on whether the player looks at the avatar or not [181]. In multiplayer games, the player can look at other player avatars to see how they roll their eyes [141, 222], or to petrify them with Medusa's powers [98].

The User dimension describes a case scenario that is exclusive to multiplayer games in which the player can look at where another player is looking. This refers to the opponent's gaze point visualised on the game scene; e.g. a laser pointer in *LaserViz's cup* game [261]. In design, introducing gaze markers in the game scene can create different gameplay experiences. For instance, communicate with another player to guide them through the game tasks [160, 42, 161], spy their strategy [139] or even try to deceive the opponent by looking elsewhere [182].

Gaze *direction*s could co-exist in the same context. However, dynamics involving gazing at diegetic elements of the game (the world, the avatar or the NPCs) have the potential to extend the game's field of view; increase immersion; or augment the efficiency of other controllers. On the other hand, one could think of creating mechanics that are not related to game elements, but players' behaviours. For instance, looking at other users or their markers can foster player collaboration; explore different competitive behaviours; or increase social presence and engagement.

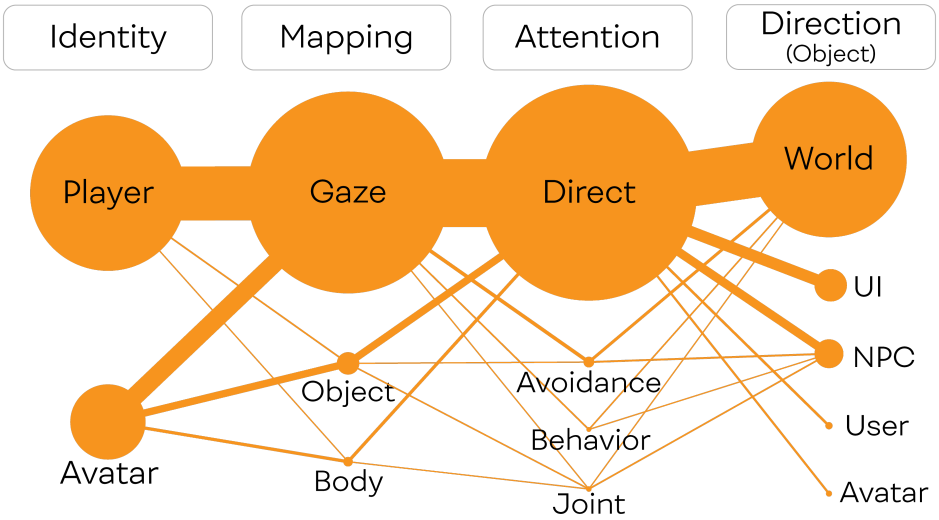


Figure 8.5: Gaze Mechanics Patterns.

8.3.5 Making sense of Gaze in Play

We have discussed four dimensions that shape a design framework which can be interpreted in distinct ways. We did not aim to define the relations between dimensions in a definite hierarchy as we aim this framework to be generative as much as it could be guiding. The possible gaze configurations we described are representations found in the literature following the subject-action-object metaphor and seeking aesthetic experiences enabled by gaze interaction. Still, we also acknowledge that single dimensions could be further utilised, or that other structures can be formed, leading to unique and novel gaze-based game mechanics.

To make sense of the population of surveyed games and the four dimensions described, we mapped all the games in a weighted network diagram (see *Figure 8.5*). The visualisation helps to identify general patterns and trends among the different categories that emerged. The size of the nodes and the thickness of the links represent the number of examples found. The mapping criteria followed each framework dimension to describe the *subject-actions-object* for each *gaze interaction* mechanic identified. These quantitative results inform about gaze interaction practices showing that a vast number of existing games utilise gaze following the construct: *players' gaze directed at the game world*. Moreover, the diagram emphasises the less crowded dimensions. However, to understand the population of surveyed games, we mapped them into the proposed dimensions to define a new design space. We aimed to highlight the opportunities to create new experiences.

We created a sunburst diagram (see *Figure 8.6*) to visualise how the dimensions expand following the proposed model from the perspective of the user's role (*identity*). We developed the visualisation in *Javascript* using the *Highcharts* library and designed an interactive tool to be able to explore the results. Link to the Online Tool can be found in Appendix B. This visualisation aims to help highlight how gaze has been adopted in the existing gaze-enabled games design space and gain a better understanding of state of the art. Moreover, it seeks to facilitate raising new questions that could extend to new opportunities for gaze in games. *Figure 8.6* achieves this purpose by emphasising

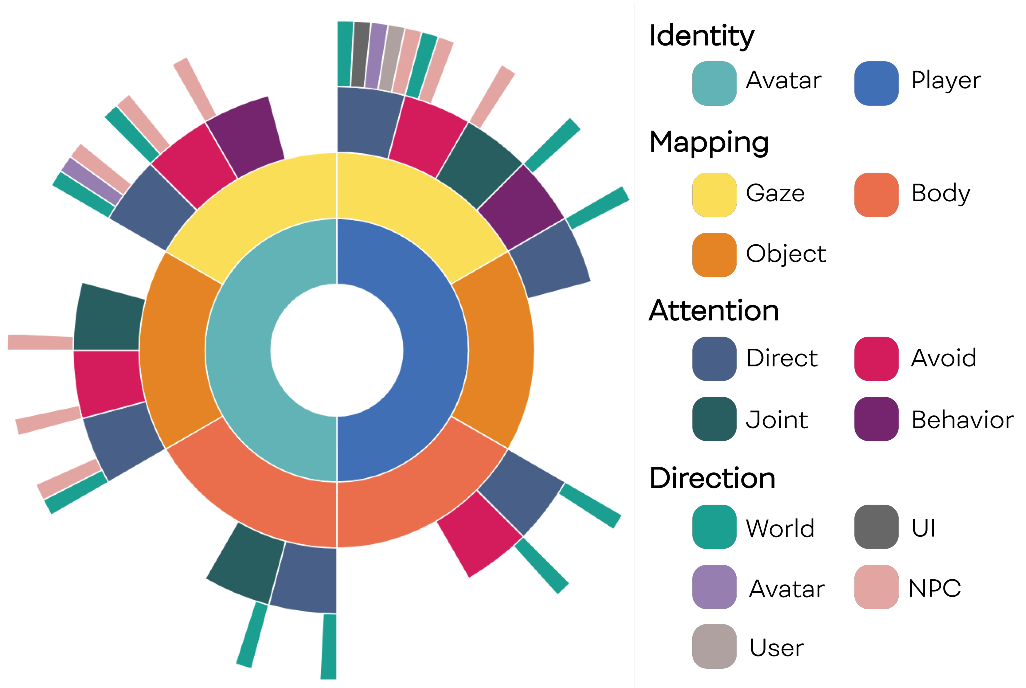


Figure 8.6: Sunburst Diagram visualising the surveyed Games mapped on the proposed conceptual framework dimensions.

which dimensions (and their combinations) have been under-explored and not explored at all (gaps), rather than highlighting the most crowded dynamics. Additionally, the interactive tool allows reviewing the number of game instances included in every single dimension and model on mouse hovers. Further, the application returns a list of games, both research-based and commercial when clicking on single elements on each of the branches.

8.3.5.1 The Ecology of the Framework

In contrast with previous surveys focusing on eye tracking input and game mechanics, here we discussed an experience-inspired and user's gaze-centred approach to gaze interaction. We consider gaze-enabled *game mechanics* as the formal elements that trigger a specific interaction for gameplay control: e.g. listed in *Velloso et al.*'s *EyePlay* framework [263]. This refers to explicit actions for game control, such as navigation or selection. Nonetheless, we believe the dimensions discussed can be considered as a framework highlighting the use of *gaze mechanics* to provide different game experiences beyond control. These are independent of the before-mentioned *game mechanics*, but can be designed in combination. The concept of *gaze mechanics* aligns with the suggestion to think about gaze action such as *looking* and *not looking* which has been the core of this thesis.

The proposed framework underlines gaze mechanics that are under-explored for interaction in games; thus, we can refer to them as *design opportunities*. There are combinations of dimensions that are unexplored because they make conceptually ambiguous models. For instance, the UI is restricted to be the object of the player's gaze. In contrast, the avatar (inside the game world) is disassociated from interacting with gaze statistics and maps because they are non-diegetic elements in the game. Moreover, other dimensions contain no examples because the outcome behaviour is unexpected. We can take as an example 'not looking at UI elements'. This would be something inconceivable as they are designed to provide in-game information. However, it does not create an incompatible scenario as designers could create playful mechanics using this paradigm. For instance, one could challenge players to complete a game task without relying on looking at the overlaid UI map. In some games, special game features get temporally deactivated when the avatar is in danger, e.g. the player cannot access the eagle-view when in combat in *Assassin's Creed: Origins*. Designers could apply the same principle to the UI.

We deem, the proposed framework extends the understanding of the adoption of gaze input in play as an experience beyond game control. Notably by identifying the dimensions of *gaze identity* and *attention* as gaze behaviours. These are concepts that could be combined with the formal game elements presented in other frameworks (e.g. *EyePlay* [263]) to create novel playful interactions. We must reinforce that we do not intend to overrule these approaches, but to work hand in hand with them. In the design process, one could think of the desired or intended gaze mechanic, e.g. the *player directly looking at the world*; and assign it to the game dynamic that will be triggered, e.g. 1:1 positioning of the gaze-marker. Depending on the designers' intention, gaze dynamics could be translated to game mechanics either fostering accessibility, e.g. moving the avatar to the gaze-point with gaze only; or for entertainment purposes, e.g. aiming the avatar's weapon.

Moreover, when thinking about gaze as an aesthetic, one of the main opportunities to extend the framework is the exploration of the richness of cultural and social situatedness of gaze. For instance, "positions of power": looking upwards or downwards. This could be associated with class; race or gender, but also feelings like awe. Accordingly, the framework helps to model the dimensions related to *social gaze* [271, 141], opening the window to integrate a meaning to the gaze mechanic, or utilise metaphors to support them as discussed in previous sections. For example, the avatar can look at NPCs to interact with them, but this could have a different *meaning* by utilising different narratives, e.g."looks that kill"; "defiant looks"; or "looks of respect".

The proposed dimensions in the framework are grounded in the analysis of gaze in games. However, its potential is not limited to playful experiences and could be extended to describe other gaze interaction-related genres in HCI. When designing applications based on eye-dwell time selection [48, 82], we could model this as the user's *gaze directly* looking at the *world* (interface). Other applications, based on gaze gestures [51, 292] could be modelled using the user's "body" in the app, the eyeballs' direction. In *Sideways* [292], the interface automatically scrolls side to side when the user looks towards the left/right of the screen. On the other hand, we could model more complex gaze attention types in desktop interfaces. *Avoidance* attention could describe a gamified version of the anti-saccades test [176]. In the test, users are asked to look away from the target appearing on the display. The user needs to roll their eyes to the opposite end of the screen, controlling their natural impulse of looking at the target. Following this example, we see how the proposed framework could model gaze interaction in general HCI applications including desktop interfaces; public displays or those fostering accessibility.

Overall, a re-evaluation of this conceptual framework examining gaze-interaction might be necessary to generalise the dimensions for the broader gaze-based interface design in the HCI literature. Nevertheless, our discussion is focused on gaze interaction for gameplay. The dimensions presented emerged from the discussion of the explored game concepts in this thesis. We identified concepts that changed how we look at gaze input from a utility for efficiency perspective. In exchange, they consider the adoption of gaze a tool with the potential to provide different gameplay experiences. We argue this approach highlights the possibilities to design more meaningful interactions that truly reflect the richness of gaze.

8.4 Outcomes: Using the Emerging Frameworks

In this chapter, we discussed the work presented in this thesis to describe three emerging frameworks. We explored the concept of "*not looking*" as an atypical and unexpected way of using eye tracking technologies for gaze interaction in games. "Not looking" has been the core of our work with the contribution of three playful concepts describing new opportunities to adopt gaze in games. By analysing the work as one piece, we defined a framework to guide the design of "not looking" interactions, which could potentially be generalised to other sensing technologies. The framework puts forward the exploration of gaze behaviours that go beyond the generalised use of eye tracking technology. In future work, designers should not be limited to thinking about gaze as a pointing device. Still, they could leverage what the eyes can do for interaction by integrating other dimensions such as cognition; attention; behaviour; the physical function of the eyes (e.g. the eyelids), or engaging the broader visual field.

Moreover, we discussed the adoption of a diegetic perspective during the design of gaze-based interaction by considering roles and gaze metaphors. Through the analysis of game examples, we described a taxonomy for the diegesis of gaze input. This is illustrated by a list list of surveyed gaze metaphors related to each gaze role. The taxonomy could support designers in integrating gaze not only as an add-on to existing game design but as an integrative element of the game world and its narrative. Following this notion, this idea aims to extend current approaches by taking the ambiguous meaning of gaze interaction and the player perspective in the game into account. We believe that the integration of dramatic elements to support the adoption of gaze input in the game reflects on the design potentials, possibilities and opportunities of gaze and other nonverbal interactions in playful experiences.

Furthermore, we discussed how the adoption of gaze input in games has the potential to provide experiences that exploit different game aesthetics, e.g. the richness of gaze as a socio-cultural phenomenon. In this analysis, we contributed a novel conceptual framework to design gaze interaction in games based on how the user looks at the game. We described four dimensions of a framework that is illustrated by gaze-enabled game examples found in the survey of the related literature. In doing so, we draw a constellation of examples that dissects the design space, giving an overview of state of the art and highlighting design and research opportunities.

Game designers and HCI practitioners could benefit from using the different dimensions presented in the emerging frameworks. However, we want to highlight its value beyond games. For instance, thinking about gaze more creatively, as we have demonstrated, could lead to new research on accessible interaction (e.g., Gaze+Hold). Moreover, thinking about how gaze is used for interaction could be of interest to research areas such as social computing, embodied interaction, and human-robot interaction. For example, HCI practitioners interested in how companion robots interact with users could rely on our gaze attention model to better design a conversational behaviour system. Finally, we must note that each framework does not intend to invalidate other conceptual dimensions found in the state of the art, e.g., the EyePlay framework [263]. We envision our emerging framework as new lenses to think of gaze interaction in games that offer new game design perspectives. Furthermore, we would like readers to think of all existing frameworks (inclusive in this thesis and beyond) as toys in a playground (or LEGO blocks). As such, we position our proposed frameworks as "ingredients" that future game designers with interest in gaze interaction could use to think of new opportunities for gameplay.

In sum, the discussion of the work presented in this thesis contributed to the description of emerging frameworks that put forward the adoption of gaze interaction as more than a utility for efficiency. Indeed, gaze input is a pointing device; however, it also integrates a natural mapping for game control with the potential to translate what the eyes can do in real life into the actions that happen in the game world. We have explored different game concepts that utilise gaze in an integrative way. They leverage different game aesthetics that surface from looking at gaze as the attention experienced and use dramatisation of the gaze input within the game narrative to support the interaction. Moreover, the games consider alternatives to gaze pointing by introducing "not looking" as a new design space for gaze in games. In this regard, what both the collection of game prototypes presented here and the emerging frameworks highlight is that gaze, and "not looking" as our focus, is not just an action, but a behaviour. As such, gaze-enabled game design needs to embrace this use of the eyes to provide meaningful experiences. We deem only then eye interaction will become an essential asset for gameplay as we imagine the possibilities of immersion by pushing our senses to the virtual world. Accordingly, there is a need to investigate how to integrate the importance of mapping gaze actions from the real world to the game environment. The emerging frameworks aim to contribute a toolbox that will inspire both designers and researchers, calling for future work as gaze-based interaction continues developing.

Conclusion 9

In this thesis, we explored the design space of playful experiences that take input from the eyes and leverage what we can do with gaze. The work presented moves away from traditional gaze pointing as a tool for gameplay efficiency by proposing game concepts that use gaze differently. We challenged the use of traditional gaze-based game mechanics by utilising gaze side effects. Moreover, we introduced playing with objects by leveraging our peripheral vision's capabilities and actively engage the broader field of view. Finally, we investigated what we can do with our eyelids closed to propose to roll the eyes behind the lids and predict the position of targets one cannot see.

We have developed a constellation of game prototype examples that illustrate three play concepts: (1) *Playing with Tension*, (2) *Playing with Peripheral Vision*, and (3) *Playing Without Looking*. These adopt gaze input creatively beyond the "what you look at is what you get" metaphor to propose designing with "not looking" metaphors in mind. This work has demonstrated that games can adopt more challenging gaze interactions based on visual capabilities (related to attention, perception or physical actions) and that designers can be inspired or use new metaphors to support such interactions in games.

We have used a variety of data collection methods to demonstrate the game concepts were engaging and fun. Each chapter investigates the usability and feasibility of the described gameplay experience. Moreover, we identified the potential benefits of playing with each proposed concept to highlight opportunities for gaze input in games but also interaction design beyond playful applications. The game *Twileyed* provides a conversation starter to think of gaze as an input with natural mapping that can contribute to different experiences (e.g. agency and identity). Moreover, the game also emphasises the potential of gaze input to pose bigger game challenges. The game *SuperVision* showed insights on skill development when peripheral awareness is put to the test which can be of interest to applications for visual performance training, but also could potentially be used for the gamification of psychology tests (e.g. for inhibition control). The game *KryptonEyed* discussed new opportunities to use "not looking" metaphors for gaze in games which highlight the potential of gaze input to provide greater game presence when actions in real life are mapped into the game world.

While we have shown that gaze input can be adopted in games in many different ways, the game concepts presented in this thesis demonstrate that ideas that are explored playfully can be generalised into techniques and applications which could be useful in other domains (e.g. training peripheral awareness). Most notably, the *Gaze+Hold* technique illustrated how play could inform interaction design and that something tested in a game can lead to an eyes-only interaction technique. As such, *Gaze+Hold* emerges from a playful concept to propose using both eyes as separate input and provide an alternative solution to the Midas Touch problem. The technique could be suitable for accessibility, including game control, with hands-free eyes-only interaction as demonstrated in the wide variety of applications we described in our work.

We wish the message of this thesis to be (1) the concepts explored, (2) the game prototypes described, and (3) the emerging frameworks we developed. Overall, these contribute to illustrate that other interaction metaphors are possible when designing for gaze input in games, and future work could think of "*playing with vision*" considering "*looking*" versus "*not looking*" interactions. Nevertheless, our work does not intend to provide a concrete answer on how to design games that take input from the eyes. Our contribution is focused on exploring opportunities that can certainly be extended. As such, we acknowledge that other game concepts could have been investigated with entirely different properties. We identified ideas to play with gaze input that researchers, designers and developers can take up in future gaze-enabled games.

We believe this work has opened a new way to think about gaze input in games by identifying and discussing the "not looking" design space. Upon the meta-analysis and reflection on the game concepts described in this thesis, we presented three emerging frameworks that provide new design opportunities for gaze by thinking about (1) "not looking" behaviours, (2) the dramatisation of gaze input to support the game diegesis, and (3) the potential of mapping the user's actions into different experiences inside the game world. These frameworks contribute to thinking about gaze differently because the eyes are not just a pointing device but have inherent abilities. We note our discussed frameworks are a sample of specific interpretations of our work based on emerging concepts. Accordingly, other lenses could lead to different frameworks as a result. For instance, we could have focused on formal game properties rather than experience aesthetics. We believe it is crucial to integrate what we can do with the eyes in games to advance in the future of gaze input in games and put forward ground-breaking playful experiences.

9.1 Gaze, Play, and Games

In this thesis, we have explored new creative ways to adopt gaze input for gameplay that move away from the use of gaze as a pointing device and as a tool for game performance efficiency. To reclaim the role of gaze in the game, we have proposed to create challenging game experiences that put our gaze abilities to the test, the dramatisation of the input in the game narrative and the introduction of new behaviours in the game. We believe these features play with game properties present in game studies' literature.

We are interested in the definition of the concept of play and its qualities proposed by sociologist Roger Caillois which is still relevant to many authors when introducing game elements in playful activities [212]. In Caillois' book "*Men, Play and Games*" [25], he attempts to classify games in four different types: games of skill, luck, imitation, and adrenaline. As such, the book outlines a simple game taxonomy with four main categories: *Agôn*, *Alea*, *Mimicry* and *Ilinx*.

Agôn describes competition and games of skill to validate one player's superiority. For instance, in a racing game, players compete to be the first to get to the finish line. *Alea* describes luck and games of chance that are ruled by randomness. For example, in card games, players are subject to the luck of drawing a card that benefits them in the game. *Mimicry* describes imitation, role-playing and games of make-believe, e.g. a child jumping around pretending to be a superhero. Finally, *Ilinx* describes vertigo and games of disorientation, which can be risk-taking and thrill-seeking. *Ilinx* is a kind of play that disrupts perception, for instance, with vertigo, brusque changes of direction or dizziness, e.g. walking in a straight line with the eyes closed. Each individual category in the taxonomy can be used to design games; however, they can also be combined to create enhanced playful experiences. For instance, competing with a friend to be the one who holds their breath for longer (Agôn and Ilinx), or playing "the floor is lava" (Agôn and Mimicry).

Accordingly, we believe the body of game concepts we presented in this thesis very much follows this taxonomy by combining elements of *Agôn* and *Mimicry* but also *Ilinx*. We must note our work does not contain features directly related to *Alea*. Still, these could be implicit in the defined randomness designed in the game engine (e.g. randomly choosing the amount and position of enemies or collectables). This inclusion of play properties in our work is in contrast with the widespread adoption of gaze input in games. For instance, when using gaze to tag opponents, dynamically move the game camera or trigger visual effects, gaze is an input for game control that does not exhibit any play properties. However, these could be implicit in other formal elements of the game (story, goals, challenges, or rules). Nevertheless, this is not limited to gaze only. Other input modalities for game control such as the keyboard or a gamepad do not usually contribute any play features to games, e.g. players could move the game camera with the mouse without introducing any play property. In contrast, one could say that gamepads support the *Agôn* of a game when the player needs to demonstrate the right skills to defeat all the enemies with a complex and swift combination of buttons. On the other hand, embracing play features that are inherited from input modalities could lead to their better integration in the game diegesis. As such, gaze input in mainstream games misses this opportunity when used as a utility for efficiency, to complement other input controllers, or as a tool for accessibility.

Unquestionably, video games are not alien to the playful features described by Caillois and include these themes in their design [163] although these properties are separate from the input modalities used for control. For example, in some games, the player needs a character to play with as their alter ego within the game world. This someone could be the game character the player controls (the simulation of the player) which can be defined as *mimicry* [284]. Moreover, video games revolve around challenges the player must achieve, involving elements of chance and competition either with other players or against the game engine [36].

We wish to build the parallelism between the concepts of this thesis and the aforementioned play properties because we believe gaze has the potential to introduce them in the game. Firstly, we focus on *Agôn*. The game concepts based on "not looking" outlined in our work present challenges of skill that relate to gaze input and not the game. The game prototypes propose to explore how can we actively use our gaze skills. They pose manipulation challenges in peripheral vision, control challenges of game mechanics with side effects, or pointing challenges when the game requires to perform eye movements behind the eyelids. Therefore, although the game sets the grounds of the challenge with rules and objectives, the challenge is adopted by gaze input, thus leveraging what we can do with our eyes for gameplay.

Moreover, we believe the use of gaze metaphors to support game interaction is aligned with the concept of *Mimicry*. We used metaphors as narratives that promote diegetic gaze in games. This approach plays with the meaning of gaze input in the game to encourage (to some extent) role-playing and make-believe, notably when empowering players with gaze abilities they do not possess in the real world. Therefore, gaze input serves as a tool with mimetic properties to describe role-playing and play pretend interactions that, as we discussed before, it does not apply to other input modalities - e.g. Medusa's gaze does not provide the same aesthetic experience when the mouse versus your gaze is used to petrify enemies. As such, game diegesis with gaze metaphors could relate to meaningful use of gaze input in play which supports connecting players' bodies to the virtual world of the game (presence). This could lead to experiencing rich aesthetic experiences because games that engage players through embodiment (e.g. physical movement) have the ability to influence player's emotions [110].

In addition, the challenges explored in each game chapter relate to the concept of *Ilinx* by requiring players to play with *tension* and perform gaze actions that could be perceived as "uncomfortable", e.g. playing with peripheral vision or the eyes closed. Furthermore, our games disrupt perception by making the player look away, rather than showcasing vertigo as a game feature. However, the data from each game experience provide insights on game enjoyment, cognitive and eye tiredness, indicating players perceived the games as physically challenging but fun. One could consider this an expression of gaze *Ilinx* as the techniques are tiring but engaging, supporting gaze mechanics that can be experienced as a "pleasurable torture".

Finally, although we have already established that the concept of *Alea* might not be directly present in the games. We believe the gaze challenges posed could contribute to introducing a shift from *Agôn* to *Alea*, concretely in the games *SuperVision* and *KryptonEyed*. All the games require players to develop the skill to overcome the proposed puzzles; however, if unsuccessful, players could give up and try to leave their actions and strategy to chance. In *SuperVision*'s Medusa game, players could just guess which mushroom to click rather than relying on peripheral vision. These contribute to our discussion on the potential of gaze input to yield playful properties beyond game mechanics, only possible when gaze diegesis is in play. Without input from the eyes, the games described would not be playful or fun, because gaze plays an important role in the game.

Our reflection on how the play experiences explored in this thesis map to Caillois' taxonomy contributes to our critique of the state of the art design frameworks for gaze input in games. We argue that approaches such as the EyePlay framework [263] do not highlight the potential of gaze aesthetics in games. We must reinforce we do not aim to make the EyePlay approach invalid, as it has contributed a taxonomy of gaze-enabled game control mechanics which could be of interest to accessibility, or to augment game performance, e.g. in eSports. In contrast, we believe we have shown that gaze input can be much more than a tool for game efficiency and there are other opportunities to adopt gaze input in games with the potential to greater challenge, agency and feeling of presence.

9.2 Future Work

In contrast with the prevailing adoption of eye tracking as a utility for game efficiency, our work has been significant in highlighting opportunities for using gaze more playfully by defining the experience and challenges of the game. We identify several future directions for gaze interaction in game design and general HCI.

9.2.1 Thinking differently about gaze input

There is more to gaze interaction than what you look at. We have challenged the "what you look at is what you get" interaction metaphor broadly adopted for gaze input to propose that other metaphors are possible. We have opened up a distinct space of inquiry: the use of gaze input in "not looking" interactions. As such, the "not looking" framework points out opportunities to design games that incorporate an understanding of the potential of the eyes in games. Gaze is rich and able to express complex emotions. Games should accommodate that looking has a meaning. It could be used as the means of gathering information about the world, but also contain traits of different behaviours. Designers should not be limited to adopt gaze interactions that consider only pointing, but they can reflect that gaze is more complex and integrate game elements that require players to look away.

Accordingly, we have identified opportunities to continue extending this body of work. We found particularly useful to design games that harvest what the eyes can do instead of constraining them to be a pointing device. Understanding the real impact of gaze input in the game can lead to the creation of games that map behaviours from the real world into the game context. For instance, players could decide if they want to interact with another character. They could look directly at them, or even ignore them, walk past and keep track of them with peripheral vision. Designers could integrate challenges in games than leverage gaze attention in a meaningful way by adding side effects, e.g. when attracting Zombies in *Dying Light*, looking has consequences, and it is up to the players to decide if they will not look. However, not all gaze interactions have to be based on realistic behaviours. Instead, designers could focus on creating "not looking" experiences that leverage what we can do with our eyes closed - for example, using eyelid closing as an indicator for eyes-only interaction.

We must note that other game mechanics and configurations can lead to new "not looking" behaviours. We call for future work that can engage with investigating new opportunities for "not looking" in games by adopting gaze meaningfully in the game mechanics. As such, we believe that future game design can find inspiration in our discussion about gaze roles and metaphors. As a guideline, when designing for gaze-enabled games that want to rely on the diegesis of gaze input, we would advise thinking about the gaze experience first. As it has been demonstrated in mainstream games that adopt gaze input, the common mistake is to add gaze interaction after the game experience has been designed. We encourage designers who intend to introduce gaze input in their games to think of the role of the eyes in the game. We find it useful to think about quotidian situations and literature references found in mythology and fiction. Accordingly, social behaviours are helpful to design games that take into account the natural richness and behaviour of the eyes. On the other hand, the occult, the mystical and science fiction could be assets to grant gaze experiences away from reality.

Therefore, future work can focus on the design of gaze input in games thinking about the experience. Gaze has the potential to be mapped into different entities of the game and involve a wide variety of actions and behaviours. As such, our emerging frameworks aim to be guiding and support the future of gaze-based games. Moreover, as we have done with previous frameworks, our work can be critiqued to give way to new interaction metaphors that might emerge as this body of research continues developing.

9.2.2 Challenging what we can do with the eyes in games

The playful concepts explored in this thesis have proposed a variety of new mechanics that contribute to the body of gaze-based games research. As such, future work can focus on the design of games posing similar challenges, namely, playing with tension, peripheral vision or the closure of the eyelids.

Gaze input as a modality for game control in games has been used as a utility that can sometimes remove the game challenge. As players can swiftly move their weapons towards the enemies they look, gaze becomes a tool only of interest of players who want to improve their gameplay performance. This approach is not wrong as it can contribute techniques suitable for accessibility, e.g. when moving characters with your eyes only. Moreover, adopting gaze as a pointing device has served to provide greater game immersion by dynamically adapting the game rendering; e.g. with the movement of the camera at gaze or adaptive field of view blur. As designers, we should not expect that all players would be interested in using gaze input, as the features introduced might be unappealing for thrill-seeking players who are not keen on improving their gaming skills but experiencing novel game narratives. Accordingly, gaze input should be integrated into games to offer new and ground-breaking experiences to earn its relevance in the gaming industry.

Therefore, it is crucial to understand how to integrate gaze input in the game experience. Take as an example the Xbox Kinect sensor, capable of mapping your body movement and position in the real world into the virtual one. Kinect is not used as a supporting modality for gamepads, e.g. point with one hand the object we want to select and confirming selection with a button. On the contrary, Kinect interactions are designed to leverage the body movement. In this regard, designing with gaze input should follow this approach to leverage visual capabilities in games. Appropriately, we have proposed to challenge the adoption of gaze as a pointing device and explored what we can do with the eyes. Designers could follow the description of our concepts to create similar games. For instance, forbidding to look at game elements to push attention to peripheral vision, playing with side effects, or leverage that we can move our eyes with the lids closed and encode different interaction events.

However, we understand that our proposed game concepts are limited by providing short, casual puzzle-based experiences that might not be of interest to players looking for long-hours gameplay in AAA games (mainstream and high-budget titles). Consequently, we wish to discuss directions where these unusual challenges and behaviours could be beneficial for future work. *Playing with tension* considers that gaze pointing does not have to be accurate all the time. Moreover, we games could introduce side effects to gaze input to add challenges to the experience. For instance, games that adopt gaze for the control of weapons could add a biased mapping of the input to resemble an uncalibrated firearm. In most action games, the hero character runs around killing enemies and collecting their weapons after they fall in their bed of death. These guns always work perfectly, putting all the odds in the players' favour. We could envision more challenging experiences that introduce side effects to the actions controlled by gaze. In our example, finding a gun on the floor does not mean it is going to work as new; it might be faulty. We deem the use of gaze side effects in explicit actions in the game could provide novel game experiences that exploit that using gaze for interaction can also pose a new challenge.

Moreover, we understand that not all interactions that take gaze input have to be challenging. As discussed in Chapter 4, gaze could allow the control of game characters that are not usually possible to play with; e.g. Non-Player characters (NPCs). In the game *Twileyed*, we introduced a side effect to attract enemies to where players were looking at in the game world. However, participants in the user study perceived they were controlling the enemies. This suggests there is an opportunity to extend gaze interaction to control NPCs. For example, the player could control the hero character (e.g. Batman) with a gamepad, and the companion NPC (e.g. Robin) with their eyes. Moreover, we believe future research could focus on the use of gaze input to empower audience members, e.g. in Maurer et al. [159] version of Super Mario Bros in which a second player controls a pinhole that allows the primary player to see what comes next. In this promising scenario, audience users could become sidekicks in the game experience with the help of gaze input.

Playing with Peripheral Vision highlights that there is more to gaze than the gaze-point and games should compensate for what does not fall into our visual focus. Accordingly, designers could create experiences that take into account the broader field of view. Here, we have engaged our visual capabilities by using gaze aversion mechanics. We described these interactions with behaviours that require players that they must not look at game objects. Beyond posing challenges in peripheral vision that add a somewhat restrictive game experience, we could think of playful scenarios aligned with other "not looking" behaviours. Take as an example, a spy-based game scenario. When spies infiltrate the party of the villain, they must be vigilant but also unnoticed so it might be useful to track the enemy in peripheral vision. This could allow games that integrate social behaviours, but also the natural properties of vision as we usually perceive objects of interest in our periphery before we shift our focus towards them. We deem that introducing these innate abilities in games could contribute to the feeling of presence, calling for future research that evaluates the impact of engaging peripheral vision.

Similarly, the proposed concept on *playing without looking* could address game immersion and presence. Beyond the technique presented in the game chapter, future work could focus on introducing the closure of the eyes during the game experience. The eyes are a tool to perceive the environment. However, closing one's eyes could hold many social and communication meanings. For instance, we close our eyes when we want to rest, concentrate or when in danger as a reflex. As such, integrating this "not looking" behaviour can lead to more realistic game experiences. For instance, in Assassin's Creed [254], the player can press a button to make the character sit down, rest and see time fly. In contrast, adopting gaze input to trigger the same action could generate a completely different aesthetic game experience.

We envision future research could focus on investigating the player experience, player presence and experiencing immersion during gameplay by using the concepts presented in this thesis as punctual events in the game. As described in this section, future work can study the effects of introducing *playing with tension* by biasing the gaze point temporarily; *playing with peripheral vision* by requiring players to perform ad-hoc tasks based on what they could only see in their periphery; and integrating into the game narrative *playing without looking* by requiring players to close their eyes to advance in the story. We anticipate these concepts have the potential to augment the feeling of immersion in the game when events in the virtual world relate to gaze behaviours from the real one. This has potential especially in first-person applications with Virtual Reality headsets that consider the capabilities of gaze input. Accordingly, future work can focus on studying the effect of "natural" gaze actions mapped into the game world.

9.2.3 Eyes-only interaction

Beyond the game concepts as such, our work has demonstrated that techniques that are tested in playful scenarios can evolve into new and useful methods for eyes-only interaction in mainstream applications. Accordingly, future work could be inspired by our "play-testing" approach and use games as the playground to test new ideas. We believe games provide a safety net to try out concepts that would not necessarily work or they could be of poor usability if applied directly into other applications.

Moreover, future work could take up our investigation on eyes-only interaction to explore new applications that leverage the Gaze+Hold technique. This could be of interest to research on accessibility as we have identified a framework of techniques that take input from both eyes separately to enable interactions over a continuum. Finally, our exploration is limited in describing applications in which the technique is used. As such, there is an opportunity to evaluate the usability of Gaze+Hold for accessibility and eyes-only interaction.

9.3 Game Over

The immediate contribution of this thesis has been advancing the gaze in games research corpus with an exploration of three novel playful concepts that take input from the eyes. Moreover, we have demonstrated how thinking differently and more playfully about gaze input in games can lead to new techniques useful in other domains, e.g. health, or accessibility. This thesis has opened a new space to think about the eyes for game interaction design. Beyond the traditional use of gaze as a utility for game efficiency, we have shown that there are new opportunities to explore how gaze can be embedded in different and creative ways in games. Beyond the games and playful concepts as such, the work presented opens up a design space accounting for "looking" and "not looking" behaviours when adopting gaze input in games. Therefore, future gaze-enabled games could join our research efforts to move away from traditional gaze pointing and propose more challenging uses of gaze in gameplay.

We believe our work has discussed the necessity of integrating gaze input, so it assumes a meaningful role within the game experience. It is crucial to take into account what we can do with the eyes to enable seamless interactions in the game world that relate to gaze behaviours from the real world. This integrative approach for gaze input could lead to developing a deeper connection between the player and the game narrative as they are anticipated to experience a more immersive and stronger presence in the game. Furthermore, we have discussed that gaze input does not have to be adopted only to resemble behaviours relevant to real life. In contrast, we provided insights on the utilisation of dramatic elements to support the integration of gaze input in the game narrative. This approach advocates for the diegesis of gaze which has the potential to result in different aesthetic experiences; e.g. the use of social gaze in the game context, or to enable the player to become a superhero.

As gaze input keeps being adapted in mainstream games, there is an opportunity to dream of the future possibilities for gaze-based interaction in playful contexts. Designers will need to create meaningful gaze interactions, that add value to the player experience while allowing the integration with other game mechanics and in a wide variety of game genres. We believe specific attention should be given to gaze input during the game design process in order to allow the integration of the modality in the game narrative. By making use of the insights generated by this thesis, future gaze-enabled games can lead to meaningful and diegetic interaction leveraging what we can do with our eyes in the virtual world.

A Supplementary Material: Survey Game List

This appendix contains a list of all the games surveyed as described in Chapter 3 and used for the creation of the emerging frameworks presented in Chapter 8.

Table A.1: List of Research-based gaze-enabled Games.

Game Name	Year	Game Type	Authors
The Little Prince	1990	Experience	Bolt, R. A.
Lunar Command	2006	Spce Shooter	Smith, J. D., & Graham, T. C.
Neverwinter Nights	2006	Adventure	
Quake II (Mod)	2006	First Person, Shooter	
[UNTITLED] Shooter Game	2006	Shooter	Isokoski, P., & Martin, B.
[UNTITLED] La Rochelle Lab	2007	Adventure	Da Silva, M. P., Courboulay, V., & Prigent, A.
Quake III	2008	First Person, Shooter	Hillaire, S., Lécuyer, A., Cozot, R., & Casiez, G.
Invisible Eni	2008	Adventure	Ekman, I. M., Poikola, A. W., & Mäkäräinen, M. K.
[UNTITLED] 3D Game	2008	Adventure, Shooter, Maze	Castellina, E., & Corno, F.
The Revenge of the Killer Penguins	2008	Adventure, Shooter, Maze	Wilcox, T., Evans, M., Pearce, C., Pollard, N., & Sundstedt, V.
Rabbit Run	2009	First Person, Maze	O'Donovan, J., Ward, J., Hodgins, S., & Sundstedt, V.
BreakOut	2009	Arcade	Dorr, M., Pomarjanschi, L., & Barth, E.
EyeChess	2009	Strategy	Isokoski, P., Joos, M., Spakov, O., & Martin, B.
Cgoban3	2009	Strategy	
Chicken Shoot	2009	Shooter	
EyeGuitar	2010	Music	Vickers, S., Istance, H., & Smalley, M.
World of Warcraft (Mod)	2010	MMORPG	Istance, H., Hyrskykari, A., Immonen, L., Mansikkamaa, S., & Vickers, S.
SecondLife (Mod)	2010	Online	Bates, R., Vickers, S., & Istance, H. O.
Half-Life 2 (Mod)	2010	First Person	Nacke, L. E., Stellmach, S., Sasse, D., & Lindley, C. A.
Mario Bros (Mod)	2011	Adventure, Gamepad	Munoz, J., Yannakakis, G. N., Mulvey, F., Hansen, D. W., Gutierrez, G., & Sanchis, A.
[UNTITLED] Biofeedback Shooter Game	2011	Shooter, Platform	Nacke, L. E., Kalyn, M., Lough, C., & Mandryk, R. L.
GazePilot	2012	Navigation	Nielsen, A. M., Petersen, A. L., & Hansen, J. P.
EyeGrab	2012	Puzzle	Walber, T., Neuhaus, C., & Scherp, A.
WAYLA	2013	Puzzle	Chang, W., Shen, P. A., Ponnam, K., Barbosa, H., Chen, M., & Bermudez, S.
[UNTITLED] Pursuits Frog Shooter	2013	Shooter	Vidal, M., Bulling, A., & Gellersen, H.
Limus and the eyes of the beholders	2014	Puzzle	Lankes, M., Mirlacher, T., Wagner, S., & Hochleitner, W.
Shynosaurs	2014	Puzzle	Vidal, M.
Schau Genau!	2014	Puzzle	Schaefer, C., Menges, R., Schmidt, K., Kuich, M., & Walber, T.
Virus Hunt	2015	Arcade	Velloso, E., Oechsner, C., Sachmann, K., Wirth, M., & Gellersen, H.
StarGazing	2015	Space Shooter	
Feyerball Mage	2015	Runner	
Battlefield 3	2015	First Person, Shooter	Velloso, E., Fleming, A., Alexander, J., & Gellersen, H.
Simon Game	2015	Memory, Puzzle	Djamasbi, S., & Mortazavi, S.
EyeSheep	2015	Puzzle	Carter, M., Newn, J., Velloso, E., & Vetere, F.
Fractile	2015	Experience	Lankes, M., & Wagner, S.
The Royal Corgi	2015	Adventure	Vidal, M., Bismuth, R., Bulling, A., & Gellersen, H.
Keyewai	2015	Multiplayer, Adventure	Bala, P., Noóbrega, L., Neves, G., Lopes, L. S., Morna, J., Camacho, J., & Freitas, C.
Super Mario Bros [MOD]	2015	Platform, Multiplayer	Maurer, B., Aslan, I., Wuchse, M., Neureiter, K., & Tscheligi, M.
[UNTITLED] Maze Game	2016	First Person, Maze	Ejdemyr, N.
Block! Block!	2016	AR, Tablet	Lankes, M., & Stiglbauer, B.
Dota 2 (Mod)	2016	MOBA	Nacenta, M.
GazeArchers	2016	Shooter, Collaborative, Tabletop	Pfeuffer, K., Alexander, J., & Gellersen, H.
[UNTITLED] Puzzle	2016	Puzzle	D'Angelo, S., & Gergle, D.
Ibb & Obb	2016	Collaborative, Adventure	Maurer, B., Lankes, M., Stiglbauer, B., & Tscheligi, M.
Screencheat	2016	Competitive	Lankes, M., Maurer, B., & Stiglbauer, B.
Mills	2016	Competitive	
[UNTITLED] Focus Depth VR	2016	VR	Pai, Y. S., Outram, B., Vontin, N., & Kunze, K.
[UNTITLED] Guessing Game	2016	Puzzle	Jalaliniya, S., & Mardanbegi, D.
[UNTITLED] Space Shooter	2017	Shooter	Navarro, D., & Sundstedt, V.
[UNTITLED] Social VR	2017	Communication	Seele, S., Misztal, S., Buhler, H., Herpers, R., & Schild, J.
[UNTITLED] LABYRINTH	2017	Maze, Communication	Maurer, B., Krischkowsky, A., & Tscheligi, M.
LaserViz: Cup Game	2017	Puzzle	Van Rheden, V., Maurer, B., Smit, D., Murer, M., & Tscheligi, M.
Ticket to Ride (Mod)	2017	Competitive, Board Game	Newn, J., Velloso, E., Allison, F., Abdelrahman, Y., & Vetere, F.
GazeBall	2017	Arcade	Ramirez Gomez, A.
Zombie Runner	2018	First Person, Shooter	Antunes, J., & Santana, P.
[UNTITLED] 2D Platform Runner	2018	Runner, 2D	ULUDAĞLI, M. Ç., & ACARTÜRK, C.
Rapture of the Deep	2018	VR, Experience	Probst, E., Suttner, V., Dietrich, M., & Buehler, T.
[UNTITLED] Pursuits VR Shooter	2018	VR, Shooter	Khamis, M., Oechsner, C., Alt, F., & Bulling, A.
TrackMaze	2018	Maze, Phone	Abbaszadegan, M., Yaghoubi, S., & MacKenzie, I. S.
Building Blocks Game	2018	VR, Collaborative	Lankes, M., Rajtár, M., Denisov, O., & Maurer, B.
[UNTITLED] 3D VR Social narrative	2018	Adventure, Social, Simulation	Stevanus Kevin, Yun Suen Pai, and Kai Kunze

Table A.2: List of Gaze-enabled Commercial and Indie Games.

Game Name	Year	Game Type	Authors
35MM	2018	Adventure, Horror	
7 Days To Die	2013	Action, Adventure, Horror,Indie	The Fun Pimps
Aerea	2017	Action, RPG	SOEDESCO Publishing, Triangle Studios
Aerofly FS 2 Flight Simulator	2017	Simulation	IPACS
Agents of Mayhem	2017	Action, Adventure	Deep Silver
Agony	2018	Horror	Madmind Studio
American Truck Simulator	2016	Simulator	SCS Software
Among the Sleep	2017	Action, Adventure, Indie	Krillbite Studio
Amphora	2014	Adventure, Indie, Puzzle	Moondrop
AncestorsLegacy	2018	Strategy	Destructive Creations, 1C Company
Aragami	2016	Action, Adventure, Indie	Lince Works
Arma 2	2017	Action, Simulation	Bohemia Interactive
Arma 2: Operation Awworhead	2017	Action, Simulation	Bohemia Interactive
Arma 3	2013	Action, Simulation	Bohemia Interactive
Assassin's Creed Odyssey	2018	Action, Adventure	Ubisoft
Assassin's Creed Origins	2017	Action, Adventure	Ubisoft
Assassin's Creed: Rogue	2015	Action, Adventure	Ubisoft
Assassin's Creed: Syndicate	2015	Action, Adventure	Ubisoft
Auto Age: Standoff	2017	Action	Phantom Compass
Beatshot	2014	Arcade	Burning Sushi
Blink Blink Boom	2015	Shooter	Arda Cevik, Chris McEntee, Erik Sutton, Gustav Dahl, Maxime Barnier, Sandra Madsen, Wojciech Matthew Reszke
Bus Simulator 18	2018	Simulation	Stillalive Studios, astragon Entertainment GmbH
Cluster Truck	2016	Action, Indie	tinyBuild, Landfall
Coffin Dodgers	2015	Action, Racing	Milky Tea Studios
Creativerse	2017	Action, Adventure, Indie	Playful Corporation
DCS World	2013	Action, Simulation	Eagle Dynamics SA, The Fighter Collection
Dead Effect	2014	Action	a.s. & BadFly Interactive
Deus Ex: Mankind Divided	2016	Action, RPG	Square Enix, Eidos Montreal
Distance	2014	Action, Indie, Racing	Refract
DOGOS	2016	Action, Indie, Simulation	INTERNET URL S.A., OPQAM
Don't Look	2019	Horror	Blind Studio
Dr. Langeskov, The Tiger, and The Terribly Cursed Emerald	2015	Indie	Crows Crows Crows
DreadOut	2014	Adventure, Indie	Digital Happiness
Dreamfall Chapters	2014	Adventure, Indie	Red Thread Games
Drift Streets Japan	2015	Racing, Simulation	JDM4iK
Dungeons 2	2015	RPG, Simulation, Strategy	Kalypso Media Digital, Realmforge Studios
Dying Light: Bad Blood	2018	Action	Techland
Dying Light: The Following	2015	Action, RPG	Techland
Elite Dangerous	2015	Simulation	Frontier Developments
Euro Truck Simulator 2	2017	Simulation	SCS Software
Eve: Valkyrie Warzone	2017	Action, Simulation	CCP
Event[0]	2016	Adventure, Indie	Ocelot Society
Eyeron Defender	2018	Arcade	Storm Potion
F1 2017	2017	Racing	Codemasters
F1 2018	2018	Racing	Codemasters
F1 2019	2019	Racing, Simulation	Codemasters
Far Cry 5	2018	Action, Adventure	Ubisoft
Farming Simulator 15	2015	Simulation	Giants Software, Focus Home Interactive
Farming Simulator 17	2016	Simulator	Giants Software, Focus Home Entertainment
Farming Simulator 19	2019	Simulator	Giants Software, Focus Home Entertainment
Fast Sight	2015	Action	Beyond Infinity
Final Fantasy XV	2018	Action, Adventure	Square Enix
For HONOR	2017	Action	Ubisoft
FortressCraft Evolved	2015	Adventure, Indie, RPG, Simulation, Strategy	Digital Tribe
FOVE: Judgement	2016	VR	FOVE
FOVE: Project Falcon	2016	VR	Rewind, FOVE
Giant Machines 2017	2017	Simulation	PlayWay S.A., Code Horizon
Glimpse of Fear	2015	Adventure, Indie	Beyond Infinity
Half Dead	2016	Action	Room710Games
Heavy Bullets	2014	Action, Indie	Devolver Digital, Terri Vellmann
Hitman	2017	Action	IO Interactive, Square Enix
Homeworld: Desserts of Kharak	2016	Strategy	Gearbox Publishing, Blackbird Interactive
Hyperdot	2020	Action, Arcade	Tribe Games, GLITCH
IL-2 Sturmovik: Battle of Stalingrad	2014	Simulation	1C Game Studios & 777 Studios
Iron Front Liberation 1944	2012	Action, Simulation	Deep Silver, AWAR & X1 Software

Table A.3: List of Gaze-enabled Commercial and Indie Games. (Continuation 1)

Game Name	Year	Game Type	Authors
Kingdom Come: Deliverance	2018	Action, Adventure	Warhorse Studios
Knee Deep	2015	Adventure, Indie, Mystery	Prologue Games
Layers of Fear	2016	Adventure, Indie	Aspyr, Bloober Team SA
Leaving Lyndon	2017	Adventure, Indie	Eastshade Studios
Life is Strange: Before the Storm	2017	Adventure	Deck Nine, Square Enix
Lifeless Planet	2014	Adventure	Serenity Forge, Serenity 2 Studios
Master of Orion	2016	Strategy	WG Labs, NGD Studios
Meadow	2016	Adventure, Indie	Might and Delight
Mechrunner	2016	Action	Spark Plug Games
Medusa's Labyrinth	2016	Adventure, Horror	Guru Games
Medusa's Lair	2017	Adventure, Multiplayer	Sad Hombres for GameStage@AEC
Megaton Rainfall	2017	Action	Pentadimensional Games, SL
Microsoft Flight Simulator X: Steam Edition	2006	Simulation	Microsoft Game Studio
Mindball Play	2018	Racing	Interactive Productline IP AB
Mordheim: City of the Damned	2018	RPG, Strategy	Focus Home Interactive, Rogue Factor
Mostrum	2015	Indie	Team Junkfish
My Summer Car	2016	Simulation	Amistech Games
Nevermind	2015	Adventure, Indie	Flying Mollusk
Offworld Trading Company	2016	Strategy	Stardock Entertainment, Mohawk Games
Ori and the Blind Forest	2015	Action, Adventure, Platform	Microsoft Studios, Moon Studios GmbH
Oriental Empires	2017	Strategy	Iceberg Interactive, Shining Pixel Studios
Overload	2018	Action	Revival Productions
P.O.L.L.E.N.	2016	Adventure	Mindfield Games
Pavilion	2016	Adventure, Indie, Puzzle	Visiontrick Media
Paws	2016	Adventure, Indie	Might and Delight
Plight of the Zombie	2016	Puzzle	Spark Plug Games
Polarity	2014	Puzzle	Bluebutton Games
Prepar3d	2018	Simulation	Lockheed Martin
Project CARS 2	2017	Racing	Slightly Mad Studios, BANDAI NAMCO entertainment
Project Root	2014	Action, Arcade, Indie	OPQAM
Q.U.B.E. 2	2018	Action, Adventure, Puzzle	Trapped Nerve Games, Toxic Games
Quern	2016	Adventure, Indie, Puzzle	Zadbox Entertainment
Real Farm	2017	Simulation	SOEDESCO Publishing, Triangle Studios
Reflections	2015	Adventure, Indie	Broken Window Studios
Rise of the Tomb Raider	2016	Action, Adventure	Crystal Dynamics, Square Enix
Rising Islands	2016	Adventure, Indie	SOEDESCO Publishing, Lone Hero Studios
Robot Roller-Derby Disco Dodgeball	2015	Action	82Apps, Erik Asmussen
Salt	2014	Action, Adventure, Indie	Lavaboots Studio
Serious Sam 3: BFE	2017	Action	Developer Digital, Croteam
Serious Sam HD: TFE	2017	Action	Devolver Digital, Croteam
Serious Sam HD: TSE	2017	Action	Devolver Digital, Croteam
SEUM	2016	Action, Indie	Headup Games, Pine Studio
Shadow of the Tomb Raider	2018	Action, Adventure	Eidos Montreal, Sqare Enix
Shadow Tactics	2016	Indie, Stealth, Strategy	Daedalic Entertainment, Mimimi Productions
Shelter 2	2015	Adventure, Indie	Might and Delight
Skylar & Plux: Adventure on Clover Island	2017	Action, Adventure, Indie, Platform	Grip Digital, Right Nice Games
Slime Rancher	2017	Action, Adventure, Indie	Monomi Park
SOLIRIS	2019	Arcade, Indie	School4Games, Games Science Center
Solstice Chronicles	2017	Action	Nkidy Games Inc., Ironward
SOMA	2015	Adventure, Indie	Frictional Games
Son of Noir	2015	Adventure	Stillalive Studios
Spectrophobia	2016	Adventure, Indie	Kamjford Productions
Spirits of Xanadu	2015	Action, Adventure, Indie	Nightdive Studios, Commander & Good Morning
StarCrawlers	2017	Adventure, Indie, RPG, Simulation, Strategy	Juggernaut Games
State of Mind	2018	Adventure	Daedalic Entertainment
Steep	2016	Action, Simulation, Sports	Ubisoft
Stranded Deep	2018	Open World, Survival	Beam Team Games
Sublevel Zero	2015	Action, Indie	Sigtrap
Take on Helicopters	2011	Simulation	Bohemia Interactive
The Battle of Sol	2015	Action, Simulation	Bit Planet Games, LLC
The Channeler	2018	Indie	Florida Interactive Entertainment Academy & University of Central Florida
The Church in the Darkness	2019	Action, Adventure, Indie	Fellow Travelers, Paranoid Productions

Table A.4: List of Gaze-enabled Commercial and Indie Games. (Continuation 2)

Game Name	**Year**	**Game Type**	**Authors**
The Forest	2014	Action, Adventure, Indie	Endnight Games
The Guest	2016	Adventure, Simulation	505 Games, Team Gotham
The Hunter	2014	Simulation	Avalanche Studios
the Hunter Primal	2015	Action, Adventure, Simulation	Avalanche Studios
The Hunter: Call of the Wild	2017	Adventure, Simulation	Expansive Worlds, Avalanche Studios
The Magic Circles	2015	Action, Indie, Simulation	Question
The Signal from Tölva	2017	Action	Big Robot Ltd
The Solus Project	2016	Adventure	Teol Studios, Grip Digital
The Talos Principle	2014	Adventure, Puzzle	Devolver Digital, Croteam
The Way of Life	2016	Adventure, Indie	CyberCoconut
Thea: The Awakening	2015	Indie, RpG, Strategy	MuHa Games
Through the Woods	2016	Adventure, Horror, Indie	1C Company, Antagonist
Tom Clancy's The Division® 2	2019	Action, Adventure	Massive Entertainment, Ubisoft
Tom Clancy's Ghost Recon Breakpoint	2019	Action	Ubisoft
Tom Clancy's Ghost Recon Wildlands	2017	Action	Ubisoft
Tom Clancy's The Division	2016	Action	Massive Entertainment, Ubisoft
Unknown Fate	2018	Adventure, Indie	1C Company, Marslit Games
Unturned	2017	Action, Adventure	Frontier Developments
Valley	2016	Action, Adventure, Indie	Blue Isle Studio
War for the Overlord	2015	Indie, Strategy	Brightrock Games
Warhammer: Vermintide 2	2018	Action, Adventure	Fatshark
Warhammer: End Times - Vermintide	2015	Action, Adventure, Indie	Fatshark Games
WASTED - A post-apocalyptic pub crawler	2016	Action	Adult Swim Games
Watch Dogs 2	2016	Action, Adventure	Ubisoft
We were Here	2017	Adventure, Puzzle	Total Mayhem Games
We were Here Too	2017	Adventure, Puzzle	Total Mayhem Games
White Noise 2	2017	Action, Adventure, Indie, Strategy	Milkstone Studios
X4: Foundations	2018	Simulation	Egosoft
Ziggurat	2014	Action, Indie, RPG	Milkstone Studios

B Supplementary Material: Videos

This appendix contains links to preview and gameplay videos for each game prototype described: *Twileyed* (Chapter 4), *SuperVision* (Chapter 5) and *KryptonEyed* (Chapter 6). Moreover, readers can find two videos of the Gaze+Hold technique (Chapter 7), and the link to the interactive visualisation described in Chapter 8.

Twileyed

Chapter 4

Video Preview: https://youtu.be/GgzdvDZxcz8
Gameplay Video: https://youtu.be/3gJZb9vdpUE

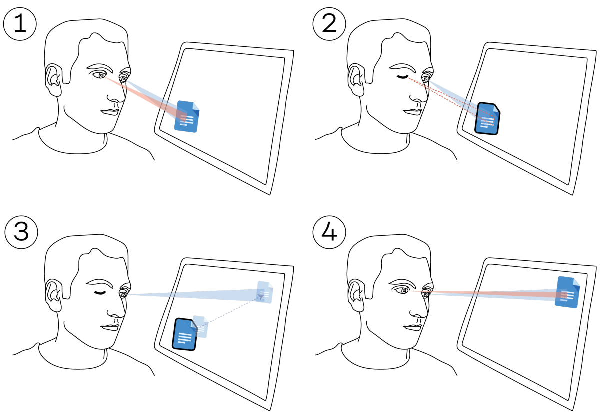
SuperVision
Chapter 5

Video Preview: https://youtu.be/6EORymQDc6o
Gameplay Video: https://youtu.be/F$_5kUc79wxg$

KryptonEyed
Chapter 6

Video Preview: https://youtu.be/Ouc350o5xLM
Gameplay Video: https://youtu.be/5X9vO7sKK7g

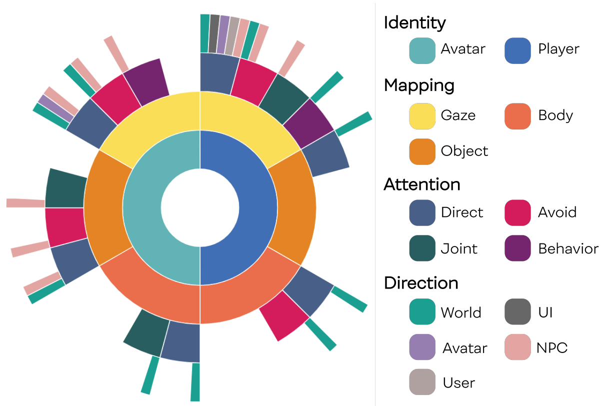
Gaze+Hold
Chapter 7



Video Preview: https://youtu.be/cEAWA9ARm6w
Techniques Video: https://youtu.be/8zCzqtCiBWc

Gaze in Play

Chapter 8



Interactive Tool: https://www.argenisrg.com/gazevis/

C Supplementary Material: Participant Demographics

This appendix contains participant demographic information for each user study described in: Chapter 4 (*Twileyed*); Chapter 5 (*SuperVision*); Chapter 6 (*KryptonEyed*); and Chapter 7 (*Gaze+Hold*).

Table C.1: Chapter 4: Participant Demographics

Participant	Age	Gender	Gaze Interaction Experience	Vision	Gamer Experience
1	28	Female	Yes	Corrected - Glasses	No
2	25	Male	Yes	Corrected - Glasses	No
3	24	Female	No	Uncorrected	Yes
4	29	Male	Yes	Uncorrected	Yes
5	24	Male	Yes	Uncorrected	No
6	35	Male	No	Uncorrected	No
7	30	Female	No	Corrected - Glasses	No
8	21	Male	No	Uncorrected	Yes
9	25	Female	Yes	Corrected - Glasses	No
10	31	Male	No	Corrected - Glasses	Yes
11	35	Male	Yes	Corrected - Glasses	No
12	25	Female	No	Uncorrected	No

Table C.2: Chapter 5: Participant Demographics

Participant	Gender	Age	Gaze Interaction Experience	Vision
1	Male	24	Yes (Some)	Corrected - Glasses
2	Male	24	No	Uncorrected
3	Female	25	Yes (Little)	Corrected - Glasses
4	Male	29	Yes (Some)	Uncorrected
5	Male	23	No	Corrected - Glasses
6	Female	26	No	Uncorrected
7	Male	27	No	Uncorrected
8	Prefer not to say	28	No	Corrected - Glasses
9	Male	34	Yes (Some)	Corrected - Glasses
10	Male	20	Yes (High)	Uncorrected
11	Male	29	No	Corrected - Glasses
12	Female	23	Yes (Little)	Uncorrected
13	Male	24	No	Uncorrected
14	Male	32	Yes (High)	Corrected - Glasses
15	Male	34	Yes (Some)	Uncorrected
16	Female	30	Yes (Little)	Uncorrected
17	Male	30	No	Uncorrected
18	Female	26	No	Corrected - Glasses
19	Male	29	No	Corrected - Glasses
20	Female	23	No	Uncorrected
21	Female	27	No	Corrected - Glasses
22	Female	39	No	Uncorrected
23	Female	35	No	Uncorrected
24	Female	28	No	Uncorrected

Table C.3: Chapter 5: Participant Game Media Acquaintance Information

Participant	How often do you play video games	For how long do you usually play?	Which kind of games do you usually play? (if applicable)	In which platform do you play the most
1	A couple of times a month	Between 1 hour and 2 hours	First or Third Person Shooter, Action/Adventure, Puzzle, Platform, Real Time or Turn-Base Strategy, Role-Playing, Survival Horror	PC
2	About once a month	1 hour or more	Action/Adventure, Role-Playing, Multiplayer Online Battle Arena	Mobile Phone
3	Less than once a month	1 hour or more	Puzzle	PC
4	Almost every day	More than 2 hours	First or Third Person Shooter	Console (Xbox, Playstation, etc)
5	Almost every day	More than 2 hours	First or Third Person Shooter, Action/Adventure, Puzzle, Real Time or Turn-Base Strategy, Role-Playing, Massively Multiplayer, Survival Horror	PC
6	About once a month	Between 1 hour and 2 hours	First or Third Person Shooter, Platform	Console (Xbox, Playstation, etc)
7	Almost every day	More than 2 hours	First or Third Person Shooter, Action/Adventure, Platform, Real Time or Turn-Base Strategy, Role-Playing, Multiplayer Online Battle Arena	PC
8	About once a month	1 hour or more	Puzzle, Role-Playing	PC
9	Never	Never		
10	A couple of times a month	Between 1 hour and 2 hours	Action/Adventure, Real Time or Turn-Base Strategy, Role-Playing	PC
11	Almost every day	More than 2 hours	First or Third Person Shooter, Action/Adventure, Puzzle, Platform, Real Time or Turn-Base Strategy, Role-Playing, Survival Horror	PC
12	Less than once a month	Less than 1 hour	Action/Adventure, Puzzle	Mobile Phone
13	About 4 or 5 times a week	More than 2 hours	First or Third Person Shooter, Action/Adventure, Role-Playing, Multiplayer Online Battle Arena	Console (Xbox, Playstation, etc)
14	Almost every day	More than 2 hours	Real Time or Turn-Base Strategy, Multiplayer Online Battle Arena	PC
15	About once a month	Less than 1 hour	Action/Adventure, Puzzle	Mobile Phone
16	Less than once a month	Less than 1 hour	Puzzle	Mobile Phone
17	About 2 or 3 times a week	Between 1 hour and 2 hours	Role-Playing, Multiplayer Online Battle Arena	PC
18	About 2 or 3 times a week	Less than 1 hour	Puzzle	Mobile Phone
19	Less than once a month	More than 2 hours	First or Third Person Shooter, Action/Adventure, Puzzle, Platform, Real Time or Turn-Base Strategy, Fighter, Role-Playing, Multiplayer Online Battle Arena	PC
20	About once a month	Between 1 hour and 2 hours	Action/Adventure, Puzzle	Console (Xbox, Playstation, etc)
21	Never	Never		
22	Never	Never		
23	A couple of times a month	Between 1 hour and 2 hours	Action/Adventure, Puzzle, Fighter	PC
24	Never	Never		

Table C.4: Chapter 5: Participant Activity Acquaintance Information

Participant	**How often do you play sports?**	**For how long do you usually play?**	**Do you cycle or ride a motorcycle?**	**How often?**	For how long?	Do you drive a car?	How often?	For how long?
1	About once a month	Between 1 hour and 2 hours	No	Never	Never	Yes	Less than once a month	Less than 1 hour
2	About once a month	1 hour or more	No	Never	Never	No	Never	Never
3	About 2 or 3 times a week	Between 1 hour and 2 hours	Yes	About 2 or 3 times a week	Less than 1 hour	Yes	A couple of times a month	Between 1 hour and 2 hours
4	About once a month	Less than 1 hour	No	Never	Never	Yes	Almost every day	Less than 1 hour
5	About 2 or 3 times a week	Less than 1 hour	No	Never	Never	Yes	Almost every day	1 hour or more
6	About 2 or 3 times a week	1 hour or more	No	Never	Never	Yes	Less than once a month	Less than 1 hour
7	About 2 or 3 times a week	More than 2 hours	No	Never	Never	No	Never	Never
8	A couple of times a month	1 hour or more	Yes	A couple of times a month	Less than 1 hour	Yes	Less than once a month	1 hour or more
9	A couple of times a month	Less than 1 hour	Yes	A couple of times a month	1 hour or more	Yes	Almost every day	1 hour or more
10	About 4 or 5 times a week	Between 1 hour and 2 hours	No	Never	Never	No	Never	Never
11	Never	Never	No	Never	Never	Yes	Almost every day	Less than 1 hour
12	About 2 or 3 times a week	Between 1 hour and 2 hours	No	Never	Never	No	Never	Never
13	About 2 or 3 times a week	Between 1 hour and 2 hours	Yes	Less than once a month	1 hour or more	Yes	Almost every day	Less than 1 hour
14	A couple of times a month	Less than 1 hour	No	Never	Never	No	Never	Never
15	About 4 or 5 times a week	Between 1 hour and 2 hours	Yes	Almost every day	Less than 1 hour	Yes	Less than once a month	More than 2 hours
16	A couple of times a month	Less than 1 hour	No	Less than once a month	Less than 1 hour	Yes	Less than once a month	1 hour or more
17	About 2 or 3 times a week	1 hour or more	Yes	About 2 or 3 times a week	Less than 1 hour	Yes	Less than once a month	1 hour or more
18	About 2 or 3 times a week	1 hour or more	No	Never	Never	Yes	A couple of times a month	More than 2 hours
19	A couple of times a month	More than 2 hours	No	Never	Never	No	Never	Never
20	Never	Never	Yes	Less than once a month	Between 1 hour and 2 hours	Yes	Almost every day	1 hour or more
21	Never	Never	Yes	Less than once a month	Less than 1 hour	No	Never	Never
22	Less than once a month	Less than 1 hour	No	Never	Never	No	Never	Never
23	About 2 or 3 times a week	Less than 1 hour	Yes	A couple of times a month	1 hour or more	Yes	Almost every day	1 hour or more
24	About 2 or 3 times a week	1 hour or more	No	Never	Never	Yes	Less than once a month	Less than 1 hour

Table C.5: Chapter 6: Participant Demographics Study 1

Participant	**Gender**	**Age**	**Gaze Interaction Experience**	**Vision**
1	Male	25	Yes	Uncorrected
2	Male	19	No	Uncorrected
3	Female	26	No	Corrected - Lenses
4	Male	23	No	Corrected - Glasses
5	Male	22	Yes	Corrected - Glasses
6	Male	23	Yes	Uncorrected
7	Male	30	Yes	Uncorrected
8	Female	25	No	Uncorrected
9	Male	27	No	Corrected - Glasses
10	Male	26	No	Uncorrected
11	Female	29	Not sure	Corrected - Lenses
12	Female	26	No	Corrected - Glasses

Table C.6: Chapter 6: Participant Demographics Study 2

Participant	Gender	Age	Gaze Interaction Experience	Vision	How often do you play video games?	For how long do you usually play?	Which kind of games do you usually play? (If applicable)	In which platform do you play the most?
1	Male	25	Yes	Uncorrected	A couple of times a month	More than 2 hours	First or Third Person Shooter, Action/Adventure, Puzzle, Platform, Real-Time or Turn-based Strategy, Role-playing, Survival Horror, Multiplayer Online Battle Arena	Console (Xbox, Playstation, etc.)
2	Female	26	No	Corrected - Lenses	Never	Never		Phone
3	Female	26	Yes	Corrected - Glasses	Less than once a month	Between 1 hour and 2 hour	First or Third Person Shooter, Puzzle, Real-Time or Turn-based Strategy	Phone
4	Male	35	Yes	Corrected - Glasses	Less than once a month	Less than 1 hour	First or Third Person Shooter, Action/Adventure, Puzzle	Phone
5	Male	21	Yes	Uncorrected	Almost every day	Between 1 hour and 2 hour	First or Third Person Shooter, Action/Adventure, Puzzle, Platform, Real-Time or Turn-based Strategy, Role-playing, Multiplayer Online Battle Arena	PC
6	Male	50	No	Corrected - Glasses	About 2 or 3 times a week	Between 1 hour and 2 hour	First or Third Person Shooter, Multiplayer Online Battle Arena	Console (Xbox, Playstation, etc.)
7	Male	30	Yes	Uncorrected	Almost every day	More than 2 hours	First or Third Person Shooter, Racing	Console (Xbox, Playstation, etc.)
8	Female	24	No	Uncorrected	A couple of times a month	Between 1 hour and 2 hour	Action/Adventure, Puzzle, Simulation	Console (Xbox, Playstation, etc.)
9	Female	21	No	Corrected - Lenses	About 2 or 3 times a week	Less than 1 hour	Action/Adventure	Phone
10	Male	21	Yes	Corrected - Glasses	A couple of times a month	More than 2 hours	First or Third Person Shooter, Action/Adventure, Real-Time or Turn-based Strategy, Role-playing	PC
11	Male	29	No	Uncorrected	A couple of times a month	Between 1 hour and 2 hour	Real-Time or Turn-based Strategy	PC
12	Female	29	No	Corrected - Glasses	A couple of times a month	1 hour or more	Action/Adventure, Puzzle, Fighter, Role-playing, Survival Horror	PC
13	Female	26	No	Uncorrected	Less than once a month	Between 1 hour and 2 hour	Puzzle, Racing game	Console (Xbox, Playstation, etc.)
14	Male	35	Yes	Corrected - Glasses	Less than once a month	Less than 1 hour	Action/Adventure, Platform	PC
15	Female	25	Yes	Uncorrected	A couple of times a month	Less than 1 hour	Puzzle, Lonely cards (solitari)	Phone
16	Female	25	No	Uncorrected	Never	Never		None
17	Male	41	No	Corrected - Glasses	Almost every day	More than 2 hours	First or Third Person Shooter, Real-Time or Turn-based Strategy, Massively Multiplayer	PC
18	Male	28	Yes	Corrected - Glasses	About 4 or 3 times a week	Between 1 hour and 2 hour	First or Third Person Shooter, Action/Adventure, Puzzle, Platform	Phone
19	Female	24	Yes	Corrected - Glasses	Less than once a month	Less than 1 hour	Puzzle	Phone
20	Female	25	No	Corrected - Glasses	Less than once a month	1 hour or more	Action/Adventure, Role-playing	Portable Console

Table C.7: Chapter 7: Participant Demographics Study 1

Participant	Gender	Age	Gaze Interaction Experience	Vision	Eye Dominance
1	Male	23	Yes (Little)	Uncorrected	Right
2	Female	27	Yes (Little)	Uncorrected	Right
3	Female	25	No	Uncorrected	Right
4	Male	22	Yes (Some)	Corrected - Glasses	Right
5	Male	31	Yes (Some)	Uncorrected	Right
6	Male	28	Yes (High)	Corrected - Glasses	Left

Table C.8: Chapter 7: Participant Demographics Study 2

Participant	Gender	Age	Gaze Interaction Experience	Vision	Eye Dominance	Spontaneous Wink
1	Male	25	Yes	Uncorrected	Right	Right
2	Male	19	No	Uncorrected	Right	Right
3	Female	26	No	Corrected - Lenses	Right	Right
4	Male	23	No	Corrected - Glasses	Right	Right
5	Male	22	Yes	Corrected - Glasses	Right	Left
6	Male	23	Yes	Uncorrected	Right	Right
7	Male	30	Yes	Uncorrected	Right	Right
8	Female	25	No	Uncorrected	Left	Right
9	Male	27	No	Corrected - Glasses	Left	Right
10	Male	26	No	Uncorrected	Right	Right
11	Female	29	Not sure	Corrected - Lenses	Right	Right
12	Female	26	No	Corrected - Glasses	Right	Right

Bibliography

[1] Mahdieh Abbaszadegan, Sohrab Yaghoubi, and I Scott MacKenzie. 2018. Track-Maze: A Comparison of Head-Tracking, Eye-Tracking, and Tilt as Input Methods for Mobile Games. In *International Conference on Human-Computer Interaction.* Springer, 393–405.

[2] Vero Vanden Abeele, Katta Spiel, Lennart Nacke, Daniel Johnson, and Kathrin Gerling. 2020. Development and validation of the player experience inventory: A scale to measure player experiences at the level of functional and psychosocial consequences. *International Journal of Human-Computer Studies* 135 (2020), 102370.

[3] Samuel Almeida, Ana Veloso, Licínio Roque, and Óscar Mealha. 2011. The eyes and games: A survey of visual attention and eye tracking input in video games. *Proceedings of SBGames* (2011), 1–10.

[4] Richard Pierson Andy Puddicombe. 2014. *Headspace.* Phone App. (- June 2014).

[5] João Antunes and Pedro Santana. 2018. A study on the use of eye tracking to adapt gameplay and procedural content generation in first-person shooter games. *Multimodal Technologies and Interaction* 2, 2 (2018), 23.

[6] Erik Sutton Gustav Dahl Maxime Barnier Sandra Madsen Wojciech Matthew Reszke Arda Cevik, Chris McEntee. 2015. *Blink Blink Boom.* Game. (5 February 2015).

[7] Saskia Bakker and Karin Niemantsverdriet. 2016. The interaction-attention continuum: considering various levels of human attention in interaction design. *International Journal of Design* 10, 2 (2016).

[8] Saskia Bakker, Elise van den Hoven, and Berry Eggen. 2010. Design for the Periphery. *EuroHaptics 2010* 71 (2010).

[9] Paulo Bala, Lucilia Noóbrega, Guilherme Neves, Lai's Lopes, Joana Morna, João Camacho, and Cristina Freitas. 2015. Keyewai: Looking at Cooperation in a Holographic Projection Screen. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems.* ACM, 61–64.

[10] Joseph Baldwin, Alistair Burleigh, Robert Pepperell, and Nicole Ruta. 2016. The Perceived Size and Shape of Objects in Peripheral Vision. *i-Perception* 7, 4 (2016), 2041669516661900.

[11] Ditte Amund Basballe and Kim Halskov. 2012. Dynamics of research through design. In *Proceedings of the Designing Interactive Systems Conference.* 58–67.

[12] Richard Bates, Stephen Vickers, and Howell O Istance. 2010. Gaze interaction with virtual on-line communities: levelling the playing field for disabled users. *Universal Access in the Information Society* 9, 3 (2010), 261–272.

[13] Eric PS Baumer, Vera Khovanskaya, Mark Matthews, Lindsay Reynolds, Victoria Schwanda Sosik, and Geri Gay. 2014. Reviewing reflection: on the use of reflection in interactive system design. In *Proceedings of the 2014 conference on Designing interactive systems*. ACM, 93–102.

[14] Jason Begy. 2013. Experiential metaphors in abstract games. *Transactions of the Digital Games Research Association* 1, 1 (2013).

[15] Steve Benford, Chris Greenhalgh, Gabriella Giannachi, Brendan Walker, Joe Marshall, and Tom Rodden. 2012. Uncomfortable interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2005–2014.

[16] Steve Benford, Holger Schnädelbach, Boriana Koleva, Rob Anastasi, Chris Greenhalgh, Tom Rodden, Tom Rodden, Jonathan Green, Ahmed Ghali, Tony Pridmore, and others. 2005. Expected, sensed, and desired: A framework for designing sensing-based interaction. *ACM Transactions on Computer-Human Interaction (TOCHI)* 12, 1 (2005), 3–30.

[17] Bernell. 2019. Bernell Vision Disk. https://www.bernell.com/product/HS6015/807. (2019). Accessed: 2019-01-07.

[18] Max V Birk, Cheralyn Atkins, Jason T Bowey, and Regan L Mandryk. 2016. Fostering intrinsic motivation through avatar identification in digital games. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 2982–2995.

[19] Jeremy Birnholtz, Lindsay Reynolds, Eli Luxenberg, Carl Gutwin, and Maryam Mustafa. 2010. Awareness beyond the desktop: exploring attention and distraction with a projected peripheral-vision display. In *Proceedings of Graphics Interface 2010*. Canadian Information Processing Society, 55–62.

[20] Richard A Bolt. 1990. A gaze-responsive self-disclosing display. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 3–10.

[21] David Boud, Rosemary Keogh, and David Walker. 2013. *Reflection: Turning experience into learning*. Routledge.

[22] Stan Brakhage. 1963. *Metaphors on vision*. Film Culture.

[23] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[24] Science Buddies. 2016. Put Your Peripheral Vision to the Test. (2016). https://www.scientificamerican.com/article/put-your-peripheral-vision-to-the-test/

[25] Roger Caillois. 2001. *Man, play, and games*. University of Illinois Press.

[26] Marcus Carter, Fraser Allison, John Downs, and Martin Gibbs. 2015. Player identity dissonance and voice interaction in games. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*. ACM, 265–269.

[27] Marcus Carter, Martin Gibbs, and Michael Arnold. 2012. Avatars, characters, players and users: multiple identities at/in play. In *Proceedings of the 24th Australian Computer-Human Interaction Conference*. ACM, 68–71.

[28] Marcus Carter, Joshua Newn, Eduardo Velloso, and Frank Vetere. 2015. Remote gaze and gesture tracking on the microsoft kinect: Investigating the role of feedback. In *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*. ACM, 167–176.

[29] Emiliano Castellina and Fulvio Corno. 2008. Multimodal gaze interaction in 3D virtual environments. *COGAIN* 8 (2008), 33–37.

[30] Wein Chang, Po-An Shen, Kushal Ponnam, Helena Barbosa, Monchu Chen, and Sergi Bermudez. 2013. WAYLA: novel gaming experience through unique gaze interaction. In *ACM SIGGRAPH 2013 emerging technologies*. ACM, 16.

[31] Ishan Chatterjee, Robert Xiao, and Chris Harrison. 2015. Gaze+ gesture: Expressive, precise and targeted free-space interactions. In *Proceedings of the 2015 ACM on International Conference on Multimodal Interaction*. ACM, 131–138.

[32] Codemasters. 2019. *F1 2019*. Game. (28 June 2019).

[33] CogniFit. 2018. Inhibition or inhibitory Control - Cognitive Ability. (2018). `https://www.cognifit.com/science/cognitive-skills/inhibition`

[34] H Collewijn, J Van Der Steen, and RM Steinman. 1985. Human eye movements associated with blinks and prolonged eyelid closure. *Journal of neurophysiology* 54, 1 (1985), 11–27.

[35] Stanley Coren. 1999. Sensorimotor Performance as a Function of Eye Dominance and Handedness. *Perceptual and Motor Skills* 88, 2 (1999), 424–426. DOI:`http://dx.doi.org/10.2466/pms.1999.88.2.424`

[36] Rui Craveirinha and Licínio Roque. 2010. Looking for the heart of interactive media: reflections on video games' emotional expression. In *Proceedings of the 3rd International Conference on Fun and Games*. 8–17.

[37] Trevor J Crawford and Steve Higham. 2016. Distinguishing between impairments of working memory and inhibitory control in cases of early dementia. *Neuropsychologia* 81 (2016), 61–67.

[38] Tarik Crnovrsanin, Yang Wang, and Kwan-Liu Ma. 2014. Stimulating a blink: reduction of eye fatigue with visual stimulus. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2055–2064.

[39] Yongqin Cui and Jan M Hondzinski. 2006. Gaze tracking accuracy in humans: Two eyes are better than one. *Neuroscience letters* 396, 3 (2006), 257–262.

[40] Matthieu Perreira Da Silva, Vincent Courboulay, and Armelle Prigent. 2007. Gameplay experience based on a gaze tracking system. In *"Gaze-based Creativity, Interacting with Games and On-line Communities" INPROCEEDINGS in proceedings of*

COGAIN 2007 (Communication by Gaze Interaction IST FP6 European Project). 25–28.

[41] Ella Dagan, Elena Márquez Segura, Ferran Altarriba Bertran, Miguel Flores, and Katherine Isbister. 2019. Designing'True Colors' A Social Wearable that Affords Vulnerability. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–14.

[42] Sarah D'Angelo and Darren Gergle. 2016. Gazed and confused: Understanding and designing shared gaze for remote collaboration. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 2492–2496.

[43] Frederik De Grove, Cédric Courtois, and Jan Van Looy. 2015. How to be a gamer! Exploring personal and social indicators of gamer identity. *Journal of Computer-Mediated Communication* 20, 3 (2015), 346–361.

[44] Alexander De Luca, Roman Weiss, and Heiko Drewes. 2007. Evaluation of eye-gaze interaction methods for security enhanced PIN-entry. In *Proceedings of the 19th australasian conference on computer-human interaction: Entertaining user interfaces*. 199–202.

[45] Soussan Djamasbi and Siavash Mortazavi. 2015. Generation Y, baby boomers, and gaze interaction experience in gaming. In *2015 48th Hawaii International Conference on System Sciences*. IEEE, 482–490.

[46] Marko Djordjevic. 2008. Metaphor-Based Interactions. (2008).

[47] Gwyneth Doherty-Sneddon and Fiona G Phelps. 2005. Gaze aversion: A response to cognitive or social difficulty? *Memory & cognition* 33, 4 (2005), 727–733.

[48] Michael Dorr, Martin Böhme, Thomas Martinetz, and Erhardt Barth. 2007. Gaze beats mouse: a case study. *Proceedings of COGAIN* (2007), 16–19.

[49] Michael Dorr, Laura Pomarjanschi, and Erhardt Barth. 2009. Gaze beats mouse: A case study on a gaze-controlled breakout. *PsychNology Journal* 7, 2 (2009), 197–211.

[50] Paul Dourish. 2001. The Foundations of Embodied Interaction. (2001).

[51] Heiko Drewes and Albrecht Schmidt. 2007. Interacting with the computer using gaze gestures. In *IFIP Conference on Human-Computer Interaction*. Springer, 475–488.

[52] Nicolas Ducheneaut, Ming-Hui Wen, Nicholas Yee, and Greg Wadley. 2009. Body and mind: a study of avatar personalization in three virtual worlds. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 1151–1160.

[53] Utkarsh Dwivedi, Karan Ahuja, Rahul Islam, Ferdous A Barbhuiya, Seema Nagar, and Kuntal Dey. 2017. EyamKayo: Interactive Gaze and Facial Expression Captcha. In *Proceedings of the 22nd International Conference on Intelligent User Interfaces Companion*. ACM, 53–56.

[54] Niclas Ejdemyr. 2016. Eye Tracking as an Additional Input Method in Video Games: Using Player Gaze to Improve Player Immersion and Performance. (2016).

[55] Inger Ekman, Antti Poikola, Meeri Mäkäräinen, Tapio Takala, and Perttu Hämäläinen. 2008b. Voluntary Pupil Size Change As Control in Eyes Only Interaction. In *Proceedings of the 2008 Symposium on Eye Tracking Research Applications (ETRA '08)*. ACM, New York, NY, USA, 115–118. DOI:http://dx.doi.org/10.1145/1344471.1344501

[56] Inger M Ekman, Antti W Poikola, and Meeri K Mäkäräinen. 2008a. Invisible eni: using gaze and pupil size to control a game. In *CHI'08 extended abstracts on Human factors in computing systems*. ACM, 3135–3140.

[57] Tomer Elbaum, Michael Wagner, and Assaf Botzer. 2017. Cyclopean vs. dominant eye in gaze-interface-tracking. (2017).

[58] Monika Elepfandt and Martin Grund. 2012. Move it there, or not?: the design of voice commands for gaze with speech. In *Proceedings of the 4th workshop on eye gaze in intelligent human machine interaction*. ACM, 12.

[59] Massive Entertainment. 2019. *Tom Clancy's The Division 2*. Game. (15 March 2019).

[60] Augusto Esteves, Eduardo Velloso, Andreas Bulling, and Hans Gellersen. 2015. Orbits: Gaze Interaction for Smart Watches Using Smooth Pursuit Eye Movements. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (UIST '15)*. Association for Computing Machinery, New York, NY, USA, 457–466. DOI:http://dx.doi.org/10.1145/2807442.2807499

[61] Anna Maria Feit, Shane Williams, Arturo Toledo, Ann Paradiso, Harish Kulkarni, Shaun Kane, and Meredith Ringel Morris. 2017. Toward everyday gaze input: Accuracy and precision of eye tracking and implications for design. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 1118–1130.

[62] Pedro Figueiredo and Manuel J. Fonseca. 2018. EyeLinks: A Gaze-Only Click Alternative for Heterogeneous Clickables. In *Proceedings of the 20th ACM International Conference on Multimodal Interaction (ICMI '18)*. ACM, New York, NY, USA, 307–314. DOI:http://dx.doi.org/10.1145/3242969.3243021

[63] Rainhard Dieter Findling, Tahmid Quddus, and Stephan Sigg. 2019a. Hide my Gaze with EOG! Towards Closed-Eye Gaze Gesture Passwords that Resist Observation-Attacks with Electrooculography in Smart Glasses. In *Proceedings of the 17th International Conference on Advances in Mobile Computing & Multimedia*. 107–116.

[64] Rainhard Dieter Findling, Stephan Sigg, and others. 2019b. Closed-Eye Gaze Gestures: Detection and Recognition of Closed-Eye Movements with Cameras in Smart Glasses. In *International Work-Conference on Artificial Neural Networks*. Springer, 322–334.

[65] Mary Flanagan, Daniel C Howe, and Helen Nissenbaum. 2005. Values at play: Design tradeoffs in socially-oriented game design. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 751–760.

[66] Rowanne Fleck and Geraldine Fitzpatrick. 2010. Reflecting on reflection: framing a design landscape. In *Proceedings of the 22nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*. ACM, 216–223.

[67] Victor Fleming. 1939. *The Wizard of Oz*. Film. (25 August 1939).

[68] FOVE. 2016. *FOVE: Judgement*. Game. (2016).

[69] Game Freak. 2019. *Pokémon Sword*. Game. (15 November 2019).

[70] Tracy Fullerton, Chris Swain, and Steven Hoffman. 2004. *Game design workshop: Designing, prototyping, & playtesting games*. CRC Press.

[71] Brian J Gajadhar, Henk Herman Nap, Yvonne AW de Kort, and Wijnand A IJsselsteijn. 2010. Out of sight, out of mind: co-player effects on seniors' player experience. In *Proceedings of the 3rd International Conference on Fun and Games*. ACM, 74–83.

[72] Frictional Games. 2015a. *Soma*. Game. (2015).

[73] Guru Games. 2016. *Medusa's Labyrinth*. Game. (2016).

[74] Prologue Games. 2015b. *Knee Deep*. Game. (2015).

[75] Red Thread Games. 2014. *Dreamfall Chapters*. Game. (21 October 2014).

[76] William Gaver. 2012. What should we expect from research through design?. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 937–946.

[77] William W Gaver, Jacob Beaver, and Steve Benford. 2003. Ambiguity as a resource for design. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 233–240.

[78] James Paul Gee. 2003. What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE)* 1, 1 (2003), 20–20.

[79] Agostino Gibaldi, Mauricio Vanegas, Peter J Bex, and Guido Maiello. 2017. Evaluation of the Tobii EyeX Eye tracking controller and Matlab toolkit for research. *Behavior research methods* 49, 3 (2017), 923–946.

[80] James Gips and Peter Olivieri. 1996. EagleEyes: An eye control system for persons with disabilities. In *The eleventh international conference on technology and persons with disabilities*. 1–15.

[81] William Goddard and Robert Cercos. 2015. Playful hacking within research-through-design. In *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*. 333–337.

[82] Teresia Gowases, Roman Bednarik, and Markku Tukiainen. 2008. Gaze vs. mouse in games: The effects on user experience. (2008).

[83] Kevin Grad, TC Graham, and A James Stewart. 2007. Effective use of the periphery in game displays. In *Proceedings of the 2007 conference on Future Play*. ACM, 69–76.

[84] Kristen Grauman, Margrit Betke, Jonathan Lombardi, James Gips, and Gary R Bradski. 2003. Communication via eye blinks and eyebrow raises: Video-based human-computer interfaces. *Universal Access in the Information Society* 2, 4 (2003), 359–373.

[85] Robert Graves. 2017. *The Greek Myths: The complete and definitive edition*. Penguin UK.

[86] Grezzo. 2019. *The Legend of Zelda: Link's Awakening*. Game. (20 September 2019).

[87] Carl Gutwin, Andy Cockburn, and Ashley Coveney. 2017. Peripheral Popout: The Influence of Visual Angle and Stimulus Intensity on Popout Effects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 208–219.

[88] Halfbrick. 2010. *Fruit Ninja*. Game [iOS][Android][Windows Phone]. (13 April 2010).

[89] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[90] Casper Harteveld, Rui Guimarães, Igor S Mayer, and Rafael Bidarra. 2010. Balancing play, meaning and reality: The design philosophy of LEVEE PATROLLER. *Simulation & Gaming* 41, 3 (2010), 316–340.

[91] Doris Hausen. 2012. Peripheral interaction: facilitating interaction with secondary tasks. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*. ACM, 387–388.

[92] Renate Häuslschmid, Sven Osterwald, Marcus Lang, and Andreas Butz. 2015. Augmenting the Driver's View with Peripheral Information on a Windshield Display. In *Proceedings of the 20th International Conference on Intelligent User Interfaces*. ACM, 311–321.

[93] Henna Heikkilä and Kari-Jouko Räihä. 2012. Simple gaze gestures and the closure of the eyes as an interaction technique. In *Proceedings of the symposium on eye tracking research and applications*. 147–154.

[94] Fabian Hemmert, Danijela Djokic, and Reto Wettach. 2008. Perspective Change: A System for Switching between on-Screen Views by Closing One Eye. In *Proceedings of the Working Conference on Advanced Visual Interfaces (AVI '08)*. Association for Computing Machinery, New York, NY, USA, 484–485. DOI:http://dx.doi.org/10.1145/1385569.1385668

[95] Jutta Hild, Patrick Petersen, and Jürgen Beyerer. 2016. Moving Target Acquisition by Gaze Pointing and Button Press Using Hand or Foot. In *Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (ETRA '16).* ACM, New York, NY, USA, 257–260. DOI:http://dx.doi.org/10.1145/2857491.2857535

[96] Sébastien Hillaire, Anatole Lécuyer, Rémi Cozot, and Géry Casiez. 2008. Using an eye-tracking system to improve camera motions and depth-of-field blur effects in virtual environments. In *Virtual Reality Conference, 2008. VR'08. IEEE.* IEEE, 47–50.

[97] Kenneth Holmqvist, Marcus Nyström, Richard Andersson, Richard Dewhurst, Halszka Jarodzka, and Joost Van de Weijer. 2011. *Eye tracking: A comprehensive guide to methods and measures.* OUP Oxford.

[98] Sad Hombres. 2017. *Medusa's Lair.* Game, Installation. (15 March 2017).

[99] Alan Hook and Paul Coulton. 2017. Games Design Research through Game Design Practice. In *Game Design Research: An Introduction to Theory and Practice.* ETC Press, 97.

[100] S Horti. 2018. Eye Tracking for Gamers: Seeing Is Believing. Techradar 2018. https://www.techradar.com/news/eye-tracking-for-gamers-seeing-is-believing. (2018). Accessed: 19/09/2019.

[101] Katrijn Houben and Anita Jansen. 2015. Chocolate equals stop. Chocolate-specific inhibition training reduces chocolate intake and go associations with chocolate. *Appetite* 87 (2015), 318–323.

[102] HTC. 2016. HTC Vive. https://www.vive.com/eu/product/vive-pro-eye/. (2016).

[103] Chien-Ming Huang, Sean Andrist, Allison Sauppé, and Bilge Mutlu. 2015. Using gaze patterns to predict task intent in collaboration. *Frontiers in psychology* 6 (2015), 1049.

[104] Robin Hunicke, Marc LeBlanc, and Robert Zubek. 2004. MDA: A formal approach to game design and game research. In *Proceedings of the AAAI Workshop on Challenges in Game AI*, Vol. 4. 1722.

[105] Zaheer Hussain and Mark D Griffiths. 2008. Gender swapping and socializing in cyberspace: An exploratory study. *CyberPsychology & Behavior* 11, 1 (2008), 47–53.

[106] T. E. Hutchinson, K. P. White, W. N. Martin, K. C. Reichert, and L. A. Frey. 1989. Human-computer interaction using eye-gaze input. *IEEE Transactions on Systems, Man, and Cybernetics* 19, 6 (1989), 1527–1534.

[107] WA IJsselsteijn, YAW de Kort, and K Karolien Poels. 2013. The Game Experience Questionnaire. (2013).

[108] Beyond Infinity. 2015. *Glimpse of Fear*. Game. (22 October 2015).

[109] IO Interactive. 2017. *Hitman*. Game. (11 July 2017).

[110] Katherine Isbister. 2016. *How games move us: Emotion by design*. Mit Press.

[111] Katherine Isbister, Mary Flanagan, and Chelsea Hash. 2010. Designing games for learning: insights from conversations with designers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2041–2044.

[112] Poika Isokoski, Markus Joos, Oleg Spakov, and Benoît Martin. 2009. Gaze controlled games. *Universal Access in the Information Society* 8, 4 (2009), 323–337.

[113] Poika Isokoski and Benot Martin. 2006. Eye tracker input in first person shooter games. In *Proceedings of the 2nd Conference on Communication by Gaze Interaction: Communication by Gaze Interaction-COGAIN 2006: Gazing into the Future*. 78–81.

[114] Howell Istance, Richard Bates, Aulikki Hyrskykari, and Stephen Vickers. 2008. Snap Clutch, a Moded Approach to Solving the Midas Touch Problem. In *Proceedings of the 2008 Symposium on Eye Tracking Research & Applications (ETRA '08)*. Association for Computing Machinery, New York, NY, USA, 221–228. DOI: http://dx.doi.org/10.1145/1344471.1344523

[115] Howell Istance, Aulikki Hyrskykari, Lauri Immonen, Santtu Mansikkamaa, and Stephen Vickers. 2010. Designing gaze gestures for gaming: an investigation of performance. In *Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications*. ACM, 323–330.

[116] Howell Istance, Aulikki Hyrskykari, Stephen Vickers, and Thiago Chaves. 2009. For your eyes only: Controlling 3d online games by eye-gaze. In *Human-Computer Interaction–INTERACT 2009*. Springer, 314–327.

[117] Masaki Iwasaki, Christoph Kellinghaus, Andreas V Alexopoulos, Richard C Burgess, Arun N Kumar, Yanning H Han, Hans O Lüders, and R John Leigh. 2005. Effects of eyelid closure, blinks, and eye movements on the electroencephalogram. *Clinical Neurophysiology* 116, 4 (2005), 878–885.

[118] Robert J. K. Jacob. 1990. What you look at is what you get: eye movement-based interaction techniques. In *Proceedings of the SIGCHI conference on Human factors in computing systems: Empowering people (CHI '90)*. ACM, New York, NY, USA, 11–18. DOI:http://dx.doi.org/10.1145/97243.97246

[119] Shahram Jalaliniya and Diako Mardanbegi. 2016. Eyegrip: Detecting targets in a series of uni-directional moving objects using optokinetic nystagmus eye movements. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 5801–5811.

[120] Jorge Jimenez, Diego Gutierrez, Pedro Latorre, and U De Zaragoza. 2008. Gaze-based Interaction for Virtual Environments. *J. UCS* 14, 19 (2008), 3085–3098.

[121] Daniel Johnson, M John Gardner, and Ryan Perry. 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 (2018), 38–46.

[122] J Johnsson and R Matos. 2011. Accuracy and precision test method for remote eye trackers. *Tobii Technology* (2011).

[123] Lee Jones, John McClelland, Phonesavanh Thongsouksanoumane, and Audrey Girouard. 2017. Ambient Notifications with Shape Changing Circuits in Peripheral Locations. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces*. ACM, 405–408.

[124] Ricardo Jota and Daniel Wigdor. 2015. Palpebrae Superioris: Exploring the Design Space of Eyelid Gestures. In *Proceedings of the 41st Graphics Interface Conference (GI '15)*. Canadian Information Processing Society, CAN, 273–280.

[125] Arie E Kaufman, Amit Bandopadhay, and Bernard D Shaviv. 1993. An eye tracking computer user interface. In *Proceedings of 1993 IEEE Research Properties in Virtual Reality Symposium*. IEEE, 120–121.

[126] Rilla Khaled. 2012. Muse-based game design. In *Proceedings of the Designing Interactive Systems Conference*. 721–730.

[127] Rilla Khaled. 2018. Questions over answers: Reflective game design. In *Playful Disruption of Digital Media*. Springer, 3–27.

[128] Mohamed Khamis, Mariam Hassib, Emanuel von Zezschwitz, Andreas Bulling, and Florian Alt. 2017. GazeTouchPIN: protecting sensitive data on mobile devices using secure multimodal authentication. In *Proceedings of the 19th ACM International Conference on Multimodal Interaction*. 446–450.

[129] Mohamed Khamis, Carl Oechsner, Florian Alt, and Andreas Bulling. 2018. VRpursuits: interaction in virtual reality using smooth pursuit eye movements. (2018).

[130] Safal Khanal. 2015. Impact of visual skills training on sports performance: Current and future perspectives. (2015).

[131] Ilpo Koskinen, John Zimmerman, Thomas Binder, Johan Redstrom, and Stephan Wensveen. 2011. *Design research through practice: From the lab, field, and showroom.* Elsevier.

[132] Piotr Kowalczyk and Dariusz Sawicki. 2019. Blink and Wink Detection as a Control Tool in Multimodal Interaction. *Multimedia Tools Appl.* 78, 10 (May 2019), 13749–13765. DOI:http://dx.doi.org/10.1007/s11042-018-6554-8

[133] Aleksandra Królak and Paweł Strumiłło. 2012. Eye-blink detection system for human–computer interaction. *Universal Access in the Information Society* 11, 4 (2012), 409–419.

[134] Pin-Sung Ku, Te-Yen Wu, Ericka Andrea Valladares Bastias, and Mike Y. Chen. 2018. Wink It: Investigating Wink-Based Interactions for Smartphones. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct (MobileHCI '18)*. Association for Computing Machinery, New York, NY, USA, 146–150. DOI:http://dx.doi.org/10.1145/3236112.3236133

[135] Manu Kumar, Terry Winograd, and Andreas Paepcke. 2007. Gaze-Enhanced Scrolling Techniques. In *CHI '07 Extended Abstracts on Human Factors in Computing Systems (CHI EA '07)*. Association for Computing Machinery, New York, NY, USA, 2531–2536. DOI:http://dx.doi.org/10.1145/1240866.1241036

[136] Michael Land and Benjamin Tatler. 2009. *Looking and acting: vision and eye movements in natural behaviour.* Oxford University Press.

[137] Nicole Lane and Nathan R Prestopnik. 2017. Diegetic Connectivity: Blending Work and Play with Storytelling in Serious Games. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*. ACM, 229–240.

[138] Michael Lankes, Regina Bernhaupt, and Manfred Tscheligi. 2010. Evaluating user experience factors using experiments: Expressive artificial faces embedded in contexts. In *Evaluating user experience in games*. Springer, 165–183.

[139] Michael Lankes, Bernhard Maurer, and Barbara Stiglbauer. 2016. An Eye for an Eye: Gaze Input in Competitive Online Games and Its Effects on Social Presence. In *Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology (ACE '16)*. ACM, New York, NY, USA, Article 17, 9 pages. DOI:http://dx.doi.org/10.1145/3001773.3001774

[140] Michael Lankes, Thomas Mirlacher, Stefan Wagner, and Wolfgang Hochleitner. 2014. Whom are you looking for?: the effects of different player representation relations on the presence in gaze-based games. In *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play*. ACM, 171–179.

[141] Michael Lankes, Matej Rajtár, Oleg Denisov, and Bernhard Maurer. 2018. Socialeyes: social gaze in collaborative 3D games. In *Proceedings of the 13th International Conference on the Foundations of Digital Games*. ACM, 3.

[142] Michael Lankes and Barbara Stiglbauer. 2016. GazeAR: Mobile gaze-based interaction in the context of augmented reality games. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 397–406.

[143] Michael Lankes and Stefan Wagner. 2015. Taking a Look at the Player's Gaze: The Effects of Gaze Visualizations on the Perceived Presence in Games.. In *DiGRA Conference*.

[144] Chris Lankford. 2000. Effective Eye-Gaze Input into Windows. In *Proceedings of the 2000 Symposium on Eye Tracking Research & Applications (ETRA '00)*. Association for Computing Machinery, New York, NY, USA, 23–27. DOI:http://dx.doi.org/10.1145/355017.355021

[145] Petri Lankoski and Jussi Holopainen. 2017. *Game design research.* ETC Press Pittsburgh, PA.

[146] Effie L-C Law, Florian Brühlmann, and Elisa D Mekler. 2018. Systematic review and validation of the game experience questionnaire (geq)-implications for citation and reporting practice. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play.* 257–270.

[147] Stan Lee and Jack Kirby. 1963. The X-Men# 1. *Marvel Comics Google Scholar* (1963).

[148] Zunshuai Li. 2013. A Comparative Survey of Vision Metaphors Based on the Corpus in English and Chinese. *Theory & Practice in Language Studies* 3, 7 (2013).

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

[150] Min Lin and Guoming Mo. 2011. Eye gestures recognition technology in Human-computer Interaction. In *2011 4th International Conference on Biomedical Engineering and Informatics (BMEI)*, Vol. 3. IEEE, 1316–1318.

[151] Dagmar CG Lorenz. 2003. *A companion to the works of Arthur Schnitzler.* Camden House.

[152] Christof Lutteroth, Moiz Penkar, and Gerald Weber. 2015. Gaze vs. mouse: A fast and accurate gaze-only click alternative. In *Proceedings of the 28th annual ACM symposium on user interface software & technology.* 385–394.

[153] Kris Luyten, Donald Degraen, Gustavo Rovelo Ruiz, Sven Coppers, and Davy Vanacken. 2016. Hidden in plain sight: an exploration of a visual language for near-eye out-of-focus displays in the peripheral view. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.* ACM, 487–497.

[154] Päivi Majaranta, Ulla-Kaija Ahola, and Oleg Špakov. 2009. Fast Gaze Typing with an Adjustable Dwell Time. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09).* Association for Computing Machinery, New York, NY, USA, 357–360. DOI:`http://dx.doi.org/10.1145/1518701.1518758`

[155] Pierre Maquet, Jean-Marie Péters, Joël Aerts, Guy Delfiore, Christian Degueldre, André Luxen, and Georges Franck. 1996. Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. *Nature* 383, 6596 (1996), 163.

[156] Maria J Maraver, M Teresa Bajo, and Carlos J Gomez-Ariza. 2016. Training on working memory and inhibitory control in young adults. *Frontiers in human neuroscience* 10 (2016), 588.

[157] Diako Mardanbegi, Tobias Langlotz, and Hans Gellersen. 2019. Resolving Target Ambiguity in 3D Gaze Interaction through VOR Depth Estimation. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* ACM, 612.

[158] JJ Marotta, TS Perrot, D Nicolle, P Servos, and MA Goodale. 1995. Adapting to monocular vision: grasping with one eye. *Experimental Brain Research* 104, 1 (1995), 107–114.

[159] Bernhard Maurer, Ilhan Aslan, Martin Wuchse, Katja Neureiter, and Manfred Tscheligi. 2015. Gaze-based onlooker integration: exploring the in-between of active player and passive spectator in co-located gaming. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*. ACM, 163–173.

[160] Bernhard Maurer, Alina Krischkowsky, and Manfred Tscheligi. 2017. Exploring Gaze and Hand Gestures for Non-Verbal In-Game Communication. In *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '17 Extended Abstracts)*. ACM, New York, NY, USA, 315–322. DOI:http://dx.doi.org/10.1145/3130859.3131296

[161] Bernhard Maurer, Michael Lankes, Barbara Stiglbauer, and Manfred Tscheligi. 2016. EyeCo: Effects of shared gaze on social presence in an online cooperative game. In *International Conference on Entertainment Computing*. Springer, 102–114.

[162] Bernhard Maurer, Michael Lankes, and Manfred Tscheligi. 2018. Where the eyes meet: Lessons learned from shared gaze-based interactions in cooperative and competitive online games. *Entertainment Computing* 27 (2018), 47–59.

[163] Nicole McMahon, Peta Wyeth, and Daniel Johnson. 2015. Engaging in videogame play: An activity-centric analysis of the player experience. In *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*. 101–108.

[164] Elisa D Mekler, Ioanna Iacovides, and Julia Ayumi Bopp. 2018. A Game that Makes You Question...: Exploring the Role of Reflection for the Player Experience. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*. ACM, 315–327.

[165] Microsoft. 2010. Microsoft Kinect. https://developer.microsoft.com/en/windows/kinect. (2010).

[166] Might and Delight. 2015. *Shelter 2*. Game. (2015).

[167] Might and Delight. 2016. *Paws*. Game. (2016).

[168] Emiliano Miluzzo, Tianyu Wang, and Andrew T Campbell. 2010. EyePhone: activating mobile phones with your eyes. In *Proceedings of the second ACM SIGCOMM workshop on Networking, systems, and applications on mobile handhelds*. ACM, 15–20.

[169] Eric Missimer and Margrit Betke. 2010. Blink and wink detection for mouse pointer control. In *Proceedings of the 3rd International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 23.

[170] Pranav Mistry, Kentaro Ishii, Masahiko Inami, and Takeo Igarashi. 2010. Blinkbot: Look at, Blink and Move. In *Adjunct Proceedings of the 23Nd Annual ACM Symposium on User Interface Software and Technology (UIST '10)*. ACM, New York, NY, USA, 397–398. DOI:http://dx.doi.org/10.1145/1866218.1866238

[171] Flying Mollusk. 2015. *Nevermind*. Game. (29 September 2015).

[172] Eidos Montreal. 2018. *Shadow of the Tomb Raider*. Game. (14 September 2018).

[173] Moondrop. 2014. *Amphora*. Game. (2014).

[174] James W Moore. 2016. What is the sense of agency and why does it matter? *Frontiers in psychology* 7 (2016), 1272.

[175] Carlos H Morimoto and Marcio RM Mimica. 2005. Eye gaze tracking techniques for interactive applications. *Computer Vision and Image Understanding* 98, 1 (2005), 4–24.

[176] Douglas P. Munoz and Stefan Everling. 2004. Look away: the anti-saccade task and the voluntary control of eye movement. *Nature Reviews Neuroscience* 5 (01 03 2004), 218 EP –. http://dx.doi.org/10.1038/nrn1345

[177] Jorge Munoz, Georgios N Yannakakis, Fiona Mulvey, Dan Witzner Hansen, German Gutierrez, and Araceli Sanchis. 2011. Towards gaze-controlled platform games. In *Computational Intelligence and Games (CIG), 2011 IEEE Conference on*. IEEE, 47–54.

[178] Sheila C Murphy. 2004. 'Live in your world, play in ours': The spaces of video game identity. *Journal of visual culture* 3, 2 (2004), 223–238.

[179] Lennart Erik Nacke, Michael Kalyn, Calvin Lough, and Regan Lee Mandryk. 2011. Biofeedback game design: using direct and indirect physiological control to enhance game interaction. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 103–112.

[180] Lennart E Nacke, Sophie Stellmach, Dennis Sasse, and Craig A Lindley. 2010. Gameplay experience in a gaze interaction game. *arXiv preprint arXiv:1004.0259* (2010).

[181] Diego Navarro and Veronica Sundstedt. 2017. Simplifying game mechanics: gaze as an implicit interaction method. In *SIGGRAPH Asia 2017 Technical Briefs*. ACM, 4.

[182] Joshua Newn, Fraser Allison, Eduardo Velloso, and Frank Vetere. 2018. Looks can be deceiving: Using gaze visualisation to predict and mislead opponents in strategic gameplay. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 261.

[183] Joshua Newn, Eduardo Velloso, Fraser Allison, Yomna Abdelrahman, and Frank Vetere. 2017. Evaluating Real-Time Gaze Representations to Infer Intentions in Competitive Turn-Based Strategy Games. In *Proceedings of the Annual Symposium*

on Computer-Human Interaction in Play (CHI PLAY '17). ACM, New York, NY, USA, 541–552. DOI:http://dx.doi.org/10.1145/3116595.3116624

[184] Kher Hui Ng, Steve Benford, and Boriana Koleva. 2005. PINS push in and POUTS pop out: creating a tangible pin-board that ejects physical documents. In *CHI'05 Extended Abstracts on Human Factors in Computing Systems*. ACM, 1981–1984.

[185] Kher Hui Ng, Boriana Koleva, and Steve Benford. 2007. The iterative development of a tangible pin-board to symmetrically link physical and digital documents. *Personal and Ubiquitous Computing* 11, 3 (2007), 145–155.

[186] Dong Nguyen. 2013. *Flappy Bird*. Game [Phone]. (24 May 2013).

[187] Simon Niedenthal. 2009. What we talk about when we talk about game aesthetics. In *Digital Games Research Association (DiGRA), London, UK (2009)*. DiGRA Online Library.

[188] Anders Møller Nielsen, Anders Lerchedahl Petersen, and John Paulin Hansen. 2012. Gaming with gaze and losing with a smile. In *Proceedings of the Symposium on Eye Tracking Research and Applications*. ACM, 365–368.

[189] Antje Nuthmann and George L Malcolm. 2016. Eye guidance during real-world scene search: The role color plays in central and peripheral vision. *Journal of Vision* 16, 2 (2016), 3–3.

[190] J O'Donovan, J Ward, S Hodgins, and V Sundstedt. 2009. Rabbit run: Gaze and voice based game interaction. In *Eurographics Ireland Workshop, December*.

[191] Florida Interactive Entertainment Academy University of Central Florida. 2018. *The Channeler*. Game [PC]. (31 March 2018).

[192] Pablo Ortiz and D Fox Harrell. 2018. Enabling Critical Self-Reflection through Roleplay with Chimeria: Grayscale. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*. ACM, 353–364.

[193] Lyelle L Palmer. 1976. Inability to wink an eye and eye dominance. *Perceptual and motor skills* 42, 3 (1976), 825–826.

[194] Kyung S Park and Kyung T Lee. 1996. Eye-controlled human/computer interface using the line-of-sight and the intentional blink. *Computers & industrial engineering* 30, 3 (1996), 463–473.

[195] Robert Pepperell. 2012. The perception of art and the science of perception. SPIE-IS&T.

[196] Ken Pfeuffer, Jason Alexander, Ming Ki Chong, and Hans Gellersen. 2014. Gaze-touch: combining gaze with multi-touch for interaction on the same surface. In *Proceedings of the 27th annual ACM symposium on User interface software and technology*. ACM, 509–518.

[197] Ken Pfeuffer, Jason Alexander, Ming Ki Chong, Yanxia Zhang, and Hans Gellersen. 2015. Gaze-shifting: Direct-indirect input with pen and touch modulated by gaze. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*. ACM, 373–383.

[198] Ken Pfeuffer, Jason Alexander, and Hans Gellersen. 2016a. GazeArchers: Playing with Individual and Shared Attention in a Two-player Look&Shoot Tabletop Game. In *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia (MUM '16)*. ACM, New York, NY, USA, 213–216. DOI: http://dx.doi.org/10.1145/3012709.3012717

[199] Ken Pfeuffer, Jason Alexander, and Hans Gellersen. 2016b. Partially-indirect bimanual input with gaze, pen, and touch for pan, zoom, and ink interaction. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 2845–2856.

[200] Ken Pfeuffer and Hans Gellersen. 2016. Gaze and Touch Interaction on Tablets. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 301–311. DOI:http://dx.doi.org/10.1145/2984511.2984514

[201] Ken Pfeuffer, Benedikt Mayer, Diako Mardanbegi, and Hans Gellersen. 2017. Gaze+ pinch interaction in virtual reality. In *Proceedings of the 5th Symposium on Spatial User Interaction*. 99–108.

[202] Edgar Allan Poe. 2015. *The imp of the perverse*. Edgar Allan Poe.

[203] Marco Porta, Alice Ravarelli, and Giovanni Spagnoli. 2010. ceCursor, a contextual eye cursor for general pointing in windows environments. In *Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications*. 331–337.

[204] Enzio Probst, Vincent Suttner, Monja Dietrich, and Theres Buehler. 2018. Rapture of the deep. In *SIGGRAPH Asia 2018 Virtual & Augmented Reality*. ACM, 14.

[205] Kamfjord Productions. 2016. *Spectrophobia*. Game. (2016).

[206] Luisa Jesús Quevedo Junyent, Fernando Palomar Mascaró, and José Antonio Aznar-Casanova. 2017. Effective Visual Field Rehabilitation in Homonymous Hemianopia by Attaching Binocular Prisms to Lenses. *American Research Journal of Ophthalmology and Optometry* 1, 1 (2017), 1–11.

[207] Argenis Ramirez Gomez and Hans Gellersen. 2018. Smooth-i: smart re-calibration using smooth pursuit eye movements. In *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications*. ACM, 10.

[208] Argenis Ramirez Gomez and Hans Gellersen. 2019a. Looking Outside the Box: Reflecting on Gaze Interaction in Gameplay. In *Proceedings of the 2019 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '19)*. ACM, New York, NY, USA. DOI:http://dx.doi.org/10.1145/3311350.3347150

[209] Argenis Ramirez Gomez and Hans Gellersen. 2019b. SuperVision: Playing with Gaze Aversion and Peripheral Vision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. ACM, 473.

[210] Argenis Ramirez Gomez and Hans Gellersen. 2020. More than Looking: Using Eye Movements Behind the Eyelids as a New Game Mechanic. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '20)*. ACM, New York, NY, USA. DOI:http://dx.doi.org/10.1145/3410404.3414240

[211] Argenis Ramirez Gomez and Hans-Werner Georg Gellersen. 2017. GazeBall: Leveraging Natural Gaze Behavior for Continuous Re-calibration in Gameplay. In *COGAIN Symposium*.

[212] Michael Rosen. 2019. *Michael Rosen's Book of Play: Why play really matters, and 101 ways to get more of it in your life*. Wellcome Collection.

[213] Ruth Rosenholtz. 2016. Capabilities and limitations of peripheral vision. *Annual Review of Vision Science* 2 (2016), 437–457.

[214] Michael Joshua Rowin. 2017. Metaphors on Vision. *Film Comment* 53, 5 (2017), 78.

[215] Lingyan Ruan, Bin Chen, and Miu-Ling Lam. 2018. Human-computer interaction by voluntary vergence control. In *SIGGRAPH Asia 2018 Posters*. 1–2.

[216] Toshiyuki Sakuragi and Judith W Fuller. 2003. Body-part metaphors: A cross-cultural survey of the perception of translatability among Americans and Japanese. *Journal of psycholinguistic research* 32, 4 (2003), 381–395.

[217] Ozge Samanci, Blacki Li Rudi Migliozzi, and Daniel Sabio. 2014. Plink Blink: Collaborative Music Production via Blinking Eyes. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology (ACE '14)*. ACM, New York, NY, USA, Article 61, 4 pages. DOI:http://dx.doi.org/10.1145/2663806.2663809

[218] Javier San Agustin, Julio C Mateo, John Paulin Hansen, and Arantxa Villanueva. 2009. Evaluation of the potential of gaze input for game interaction. *PsychNology Journal* 7, 2 (2009), 213–236.

[219] Pedro Sanches, Kristina Hook, Corina Sas, and Anna Stahl. 2019. Ambiguity as a resource to inform proto-practices: The case of skin conductance. *ACM Transactions on Computer-Human Interaction (TOCHI)* (2019).

[220] C Schaefer, R Menges, K Schmidt, M Kuich, and T Walber. 2014. Schau genau! an eye tracking game with a purpose. *Applications for Gaze in Games* (2014).

[221] Franklin R Schneier, Thomas L Rodebaugh, Carlos Blanco, Hillary Lewin, and Michael R Liebowitz. 2011. Fear and avoidance of eye contact in social anxiety disorder. *Comprehensive Psychiatry* 52, 1 (2011), 81–87.

[222] Sven Seele, Sebastian Misztal, Helmut Buhler, Rainer Herpers, and Jonas Schild. 2017. Here's Looking At You Anyway!: How Important is Realistic Gaze Behavior in Co-located Social Virtual Reality Games?. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '17)*. ACM, New York, NY, USA, 531–540. DOI:http://dx.doi.org/10.1145/3116595.3116619

[223] Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph'Jofish' Kaye. 2005. Reflective design. In *Proceedings of the 4th decennial conference on Critical computing: between sense and sensibility*. ACM, 49–58.

[224] Baris Serim and Giulio Jacucci. 2016. Pointing While Looking Elsewhere: Designing for Varying Degrees of Visual Guidance During Manual Input. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 5789–5800. DOI:http://dx.doi.org/10.1145/2858036.2858480

[225] Robin Shaw, Everett Crisman, Anne Loomis, and Zofia Laszewski. 1990. The eye wink control interface: using the computer to provide the severely disabled with increased flexibility and comfort. In *[1990] Proceedings. Third Annual IEEE Symposium on Computer-Based Medical Systems*. IEEE, 105–111.

[226] Miguel Sicart. 2008. Defining game mechanics. *Game Studies* 8, 2 (2008), n.

[227] Ludwig Sidenmark, Christopher Clarke, Xuesong Zhang, Jenny Phu, and Hans Gellersen. 2020. Outline Pursuits: Gaze-Assisted Selection of Occluded Objects in Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. DOI:http://dx.doi.org/10.1145/3313831.3376438

[228] Ludwig Sidenmark and Hans Gellersen. 2019. Eye, Head and Torso Coordination During Gaze Shifts in Virtual Reality. *ACM Trans. Comput.-Hum. Interact.* 27, 1, Article Article 4 (Dec. 2019), 40 pages. DOI:http://dx.doi.org/10.1145/3361218

[229] Deep Silver. 2017. *Agents of Mayhem*. Game. (2017).

[230] Hari Singh and Jaswinder Singh. 2018. Real-time eye blink and wink detection for object selection in HCI systems. *Journal on Multimodal User Interfaces* 12, 1 (2018), 55–65.

[231] J David Smith and TC Graham. 2006. Use of eye movements for video game control. In *Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology*. ACM, 20.

[232] Oleg Špakov. 2005. EyeChess: the tutoring game with visual attentive interface. *Alternative Access: Feelings & Games* 5 (2005).

[233] Oleg Špakov and Darius Miniotas. 2005. Gaze-based selection of standard-size menu items. In *Proceedings of the 7th international conference on Multimodal interfaces*. ACM, 124–128.

[234] India Starker and Richard A. Bolt. 1990. A Gaze-responsive Self-disclosing Display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '90)*. ACM, New York, NY, USA, 3–10. DOI:http://dx.doi.org/10.1145/97243.97245

[235] Sophie Stellmach and Raimund Dachselt. 2013. Still looking: investigating seamless gaze-supported selection, positioning, and manipulation of distant targets. In *Proceedings of the sigchi conference on human factors in computing systems*. ACM, 285–294.

[236] Robert Louis Stevenson. 2018. Strange Case of Dr Jekyll and Mr Hyde. In *Medicine and Literature, Volume Two*. CRC Press, 105–118.

[237] Broken Window Studios. 2015a. *Reflections*. Game. (2015).

[238] Starbreeze Studios. 2013. *Brothers: A Tale of Two Sons*. Game. (7 August 2013).

[239] Stillalive Studios. 2015b. *Son of Nor*. Game. (28 April 2015).

[240] Veronica Sundstedt. 2010. Gazing at games: using eye tracking to control virtual characters. In *ACM SIGGRAPH 2010 Courses*. ACM, 5.

[241] Veronica Sundstedt, Diego Navarro, and Julian Mautner. 2016. Possibilities and challenges with eye tracking in video games and virtual reality applications. In *SIGGRAPH ASIA 2016 Courses*. ACM, 17.

[242] Penelope Sweetser and Peta Wyeth. 2005. GameFlow: A Model for Evaluating Player Enjoyment in Games. *Comput. Entertain.* 3, 3 (July 2005), 3–3. DOI:http://dx.doi.org/10.1145/1077246.1077253

[243] Techland. 2018. *Dying Light: Bad Blood*. Game. (13 September 2018).

[244] MPS To, BC Regan, Dora Wood, and JD Mollon. 2011. Vision out of the corner of the eye. *Vision Research* 51, 1 (2011), 203–214.

[245] Tobii. 2020. Tobii Gaming Games. https://gaming.tobii.com/games/. (2020). Accessed: 2020-03-23.

[246] Sabine Trepte and Leonard Reinecke. 2010. Avatar creation and video game enjoyment. *Journal of Media Psychology* (2010).

[247] Jayson Turner, Jason Alexander, Andreas Bulling, and Hans Gellersen. 2015. Gaze+ RST: integrating gaze and multitouch for remote rotate-scale-translate tasks. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 4179–4188.

[248] Jayson Turner, Jason Alexander, Andreas Bulling, Dominik Schmidt, and Hans Gellersen. 2013. Eye pull, eye push: Moving objects between large screens and personal devices with gaze and touch. In *IFIP Conference on Human-Computer Interaction*. Springer, 170–186.

[249] Jayson Turner, Andreas Bulling, Jason Alexander, and Hans Gellersen. 2014. Cross-device gaze-supported point-to-point content transfer. In *Proceedings of the Symposium on Eye Tracking Research and Applications*. ACM, 19–26.

[250] Jayson Turner, Andreas Bulling, and Hans Gellersen. 2011. Combining gaze with manual interaction to extend physical reach. In *Proceedings of the 1st international workshop on pervasive eye tracking & mobile eye-based interaction*. ACM, 33–36.

[251] Jayson Turner, Eduardo Velloso, Hans Gellersen, and Veronica Sundstedt. 2014. EyePlay: applications for gaze in games. In *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play*. ACM, 465–468.

[252] Ubisoft. 2015. *Assassin's Creed: Rogue*. Game. (10 March 2015).

[253] Ubisoft. 2016. *Watch Dogs 2*. Game. (29 November 2016).

[254] Ubisoft. 2018. *Assassin's Creed Odyssey*. Game. (5 October 2018).

[255] Ubisoft Montreal and Ubisoft Toronto. 2018. *Far Cry 5*. Game [Xbox][Windows][PlayStation]. (27 March 2018).

[256] Ultrahaptics. 2013. Leap Motion. `https://www.leapmotion.com/`. (2013).

[257] MUHTAR ÇAĞKAN ULUDAĞLI and CENGİZ ACARTÜRK. 2018. User interaction in hands-free gaming: a comparative study of gaze-voice and touchscreen interface control. *Turkish Journal of Electrical Engineering & Computer Sciences* 26, 4 (2018), 1967–1976.

[258] Jan Van der Kamp and Veronica Sundstedt. 2011. Gaze and voice controlled drawing. In *Proceedings of the 1st conference on novel gaze-controlled applications*. ACM, 9.

[259] Jelle Van Dijk, Remko Van Der Lugt, and Caroline Hummels. 2014. Beyond distributed representation: embodied cognition design supporting socio-sensorimotor couplings. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*. ACM, 181–188.

[260] Eva A Van Reijmersdal, Jeroen Jansz, Oscar Peters, and Guda Van Noort. 2013. Why girls go pink: Game character identification and game-players' motivations. *Computers in Human Behavior* 29, 6 (2013), 2640–2649.

[261] Vincent Van Rheden, Bernhard Maurer, Dorothé Smit, Martin Murer, and Manfred Tscheligi. 2017. LaserViz: Shared gaze in the Co-located physical world. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, 191–196.

[262] Boris Velichkovsky, Andreas Sprenger, and Pieter Unema. 1997. Towards gaze-mediated interaction: Collecting solutions of the "Midas touch problem". In *Human-Computer Interaction INTERACT'97*. Springer, 509–516.

[263] Eduardo Velloso and Marcus Carter. 2016. The Emergence of EyePlay: A Survey of Eye Interaction in Games. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. ACM, New York, NY, USA, 171–185. DOI:http://dx.doi.org/10.1145/2967934.2968084

[264] Eduardo Velloso, Marcus Carter, Joshua Newn, Augusto Esteves, Christopher Clarke, and Hans Gellersen. 2017. Motion correlation: Selecting objects by matching their movement. *ACM Transactions on Computer-Human Interaction (TOCHI)* 24, 3 (2017), 1–35.

[265] Eduardo Velloso, Amy Fleming, Jason Alexander, and Hans Gellersen. 2015a. Gaze-Supported Gaming: MAGIC Techniques for First Person Shooters. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '15)*. ACM, New York, NY, USA, 343–347. DOI:http://dx.doi.org/10.1145/2793107.2793137

[266] Eduardo Velloso, Carl Oechsner, Katharina Sachmann, Markus Wirth, and Hans Gellersen. 2015b. Arcade+: A Platform for Public Deployment and Evaluation of Multi-Modal Games. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '15)*. ACM, New York, NY, USA, 271–275. DOI:http://dx.doi.org/10.1145/2793107.2793145

[267] Eduardo Velloso, Markus Wirth, Christian Weichel, Augusto Esteves, and Hans Gellersen. 2016. AmbiGaze: Direct control of ambient devices by gaze. In *Proceedings of the 2016 acm conference on designing interactive systems*. 812–817.

[268] Roel Vertegaal. 2008. A Fitts Law comparison of eye tracking and manual input in the selection of visual targets. In *Proceedings of the 10th international conference on Multimodal interfaces*. ACM, 241–248.

[269] Stephen Vickers, Howell Istance, and Matthew Smalley. 2010. EyeGuitar: making rhythm based music video games accessible using only eye movements. In *Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology*. ACM, 36–39.

[270] Melodie Vidal. 2014. Shynosaurs: A Game of Attention Dilemma. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14)*. ACM, New York, NY, USA, 391–394. DOI:http://dx.doi.org/10.1145/2658537.2662979

[271] Melodie Vidal, Remi Bismuth, Andreas Bulling, and Hans Gellersen. 2015. The Royal Corgi: Exploring Social Gaze Interaction for Immersive Gameplay. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 115–124. DOI:http://dx.doi.org/10.1145/2702123.2702163

[272] Mélodie Vidal, Andreas Bulling, and Hans Gellersen. 2013. Pursuits: Spontaneous Interaction with Displays Based on Smooth Pursuit Eye Movement and Moving Targets. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive*

and Ubiquitous Computing (UbiComp '13). ACM, New York, NY, USA, 439–448. DOI:http://dx.doi.org/10.1145/2493432.2493477

[273] All About Vision. 2017. Finding Your Dominant Eye Video. (2017). https://www.allaboutvision.com/video/dominant-eye.htm

[274] Annika Waern and Jon Back. 2015. Experimental game design. In *Game Research Methods*. 341–353.

[275] Bryan Wang and Tovi Grossman. 2020. BlyncSync: Enabling Multimodal Smartwatch Gestures with Synchronous Touch and Blink. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. DOI:http://dx.doi.org/10.1145/3313831.3376132

[276] Colin Ware and Harutune H Mikaelian. 1986. An evaluation of an eye tracker as a device for computer input. In *Proceedings of the SIGCHI/GI conference on Human factors in computing systems and graphics interface*. 183–188.

[277] Henrik Warpefelt. 2016. *The Non-Player Character: Exploring the believability of NPC presentation and behavior*. Ph.D. Dissertation. Department of Computer and Systems Sciences, Stockholm University.

[278] Daniel M Wegner. 2009. How to think, say, or do precisely the worst thing for any occasion. *Science* 325, 5936 (2009), 48–50.

[279] Emma Westecott. 2009. The player character as performing object. (2009).

[280] Denise Chapman Weston. 2004. Interactive dark ride. (Sept. 28 2004). US Patent 6,796,908.

[281] David Whitney and Dennis M Levi. 2011. Visual crowding: A fundamental limit on conscious perception and object recognition. *Trends in cognitive sciences* 15, 4 (2011), 160–168.

[282] Tom Wilcox, Mike Evans, Chris Pearce, Nick Pollard, and Veronica Sundstedt. 2008. Gaze and voice based game interaction: the revenge of the killer penguins. *SIGGRAPH Posters* 81 (2008).

[283] Oscar Wilde and Joseph Bristow. 2006. *The picture of dorian gray*. OUP Oxford.

[284] Ulf Wilhelmsson. 2006. Computer games as playground and stage. In *Proceedings of the 2006 international conference on Game research and development*. 62–68.

[285] Jean M Williams and Joel Thirer. 1975. Vertical and horizontal peripheral vision in male and female athletes and nonathletes. *Research Quarterly. American Alliance for Health, Physical Education and Recreation* 46, 2 (1975), 200–205.

[286] Jacob O Wobbrock, James Rubinstein, Michael W Sawyer, and Andrew T Duchowski. 2008. Longitudinal evaluation of discrete consecutive gaze gestures for text entry. In *Proceedings of the 2008 symposium on Eye tracking research & applications*. 11–18.

[287] Lince Works. 2016. *Aragami.* Game. (4 October 2016).

[288] Deyue Yu, Gordon E Legge, Heejung Park, Emily Gage, and Susana TL Chung. 2010. Development of a training protocol to improve reading performance in peripheral vision. *Vision research* 50, 1 (2010), 36–45.

[289] Shumin Zhai, Carlos Morimoto, and Steven Ihde. 1999. Manual and gaze input cascaded (MAGIC) pointing. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems.* ACM, 246–253.

[290] Xiaoyi Zhang, Harish Kulkarni, and Meredith Ringel Morris. 2017a. Smartphone-Based Gaze Gesture Communication for People with Motor Disabilities. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17).* Association for Computing Machinery, New York, NY, USA, 2878–2889. DOI: http://dx.doi.org/10.1145/3025453.3025790

[291] Xiaoyi Zhang, Harish Kulkarni, and Meredith Ringel Morris. 2017b. Smartphone-Based Gaze Gesture Communication for People with Motor Disabilities. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17).* Association for Computing Machinery, New York, NY, USA, 2878–2889. DOI: http://dx.doi.org/10.1145/3025453.3025790

[292] Yanxia Zhang, Andreas Bulling, and Hans Gellersen. 2013. Sideways: A gaze interface for spontaneous interaction with situated displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM, 851–860.

[293] John Zimmerman and Jodi Forlizzi. 2014. Research through design in HCI. In *Ways of Knowing in HCI.* Springer, 167–189.

[294] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems.* 493–502.

[295] John Zimmerman, Erik Stolterman, and Jodi Forlizzi. 2010. An analysis and critique of Research through Design: towards a formalization of a research approach. In *proceedings of the 8th ACM conference on designing interactive systems.* 310–319.