LightPlay: An Ambient Light System for Video Game Indicators and Notifications

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Mathematics
in
Computer Science

Waterloo, Ontario, Canada, 2020

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Video games often have indicators and notifications to convey in-game information. However, displaying these visuals on-screen come with trade-offs, such as consuming screen real estate and an inability for them to be configured independently from its host screen; denying users freedoms such as increasing indicator and notification brightness levels for better awareness without increasing the brightness of main content. As an alternative, we introduce LightPlay, an ambient light system set on the back border of a monitor to display video game indicators and notifications. We compare the speed, error rate, and perceived workload, between on-screen and ambient light indicators and notifications in a first-person camera view video game environment. Results show that ambient lights provide 17.5% faster times for capturing attention compared to on-screen indicators. In addition, ambient lights performed at least as well as on-screen across all other tested metrics. Based on these results, LightPlay could be an effective replacement for on-screen methods of displaying indicators and notifications, allowing users to reclaim screen real estate and configuration flexibility without sacrificing performance. Additionally, we outline possible designs and applications for LightPlay in video games.

Acknowledgements

I would like to thank my supervisor Lennart Nacke for his guidance and encouragement during my studies. I will always be grateful that he gave me the opportunity to pursue computer science.

Thank you to Lennart Nacke, Katja Rogers, and Dan Vogel for their help with this thesis.

Thank you to everyone at the HCI Games Group, I loved my desk and all the interesting people sitting around it.

Thank you to my amazing friends that gave me the courage to continue when times were tough. I will never forget the experiences I’ve had with all of you, and I’m looking forward to more adventures in the future.

Thank you to Waterloo, I have been here for almost 9 years and it’s time to say goodbye. I have made life-long friends here, and accomplished things I never thought would be possible for me.

Thank you to my family, especially to my Dad who supported me throughout my endeavours.

Finally, thank you to myself for taking the chance. Thanks Kenny.

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Chapter 1

Introduction

In video games, visual representations such as maps, icons, and avatars, are often used to convey in-game information. Although useful, indicators and notifications can impair a player's visibility with screen clutter and occlusion [49]. In addition, on-screen indicator and notification configurations such as brightness levels are limited by the screen; restricting potential visibility improvements. These two problems, occupation of screen space and configuration dependency, that accompany on-screen indicators in video games motivate LightPlay, an ambient light system which displays in-game indicators and notifications on an LED strip instead of on-screen.

In particular, we look at in-game damage indicators and colour-coded notifications in the first-person camera view. Indicators are defined as visual representations that additionally provide directional information while notifications are defined as visual representations that only offer non-directional information. For instance, in-game damage indicators are often used to represent the position from where damage originates (Figure 1.1).

Figure 1.1: Example of in-game damage indicator (orange box) conveying player damage originating from enemy (circled in red) in the game *Borderlands 2* [52].

Colour-coded notifications are frequently used to display different player or in-game equipment states such as health level (Figure 1.2) or ammunition count (Figure 1.3).

Figure 1.2: Example of in-game notification: Player in the game *The Last of Us* [53] with very low in-game health represented by the red on-screen notification along the border of the display.

Figure 1.3: Example of in-game notifications: Ammunition notifications in the game *Call of Duty Modern Warfare: Warzone* [54] (Left, circled in red). (Top Right) zoomed in on display showing sufficient ammunition in white coloured text. (Bottom Right) zoomed in on display showing no ammunition left in clip in red coloured text.

Ambient light systems have the ability to convey information to a user with minimum interference to a primary task [10]. As such, they have been explored as a replacement or supplement for current methods of updating users digitally (i.e. notifications displayed on a screen) [2, 13, 19, 20, 21]. Used with a screen, ambient light systems provide potential benefits including alleviating screen clutter from on-screen indicators, and the ability to configure the system independently without affecting screen settings (i.e., brightness levels). These benefits have motivated the research and development of combined applications with high-resolution displays for real-time systems. However, there is little research exploring speed performance times and error rates of ambient light indicators and notifications compared against on-screen ones in the context of first-person camera view video games.

Speed performance of indicators is important for how quickly a player can respond to real-time in-game events such as recognizing they are under enemy fire. In another example, the time it takes for a player to consume a health pack when necessary is dependent on the reaction time to low-health notifications. The ability for an indicator to effectively convey information is separate and also just as essential. Following the previous example, once the player knows they are being damaged an indicator should be able to give them the direction of the enemy so that they can accurately react. As such, we built LightPlay, a prototype ambient light system for conveying first-person camera view in-game information to a user to test these metrics (Figure 1.4). We refer to indicators and notifications that are shown on the ambient light display as ambient light indicators and ambient light notifications respectively.

To build LightPlay, we followed previous implementations of using LED strips for ambient light systems that were coupled with screens [11, 12, 24]. Just as previous studies have done, we placed the LED strips along the back border of our screen, in our case a high definition monitor. We controlled these strips via an Arduino UNO microcontroller that was programmed to receive input from a first-person camera view game built in the game engine Unity.

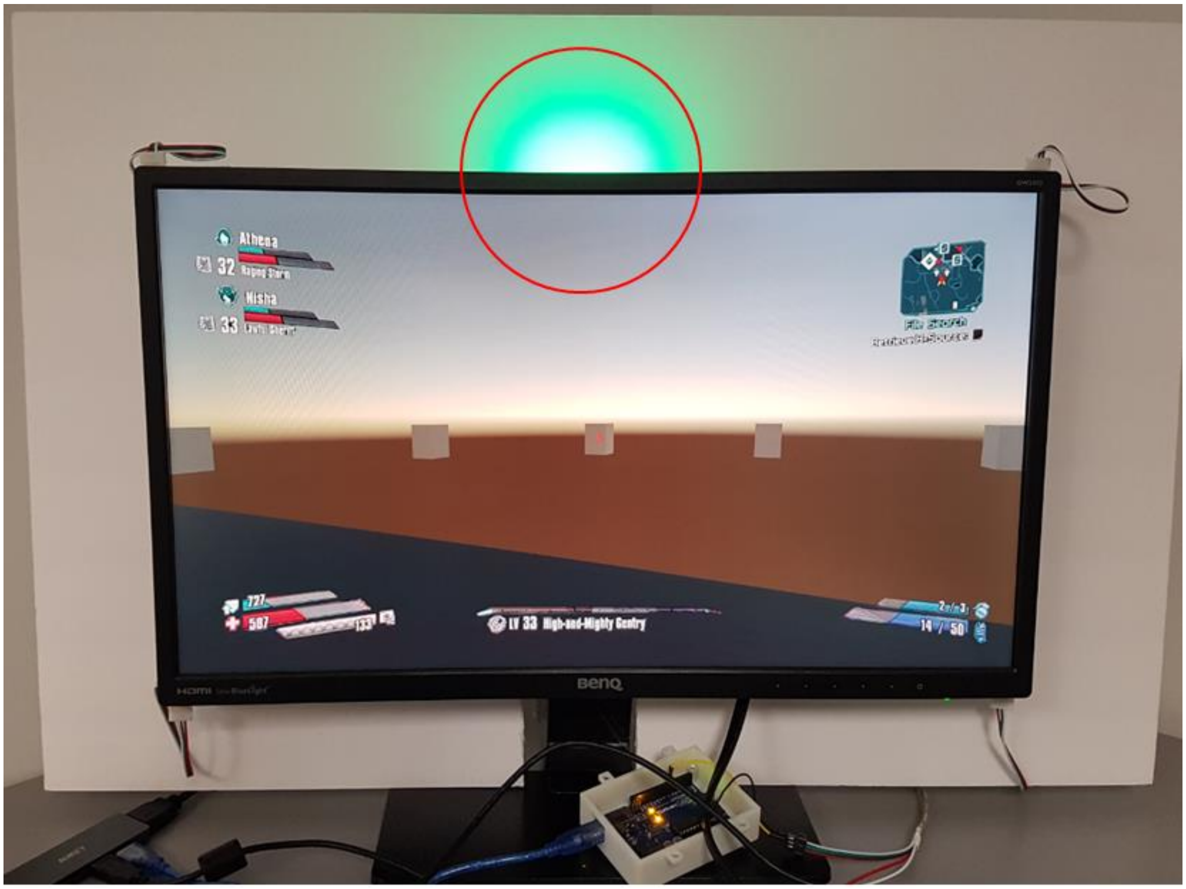


Figure 1.4: LightPlay with ambient light indicator (circled in red) displaying information that the target is directly in front of the player.

We define reaction time as the time it takes to be made aware of the appearance of an indicator or notification, and selection time as the time it takes to make a response following reaction time. To illustrate, the time it takes to notice the appearance of a damage indicator is reaction time while the time it takes to start shooting the enemy attacking you is selection time. This distinction can also be seen in a taxonomy for ambient information systems by Pousman and Stasko [16]. The authors define four design dimensions: Information Capacity, Representational Fidelity, Notification Level, and Aesthetic Emphasis. Representational fidelity refers to how a system might map information. For instance, the colour red may stand for low phone battery, or in a video game environment how the colour red could represent low health. Notification level refers to the intensity at which the system demands attention. Matthews et al. [17] further breaks notification level down to: ignore, change, blind, make aware, interrupt and demand action. The authors define interrupt and demand action as a representation of information that should grab focused attention, and requires that the user perform some action to stop the alerting. In the context of a video game, this would be when there is a low health notification on the screen that will persist until the player has consumed a health pack.

To validate the use of LightPlay to display in-game indicators and notifications instead of on-screen, we compared speed performance times, error rates, and perceived workload.

In experiment one, we compared the reaction time, selection time, error rate, and perceived workload, between on-screen and ambient light indicators. In particular, the indicator conveyed information about where a current target was.

An audio condition was added to validate the use of visual indicators. Audio indicators could be used instead of either visual indicator if it proved to be not significantly different in performance. However, Gröhn et al. [50] compared auditory and visual cues in a 3D space in a navigation task and found that auditory cues performed poorly with much higher search times. As such, we did not expect the audio condition to do well but we have placed it in the experiment to confirm. Results for experiment one showed that for reaction time ambient was significantly faster than on-screen and ambient was at least equally effective to both audio and on-screen in all other tested metrics. As expected, audio had significantly longer selection times. In addition audio had significantly higher error rates and was not significantly better than ambient in terms of reaction time.

In experiment two, we compared reaction time, selection time, error rate, and perceived workload, between on-screen and ambient light notifications. In particular, the notification conveyed colour-coded information about which keyboard key to respond with. Results for experiment two showed that ambient was not significantly different from on-screen in all tested metrics.

1.1 Contributions

We contribute empirical results that show an ambient light system is a viable replacement for on-screen indicators and notifications in a first-person camera view video game environment. By offering at least on-par performance as an on-screen implementation ambient light allows users to benefit from reclaimed screen real estate and independent system configurations without sacrificing performance. We also introduce various possible applications of LightPlay.

1.2 Organization

This thesis is organized as follows:

- Chapter 2 describes previous work relating to ambient light systems, their use in video games, and potential benefits involved.
- Chapter 3 describes the potential design space and use cases for LightPlay
- Chapter 4 describes the system we implemented to deliver ambient light indicators and notifications in a video game environment.
- Chapter 5 describes experiment one, where participants use LightPlay to navigate a video game environment to locate targets for selection.
- Chapter 6 describes experiment two, where participants use LightPlay to react to colour coded information.
- Chapter 7 describes potential uncaptured benefits, and possible system limitations.
- Chapter 8 concludes by summarizing our work and discussing future work.

Chapter 2

Background and Related Work

We look at previous literature regarding ambient light for information systems to explore their effectiveness for alerting and delivering information to users across different applications. We then focus on the current landscape of ambient lighting being applied in a video game context. Furthermore, we explore how information can be coded through light to solidify the efficacy of ambient light information systems. Finally, we look at the negative effects of screen clutter to outline one of the primary benefits ambient light systems provide when coupled with a digital display.

2.1 Ambient Light for Information Systems

Lund and Wiberg define ambient displays as "displays that unobtrusively convey information to users, without requiring the user's full attention" [6]. Ambient light has the ability to display information in the user’s periphery, providing a method of conveying information to the user with minimum interference to a primary task [10]. Graphical User Interfaces (GUIs) require constant central vision attention and occupy valuable screen space. By displaying information through the periphery of awareness, instead of GUIs, ambient indicators are able to take advantage of our background processing abilities [18]. In addition, ambient lights have the inherent capability of being adjustable for the level of disruption and visibility most effective for the user [20]. As such, researchers have explored ambient light for developing systems that deliver information updates in an unobtrusive and personalized manner.

Ambient displays can be useful in situations that require a large amount of cognitive resources, such as driving [15]. Information placed on external navigation displays in vehicles cause drivers to glance frequently to updates causing distractions while driving [19]. Matviienko et al.’s NaviLight investigated ambient light displays for turn-by-turn navigation in cars by offering directional information via ambient lights on the steering wheel [21]. The effectiveness of the ambient light system was compared with a GUI displayed on-screen behind the steering wheel. Results showed that NaviLight not only lowered driver distraction but can be effectively used to aid in-car navigation tasks.

While there are multiple instances of ambient light displays being used to convey information [22, 23, 10], we focus on examples where ambient light systems are used in conjunction with high resolution displays. Müller et al.'s Sparkle is an ambient light display for dynamic off-screen points of interest used in combination with a tablet computer [11]. Sparkle used LEDs placed around the edge of tablet to display colour encoded information. The authors explored multiple methods of encoding directional information such as brightness to represent distance. Results showed that Sparkle reduces a user's workload and is competitive to state-of-the-art on-screen display techniques for off-screen points of interest. The authors argued that the main benefits of Sparkle provided included: the peripheral perception and ability to attract attention, reduced amount of information on the display, and that information could be interpreted easily and fast.

Müller et al. created Ambient Timer, an ambient light system to unobtrusively remind users of upcoming tasks [24]. LEDs were set on the back of a monitor to display dynamically changing colour codes to indicate how much time was left until the next task. Results showed that a change between complementary colours (green and red) seemed better than a change between neighbouring colours (green and orange). Overall, the authors found that the system helps users understand when they should finish a task in an unobtrusive way.

Perteneder et al. looked at using ambient light to enhance large interactive surfaces [12]. The authors fitted LEDs around the edge of a large interactive whiteboard to display alerts. On-screen indicators were compared against the ambient light system, testing metrics such as recognition rate between different ambient light patterns (blinking, static) across different distance positions. Results showed that recognition rates for ambient light were at least as good and in some conditions better than on-screen indicators. The authors also looked at testing ambient light in off-screen search tasks, comparing against established off-screen visualization techniques such as wedge and halo [1, 2]. Results showed that ambient light was on-par in terms of performance to these techniques and that users preferred the ambient light. Although this study may appear to be similar to our work Perteneder et al. did not look at reaction times to the appearance of notifications, but studied recognition rates. They did this by instructing participants to audibly name one of eight distinct positions (top-left, left, bottom-left, top, bottom, top-right, right, bottom-right) where a notification was once it was noticed. Indicators lasted for 3 seconds and if the user managed to identify it during that time period it would be counted as a recognition count. The authors also do not address any type of error rates associated with their notifications and the information they conveyed.

Although Perteneder et al. found that a blinking notification for their ambient light system performed better than a static version, we decided to use static indicators and notifications. This is because of our difference in screen size and its effects on detection. They used a large whiteboard with a width of 400 centimeters while we used a monitor with a width of 55 centimeters. In addition, the distance of the participant in the most comparable condition in their study is 160 to 200 centimeters away from the whiteboard, creating a situation where the viewing angle of potential notifications falls between 45 to 51 degrees, while in our study our participants are 50 to 80 centimeters away from the monitor, allowing indicators and notifications to be seen in a viewing angle between 19 to 24 degrees. This is significant as there is considerably less rod cells in that region to support motion detection in their study environment when compared to ours (Figure 2.1). The reason why Perteneder et al. used blinking notifications was to refresh the appearance of sudden change in order to improve their ability to be noticed. However, our pilot studies indicated that there were no issues in recognition rates for our study environment. In addition, depending on the frequency, blinking may be detrimental to our indicators that are used for target direction; the user may lose track of a target location between blinks.

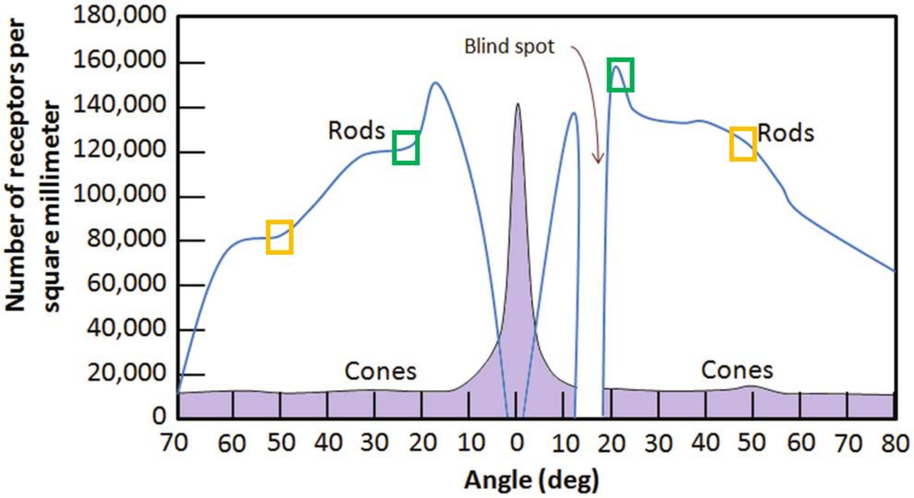


Figure 2.1: The number of rods and cones available across viewing angles [55]. Green boxes indicate range in which our study falls under while orange boxes indicate range in which Perteneder et al.'s study is in.

Matviienko et al. provides a systematic overview of 72 ambient light systems from 66 papers between 2000 and 2015. Out of the 72 systems 23 were categorized under the notification information class, defined as shows information that grabs the user's attention. None of these 23 notification systems that were combined with a digital display looked at reaction time and error rates of notifications between an on-screen and ambient light condition. In addition, none were done in a video game context.

2.2 Ambient Light for Video Games

Ambient lights have been used with video games but current applications are primarily for aesthetic extensions. Products such as Hue 2 by NZXT and Hue Sync from Philips both use LED strips to sync with media being displayed on the monitor, in order to extend the predominant colours as ambient light [14, 25, 26]. These products attempt to improve immersion and are not designed to deliver dynamic information.

Jones et al. created a proof of concept system called IllumiRoom; it utilizes a projector and a Microsoft Kinect to augment the area surrounding a television screen with projected visualizations for video games [5]. IllumiRoom takes advantage of the projector's ability to display detailed graphics to enhance a player's experience. For instance, motion flow can be emulated through the peripheral appearance of the game environment (i.e. snowfall being blown according to the movement of your in-game character). Although IllumiRoom may provide an effective method in displaying peripheral information for video games on televisions, it would be ineffective in a monitor setting due to user occlusion (i.e. user's body placement interrupting projections), high relative costs compared to LEDs, and calibration complexities.

Xiao et al. explored using LEDs in combination with head mounted displays such as Virtual Reality (VR) headsets and augmented reality (AR) headsets to extend the perceived field of vision, and reduce simulator sickness [28]. Participants had varied responses such as the LEDs were too bright, while others found it hard to see cues. The authors concluded that the system could be configurable to user preferences and improve the experience. In addition, they believed that a promising area of research would be to integrate peripheral flicker notifications onto the LED displays.

2.3 Information Coding for Ambient Light Systems

Light has the ability to convey different types of information through multiple parameters such as colour, brightness, saturation, and frequency of duration [29]. The encoding of these parameters would be used in ambient light systems to display information in the periphery. Thus we need to look at the effectiveness of these indicators in the context of peripheral vision. Peripheral vision depends highly on rod cells of the retina while our central vision utilizes cone cells to function. Rod cells are more sensitive to light and movement compared to cone cells [27, 30], meaning that brightness and frequency of duration would be important parameters in an effective ambient light system.

Matviienko et al. found that the most common parameters of light for ambient light systems that are used for encoding are colour, brightness, LED position and temporal aspects [8].

Our system LightPlay, along with other ambient light systems [11, 28, 12, 20] is able to take advantage of brightness settings independent of the host display. As such, users have the potential to optimize these systems by adjusting to their personal configurations. In contrast systems that are based on-screen can adjust gamma of indicators but are limited to the brightness settings of the actual display.

Colour is another characteristic of light which can be used for encoding information. The cone cells of our visual system have three colour-opponent channels: red-green, yellow-blue, and black-white. Colours that are most easily distinguishable are those that are at the ends of each of the colour-opponent channels [31]. So red, green, yellow, blue, black, and white are all candidates for distinct colour coding of information. However, the retina which supports peripheral vision does not have many cone cells and thus lacks sensitivity to colour [30]. As such, there will be challenges in effectively conveying colour coded information via ambient systems which depend on the periphery.

2.4 The Effects of Data Density on Displays

A prime advantage of using ambient systems to convey information in the periphery is reducing data density on the display. With this in mind, we look at past research on data density on displays to examine the positive effects of removing clutter from the screen.

Moacdieh et al. looked at data density on displays and its effects on user performance. They found that high data density degrades performance with higher errors rates and longer response times [32]. User experience is also affected by data density on displays; it negatively influences perceived usability and perceived aesthetics [33]. Ambient light displays allow information to be displayed in the periphery instead of requiring a user’s focused vision, thereby minimizing interference to a primary task [10].

In video games, many events can happen outside the player's field of view. Traditional strategies to help players navigate the environment and find objectives include directional cues such as arrows, compasses, markers and maps [9]. Although useful, these types of indicators can impair user visibility since they occupy valuable screen real-estate [9].

Chapter 3

Applications and Design Space

We outline possible applications and design spaces that utilize an ambient light system. In particular we address video game generalization, accessibility, variations of information coding, and a mixed system approach.

3.1 Video Game Indicators and Notifications

LightPlay was designed for indicators and notifications in video games; in particular the first-person point of view with traditional indicator placements (i.e. behind player – bottom of screen, in front of player – top of screen). However, because of the similarity of indicators and notifications across various games and player point of views, LightPlay could potentially be used as a gaming peripheral across multiple video game genres and titles (Figure 3.1 & Figure 3.2).

Figure 3.1: Video game *PUBG Mobile* [40], third person view with indicator of enemy in front of player.

Figure 3.2: Video game *Gear.Club* [41], third person view with indicator of 6th place behind.

3.2 Improving Video Game Accessibility

Addressing accessibility is an important issue in video games [57]. Although LightPlay was not specifically created as an accessibility tool, we believe that it can assist video gameplay for those that suffer from hearing loss or colour blindness.

When a video game relies solely on audio to convey in-game information to the player it inadvertently creates an accessibility barrier. Imagine a game where an enemy was approaching you but the only indication of their action is footstep sounds. For instance, in the early levels of the video game *Destiny* you need to fight groups of enemies in the dark requiring the player to listen closely for nearby enemies. A deaf games critic that attempted to play this level said*, "I died about 15 times before I realized I wouldn't be able to do that part. Being that it was maybe an hour into the game, I'd just wasted $60."* [39]. LightPlay could prove to be an accessibility tool by providing visual indicators that convey in-game information independent from existing heads up displays.

Players that are legally blind with low vision may still be able to see on-screen media with corrective lenses but it will still appear unclear. As such these players will have a difficult time noticing appearances of indicators or keep track of on-screen metrics such as health points. LightPlay could independently provide brighter and larger indicators to assist with noticeability issues. In addition, different representations of the in-game HUD could also be placed on LightPlay so that they can expressed more effectively for low vision players. For instance, a player's health points could be represented by a horizontal bar of red LEDs along the bottom of the screen.

LightPlay could also be used to assist those with colour blindness. Red–green colour blindness is the most common form of colour blindness [34] and unfortunately many damage indicators are depicted with red colours. As such, colour blind players may not be able to respond to such indicators as effectively. Certain games have implemented colour blind modes but not all of them will have a wide range of colour blind support. LightPlay could potentially allow these players to configure and map in-game indicators to accommodate their type of colour blindness.

3.3 Variations of Information Coding

As mentioned in related works, there are multiple methods of conveying information with light. Here we outline some possible applications of different types of ambient light indicators for video games.

Size of indicator (Figure 3.3): The number of LEDs lit defines the size of the ambient light indicator. This property could allow for expressions of proximity and importance. For instance, targets and objectives which are closer to the player can be expressed by a larger sized ambient light indicator. In contrast attempting to implement such a mechanic on-screen would be detrimental to screen real estate and clutter.

Colour of indicator (Figure 3.3): Again colour could be used to convey information about the proximity of a target. Certain colours could be associated with different types of objectives or enemies (i.e. red for an end of level boss while blue is for in-game power ups).

Figure 3.3: LightPlay implementation of size and colour of indicator to represent proximity.

Colour could also be used for to convey y-axis navigation information. Particular colours could be mapped to height. Harrower and Brewer [37, 38] looked at how colour palettes similar to those used to represent map altitudes could be applied to represent sequential data (Figure 3.4) Coloured indicators could therefore be explored to convey exact locations of objectives and targets in a 3D virtual environment.

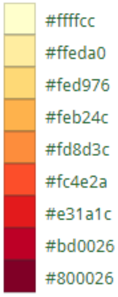


Figure 3.4: Colour palette created from Harrower and Brewer’s online tool [43].

Frequency of indicator: The frequency in which LEDs fluctuate between on and off can be used to simulate movement. Meschtscherjakov et al. [36] looked at the ability of LED strips to adjust perceived velocities in a vehicle. The authors found that reducing brightness or the frequency of an apparently moving stimulus reduces its perceived velocity. When applied to video games this type of indicator could provide information such as movement speed.

3.4 Mixed System Approach

A combination of both an ambient light system and traditional on-screen methods could be implemented. Extending on-screen indicators onto an ambient light system allows for information to be expanded. For instance, on-screen damage indicators could convey an enemy’s location while additional information about an enemy could be displayed through ambient lights (i.e. enemy health). A mixed system approach permits greater information presentation without consuming screen space.

Chapter 4

System

We created LightPlay, a prototype utilizing ambient lights to convey in-game indicators and notifications, to test if an ambient light system is a viable replacement for traditional on-screen methods. We build on previous ambient light system implementations and adapt their designs to our use case.

4.1 Hardware

We used a WS2812B individually addressable LED strip for its ability to be programmed such that we can turn on target LEDs. The LED strip is mounted along the back border of a BenQ GW2470ML full HD 24 inch screen monitor, with a total of 102 LEDs used. To control the LEDs we used an Arduino UNO microcontroller. Due to the power requirements needed for the amount of LEDs used a 5V 10A Power Supply Adapter was fitted for external power (Figure 4.1). In order to control the Arduino via software developed on Unity, we utilized serial communication through a USB connection to the computer.

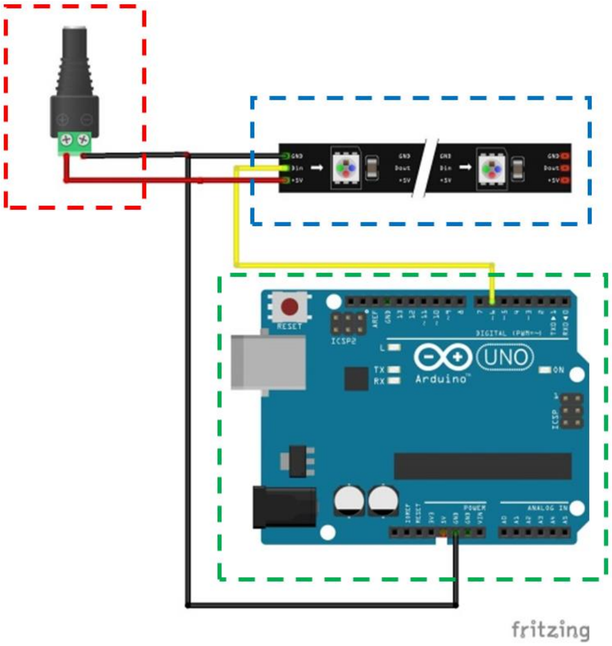


Figure 4.1: Visualization of Arduino setup. 5V 10A Power Supply (dotted red box), portion of LED strip (dotted blue box), Arduino UNO microcontroller (dotted green box) [56].

Initial pilot testing identified that if we situated the monitor in front a white wall the LEDs would have a higher intensity because of reflection. This also meant that any slight angling of the monitor along with the system would produce inconsistent perceived brightness across the LED strip. As such, we decided to mount a white back board in order to accentuate the ambient light indicators as well as to maintain the consistency of perceived brightness for all the LEDs. For future work, a calibration of each LED so that they appear constant for monitor angle and wall colour could be implemented.

4.2 Software

We developed two separate programs for a Unity3D environment that communicated with an Arduino script so that events in Unity could be used to trigger LEDs via the microcontroller.

Software Implementation for Experiment One

The software implementation for experiment one involves using positional indicators to represent points of interest in the first person camera view. The indicators will update as the player aims, so the position of the indicator will adjust smoothly at a rate of around 0.1s as the player moves their view. Further details will be outlined below.

Our custom built Unity program emulates traditional indicator outputs in first-person camera view video games; top of the screen indicating objectives in front of the player (Figure 4.2), bottom of the screen for behind the player, left of the screen for the left of the player, and right of the screen for the right of the player (Figure 4.3).

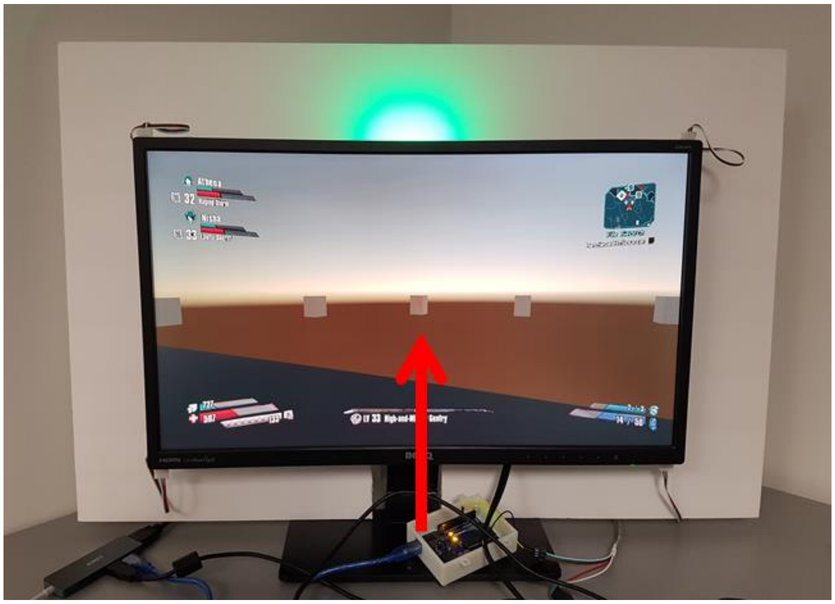


Figure 4.2: Ambient light indicator providing information on an objective in front of the player.

Figure 4.3: Ambient light indicator providing information on an objective to the right of the player.

Our Unity program makes calculations to map points of interest to the LED strip. The angle of the points of interest relative the player's direct front camera view is used to calculate which side of the monitor the indicator should appear on (left, right, top, bottom). If the point of interest is in front of the player then the indicator is adjusted to be represented on the bottom of the monitor, and vice versa with behind the player. After determining the appropriate monitor side the angle is then mapped to the number of LEDs available on the corresponding monitor side (left and right have 19 LEDs available, top and bottom have 32 LEDs available). Finally, this information is communicated to the Arduino and the appropriate LED is turned on along with two adjacent LEDs to produce the ambient light indicator, in total three LEDs are used to produce each ambient light indicator. The same calculations are made for on-screen indicators but instead of communicating to the Arduino an on-screen representation of the indicator is displayed. In addition, the number of possible positions for the appearance of an on-screen indicator followed the number of LEDs available for the ambient light (102). This helps ensure that there is no additive accuracy advantage due to pixel density while using on-screen indicators. These calculations are updated as a repeating function every 0.1 seconds so that the indicators dynamically update as the player aims.

To emulate an on-screen version of the ambient light indicator a green shape with varying gamma brightness was used. Perteneder et al. used a smaller indicator for their experiment arguing the indicator simulated practical use cases (Figure 4.4), "*...Ambient Light undoubtedly stands out more. Due to the use of different technology, its visual footprint is larger. However, we decided not to mimic the visual foot-print of the ambient light in the On-Screen Notifications as notifications of this size would be hardly used in a real world application where it is important and common practice to conserve limited display space*" [12]. However, we believe that to better compare the effectiveness of on-screen and ambient light indicators we needed to more closely replicate the ambient light (Figure 4.5). Furthermore, video game indicators such as those that depict damage are generally large relative to the display.

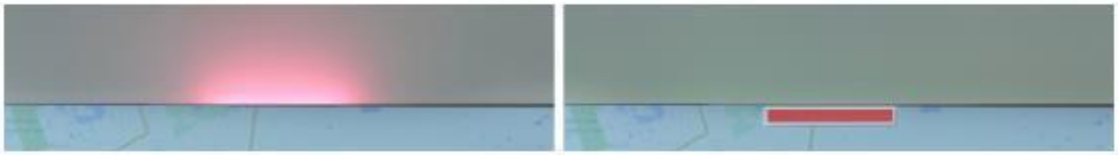


Figure 4.4: Indicator implementations from the study by Perteneder et al. ambient light (left) and on-screen indicator (right).

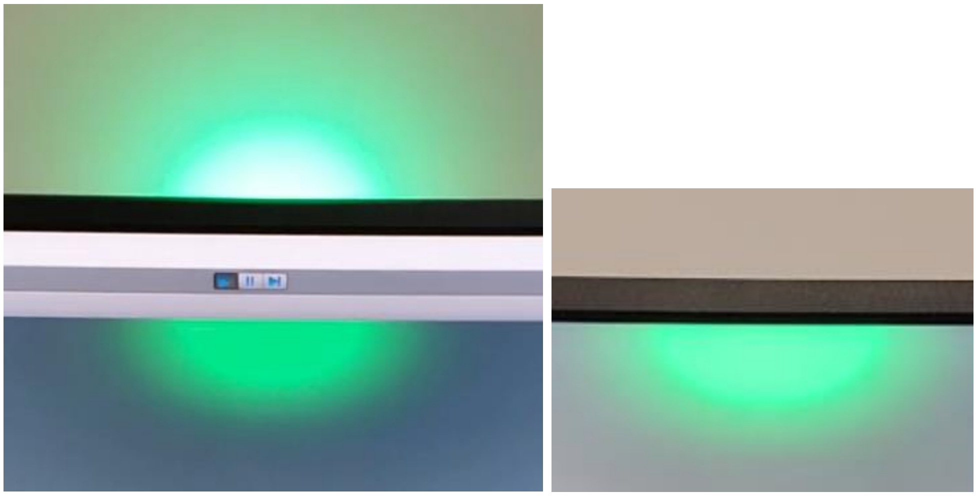


Figure 4.5. Comparisons of our implementation of ambient light (top left) and on-screen indicator (bottom left). During the experiment the on-screen indicator would be right against the monitor bezel (right). A better comparison picture was unable to be taken due to Covid-19.

The audio condition was implemented with Unity's audio spatialization API, converting provided sound clips into 3D sound. Each target in experiment one had the same spatialized 3D audio source and the current target would emit the sound. As such, we chose an arbitrary consistent sound [47] and played it on loop for our audio indicator. Gonot et al. also chose city sounds that had audio spatialization implemented, instead of a custom sound made for navigation [48]. The authors' study had a first-person camera view navigation task in a virtual city using different types of sounds. In addition, a custom sound made for navigation would not appropriately represent the average video game.

Software Implementation for Experiment Two

The software implementation for experiment two involves using indicators to represent colour coded identification. Further details will be outlined in chapter 5.

The implementation details for experiment two are simpler than for experiment one. We used the same method in communicating information to the Arduino but instead of calculating positions we sent information regarding whether to turn all 102 LEDs either into a red, green, or blue colour. This communication is only made once per experiment trial.

Figure 4.6: Colour variations for ambient light (top) and on-screen (bottom) conditions. Blue variant (left), red variant (middle), green variant (right)

Chapter 5

Experiment One

The goal of this experiment was to compare the reaction time, selection time, error rate, and perceived workload, between on-screen and ambient light indicators in a first-person camera view video game environment. As mentioned before, an audio condition was compared in order to validate the use of visual indicators in general. We expected the audio condition to have comparable reaction times, longer selection times, higher error rates, and a higher perceived workload. We also expected the ambient condition to have lower immersion ratings compared to the other conditions because of novelty. We have considered the reduction in ecological validity when testing visual indicators without audio because the majority of video games have both available to players; more details will be provided in the limitations section.

5.1 Participants

We recruited 30 participants (17 males, 13 females) using posters posted around the University of Waterloo. The posters specified that participants must be 18 or older, and must not have epilepsy because of the potential seizure risk. Remuneration was $10. Participants' age and video game history were not collected; more details will be provided in the limitations section.

5.2 Apparatus

Participants were given control of a keyboard and mouse connected to the computer running the experiment. Participants were also given a Corsair Void 7.1 surround sound gaming headset when the audio condition began, participants were told to remove the headset after the condition. Asking the participant to wear the headset only for the audio condition may have been a possible threat to internal validity, more details will be provided in the limitations section.

5.3 Tasks

Simulated Game Environment

A 3D video game environment was developed in Unity to provide the testing area for the study. The player in this environment is similar to that of a player in a first-person shooter game. The participant used the provided mouse to control the player's aim movement in the first-person view; as such, the aim movement speed was constant and set by the mouse sensitivity (set at medium in Mouse Properties in Windows). Aim movement was unrestricted, meaning they could look at any direction in the 3D environment. However, the player's body was kept stationary. A static red coloured crosshair was also displayed in the center of the screen.

We emulated established practice stages across various first-person shooter games that are used for aim training to improve gameplay. Players in these practice stages regularly stayed in place and only aimed to shoot at targets while they appear around the environment (Figure 5.1). These targets can commonly be set to shoot back at the player.

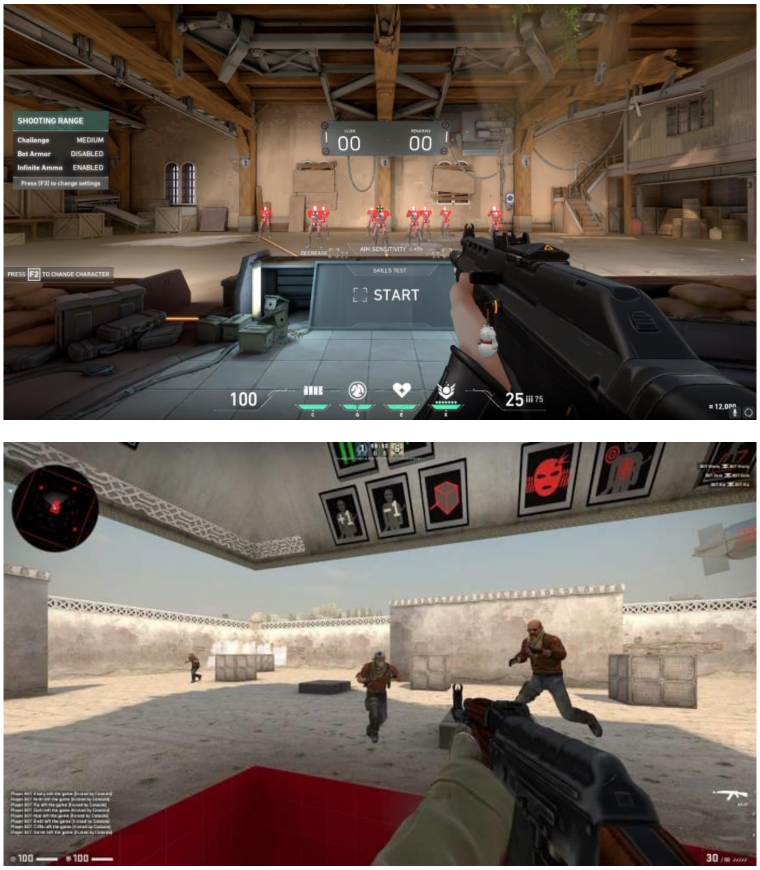


Figure 5.1: Aim practice stage in video games *Valorant* (top) [46] and *Counter Strike: Global Offensive* (bottom) [45]. Player stays in place while targets materialize to be shot at.

Many first-person camera view video games have HUDs (heads-up displays), thus to improve ecological validity an on-screen static user interface from the video game *Borderlands* was also placed to simulate a gaming heads up display (Figure 5.2). This also simulates possible screen clutter that occurs when on-screen indicators appear next to items on a HUD.

Primary Task

A primary task was used so that participants did not anticipate the appearance of an indicator. All units mentioned for the following are Unity game units. A stationary wall (4.9 by 10 units) with nine white stationary box targets (1 by 0.5 by 0.5 units) spaced 3 units across and 1.5 units on top of each other was placed 8 units in front of the player (Figure 5.2). One of the nine targets would be always highlighted with a black colour and participants were told to aim their crosshair with the mouse cursor to follow the currently highlighted box, similar to aiming a weapon in a first-person shooter. Once the crosshair crossed over the target box a new target would be highlighted and the previous target would be unhighlighted. After a random period of time between 5 to 10 seconds, the corresponding indicator for the current condition would appear (audio, on-screen, or ambient). Participants were instructed to immediately press the space bar when they realized an indicator had appeared, otherwise the primary task would continue. Once the space bar is pressed the primary task (wall and targets) will disappear and the secondary task would commence.

Figure 5.2: Primary task to prevent secondary task anticipation. Portion of static HUD (circled in red). Current target, highlighted in black colour (circled in blue). Crosshair (circled in green), subtle in figure.

Secondary Task

In the game environment, 16 white box targets (1 by 1.4 by 1 units) were placed evenly along the edge of a circle against the ground with a radius of 19 units. The player was in the center of the circle (Figure 5.3). Participants were instructed to use the current indicator to aim the crosshair and click on the correct target out of the 16 targets as quickly as possible. Targets were not highlighted so participants are dependent on the indicator for selection. The placement of visual indicators followed conventional representations in first-person shooter games; top of the screen indicating objectives in front of the player, bottom of the screen for behind the player, left of the screen for the left of the player, right of the screen for the right of the player, and all other positions are in between these mapped fields (i.e. a target behind the player on the left would have an indicator on the bottom left) (Figure 4.2 & Figure 4.3). To reiterate from the software implementation, the visual indicators will continuously update as the player moves their aim, so at any point of time and aim, the visual indicators will correctly represent the location of a current target. For instance, if the current target is behind the player visual indicators will be at the bottom of the screen, then as the player turns to aim at the current target the visual indicators will update at a rate of around 0.1s, finally when the player is aiming at the current target the visual indicators will be at the top of the screen.

The audio condition also plays the 3D sound until the current target has been clicked. The 3D sound offers the same directional update as the visual indicators. Meaning perceptions of where the sound originates will also update as the player moves their aim.

Each condition had 15 trials with each having its own single target. Targets were randomly chosen from a pool of available targets; the initial pool had all 16 targets available and once a target was selected it was removed from the pool. Pools were reset after each condition to its initial state. Progression to the next target would only happen when the correct target was selected. All other clicks would be considered errors.

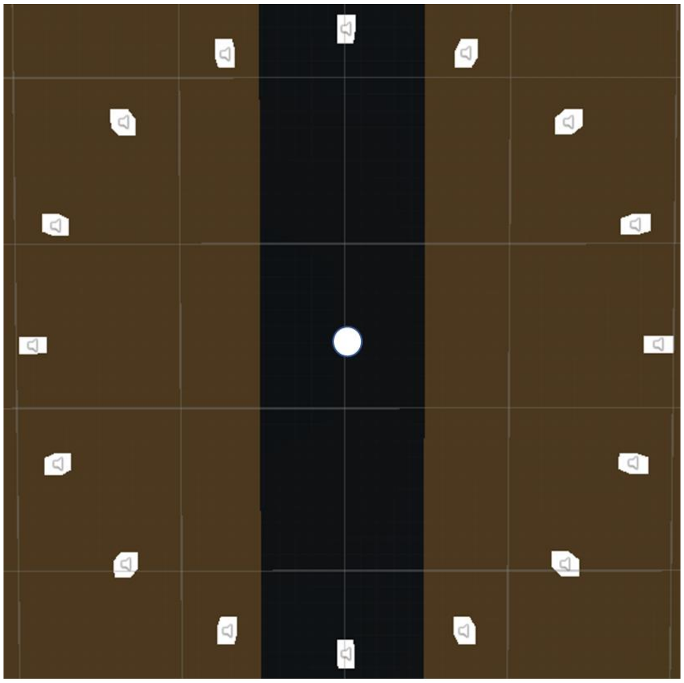


Figure 5.3: Aerial view of secondary task. Potential targets (white boxes) are evenly placed along the edge of a circle with a radius of 19 game units. Player (white circle) is in the center of the circle.

Figure 5.4: First-person view of secondary task with ambient light as the current condition. Player aims at potential targets.

5.4 Design and Procedure

This is a within-subjects design with three conditions: audio, on-screen, and ambient. The condition order was randomized for every participant instead of being counterbalanced, this may have introduced a possible threat to internal validity, more details will be provided in the limitations section. Target order in the primary and secondary task was also randomized.

To reiterate, we divide total speed performance time into two different segments, reaction time and selection time. Reaction time is defined as the time it takes for the participant to notice an indicator has appeared. Selection time is defined as the time it takes for the participant to complete a secondary task after noticing an indicator.

Data was recorded for both reaction time and selection time. When the indicator appears, reaction time will start recording. Once the participant has detected the indicator and has responded by pressing the spacebar, reaction time will stop recording and selection time begins. Once the participant has successfully clicked on the correct target, selection time finishes recording (Figure 5.5).

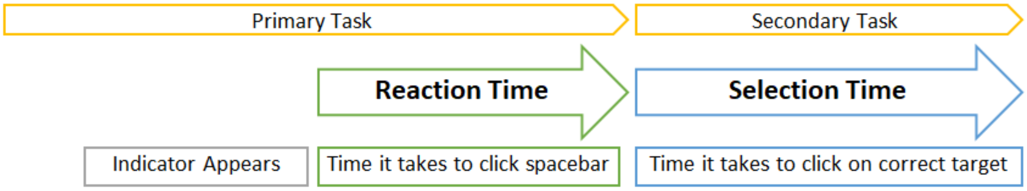


Figure 5.5: Timeline of reaction time and selection time in regards to primary and second task (arrows). Descriptions of participant actions (boxes on the bottom).

In summary: 3 Conditions x 15 trials per condition = 45 data points per participant

The ambient lighting system and tasks ahead were all explained to the participant before they started. In addition, before each condition the researcher and an instructional screen described the upcoming indicators again. After each condition participants completed a standard NASA-TLX questionnaire [44], and were told to only consider the secondary task for their answers. Finally, after the study participants completed a questionnaire, again being told to only consider the secondary task for their answers. The study lasted approximately 30 minutes.

5.5 Results

The first two trials from each condition were removed to account for learning of the indicator (13% of total raw data). The raw data is then aggregated by mean for analysis. There was one participant who had an aggregated audio trial time 3 standard deviations from the mean for both reaction and selection time. This may have been due to a hearing issue or volume error. As such, all data for that participant was removed for consistency (3.3% of total raw data). A Kolmogorov-Smirnov test determined that the assumption for normality was violated in all three conditions ($p < 0.05$) and, as such the Friedman test was used for analysis. For the post-hoc analysis we used the Wilcoxon Signed Rank tests with Bonferroni corrections. We use box plots to display the medians because our data is non-parametric. All notches on box plots indicate a 95% confidence interval.

Reaction Time

A Friedman test showed a significant difference between the conditions ($F_r = 16.34$, $p < 0.001$). Post-hoc tests showed that there were significant differences between audio and on-screen ($W = 106.0$, $p < 0.05$, $r = -0.51$) as well as between on-screen and ambient ($W = 87.0$, $p < 0.01$, $r = 0.60$). However, there was no significant difference between audio versus ambient. Overall for reaction time, ambient was 17.5% faster than on-screen, and audio was 12.5% faster than on-screen (calculated from $1 - (\frac{faster\ time}{slower\ time})$) (Figure 5.6).

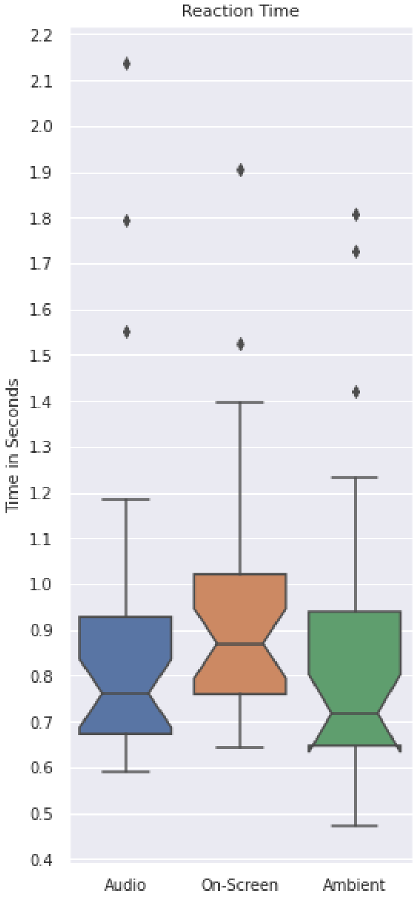


Figure 5.6: Reaction time by condition.

Selection Time

A Friedman test showed a significant difference between the conditions ($F_{\text{r}} = 43.66$, $p < 0.001$). Post-hoc tests showed that there were significant differences between audio and on-screen ($W = 0.0$, $p < 0.001$, $r = 1.0$) as well as between audio and ambient ($W = 0.0$, $p < 0.001$, $r = 1.0$). However, there was no significant difference between on-screen and ambient. Overall, ambient light and on-screen were both faster than audio in terms of selection time by 59.4% and 63.0% respectively (Figure 5.7).

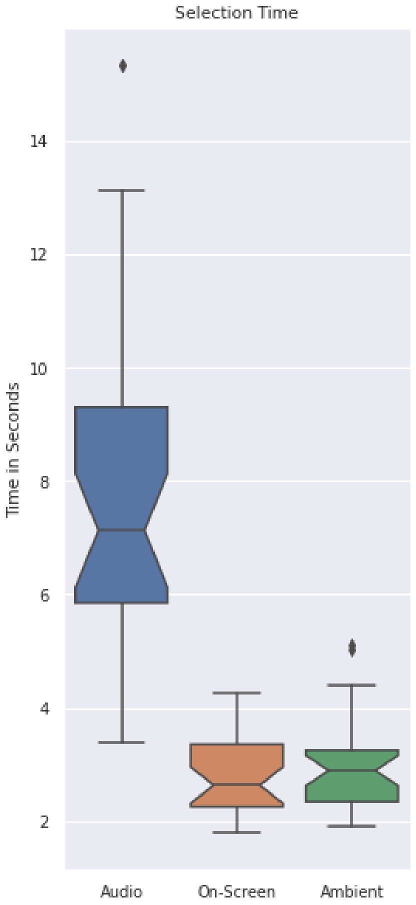


Figure 5.7: Selection time by condition.

Total Time

A Friedman test showed a significant difference between the conditions ($F_r = 44.34$, $p < 0.001$). Post-hoc tests showed that there were significant differences between audio and on-screen ($W = 0.0$, $p < 0.001$, $r = 1.0$) as well as between audio and ambient ($W = 0.0$, $p < 0.001$, $r = 1.0$). However, there was no significant difference between on-screen and ambient. Overall, ambient light and on-screen were both faster than audio in terms of total time by 52.8% and 52.6% respectively (Figure 5.8).

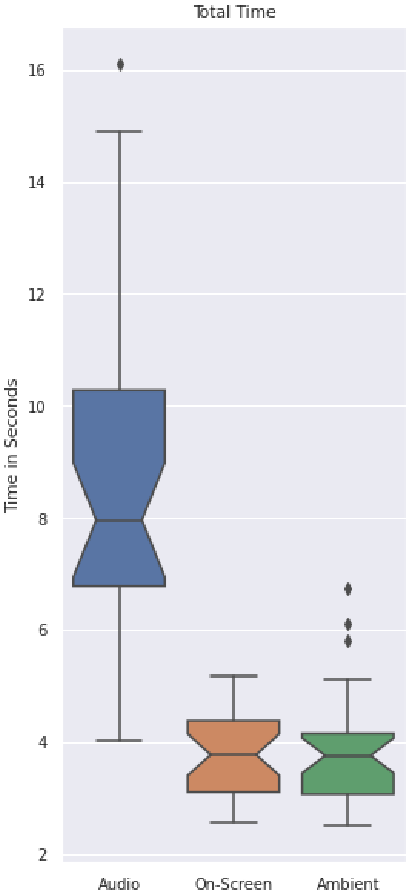


Figure 5.8: Total time by condition.

Target selection errors

The audio condition yielded a median target selection error percentage of 60%. The on-screen condition yielded a median target selection error percentage of 0%. Finally, the ambient condition yielded a median target selection error percentage of 0% (Figure 5.9). A Wilcoxon-signed rank test showed that audio has a significantly higher amount of incorrect clicks when compared to both the on-screen ($W = 0.0,\ p < 0.001,\ r = 1.0$) and ambient light condition ($W = 0.0,\ p < 0.001,\ r = 1.0$). There is no significant difference between the on-screen and ambient light condition.

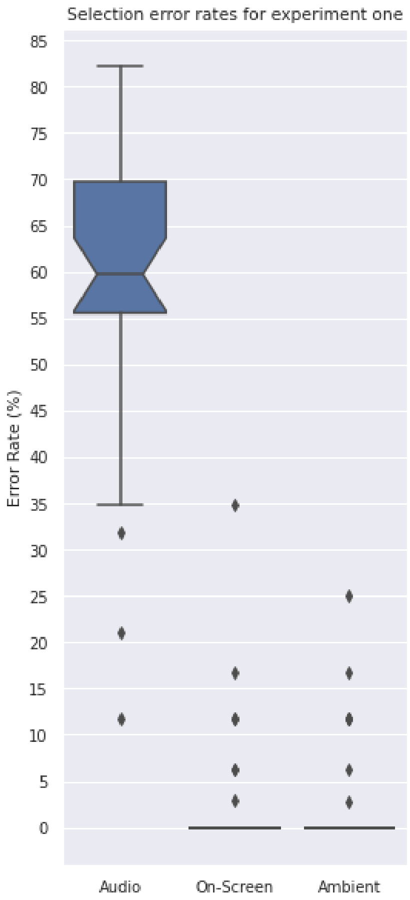


Figure 5.9: Selection error rates by condition.

Perceived Workload

Results from the NASA-TLX were compiled and analyzed. A Friedman test detected a difference for Mental Demand ($F_r = 25.52$, $p < 0.001$), Performance ($F_r = 40.91$, $p < 0.001$), Effort ($F_r = 18.70$, $p < 0.001$), and Frustration ($F_r = 22.75$, $p < 0.001$). Post-hoc tests using Wilcoxon Signed Rank showed that on-screen and ambient conditions resulted in significantly lower Mental Demand ($W = 31.0$, $p < 0.001$ and $W = 12.5$, $p < 0.001$ respectively), Performance ($W = 5$, $p < 0.001$ and $W = 0.0$, $p < 0.001$ respectively), Effort ($W = 26.0$, $p < 0.001$ and $W = 30.5$, $p < 0.001$ respectively) and Frustration ($W = 71.0$, $p < 0.01$ and $W = 23.5$, $p < 0.001$ respectively). There were however, no significant differences between on-screen and ambient conditions. Overall, visual indicators had lower levels of perceived Mental Demand, Performance, Effort and Frustration compared to audio. On average, visual indicators performed better than the neutral score. In addition, across all categories no on-screen scores were better than ambient ones signifying that the perceived workload of the ambient condition is not higher than on-screen (Figure 5.10).

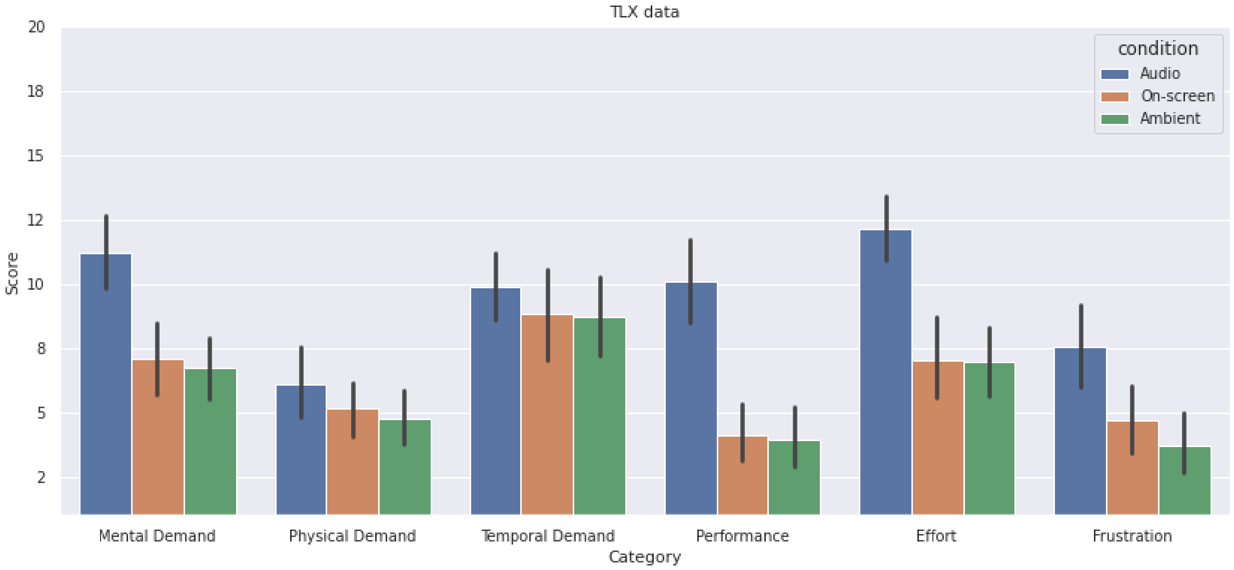
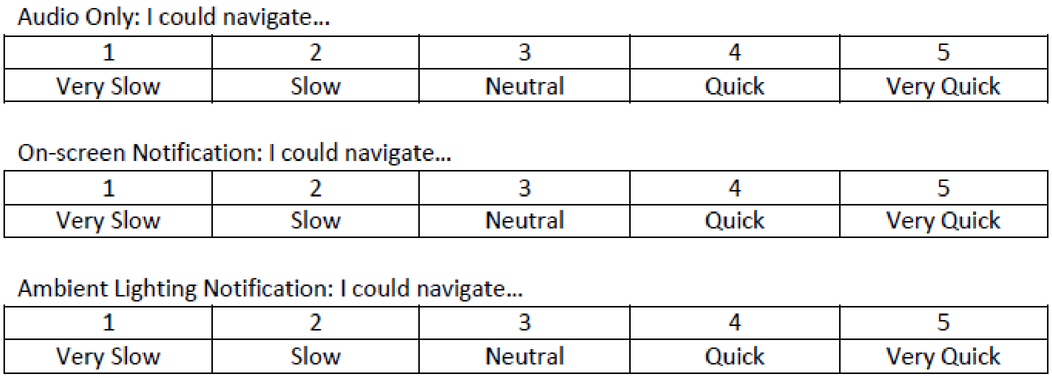


Figure 5.10: TLX data by category and condition. Error bars indicate 95% confidence interval.

Questionnaire Results

The post experiment questionnaire included ratings on navigation, immersion, and preference of indicator. Questions about navigation ability for each condition were asked with numbered options ranging from 1- Very Slow to 5- Very Quick (Figure 5.11). Audio scores had a mean of 2.1 and median of 2, on-screen scores had a mean of 4.2 and median of 4, and ambient scores had a mean of 4.3 and median of 4. Overall, participants rated audio as *slow* for navigation while on-screen and ambient were rated *quick*.



Audio Only: I could navigate…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

On-screen Notification: I could navigate…

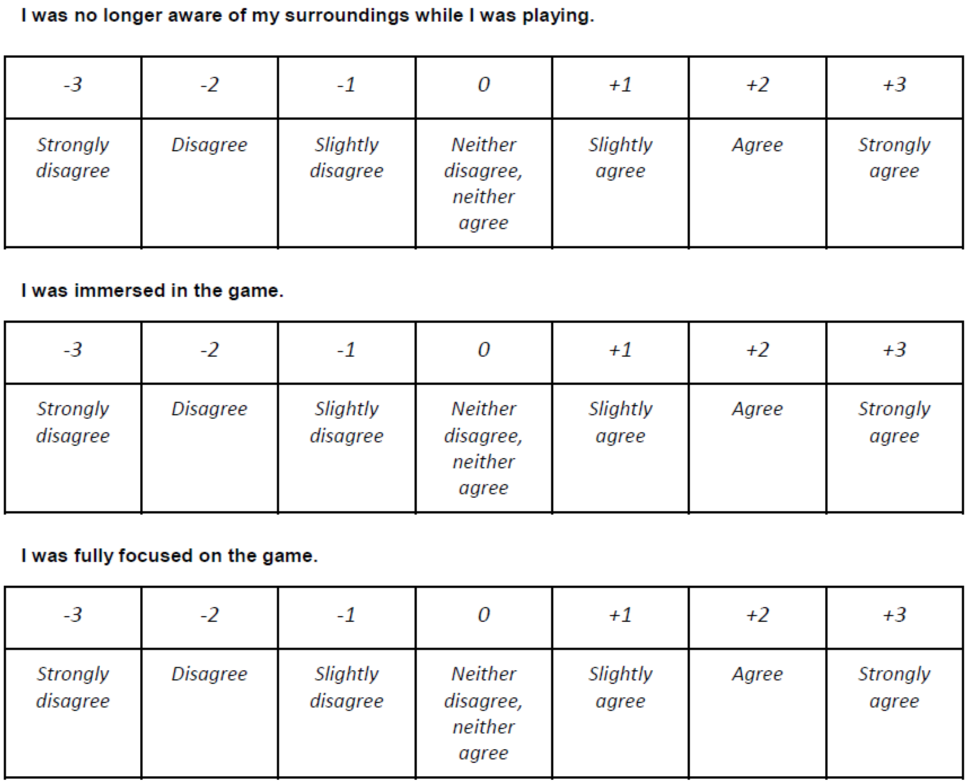
1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

Ambient Lighting Notification: I could navigate…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

Figure 5.11: Portion of post experiment questionnaire asking about navigation ability among conditions.

Questions about immersion for each condition were asked with levels of agreement (Figure 5.12). Table of aggregate scores below (Table 5.1). Overall, for *“I was immersed in the game”* and *“I was fully focused on the game”* in all three conditions, were between *slightly agree* and *agree*. For “*I was no longer aware of my surroundings while I was playing”*, ambient and on-screen were closer to neutral while audio was between *slightly agree* and *agree.*



I was no longer aware of my surroundings while I was playing.

-3	-2	-1	0	+1	+2	+3
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

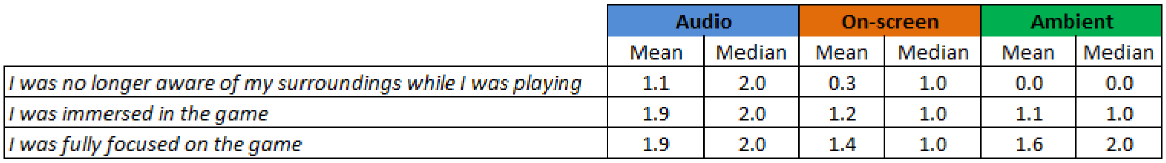
I was immersed in the game.

-3	-2	-1	0	+1	+2	+3
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was fully focused on the game.

-3	-2	-1	0	+1	+2	+3
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

Figure 5.12: Portion of post experiment questionnaire asking about immersion among conditions.



	Audio		**On-screen**		**Ambient**	
	Mean	Median	Mean	Median	Mean	Median
I was no longer aware of my surroundings while I was playing	1.1	2.0	0.3	1.0	0.0	0.0
I was immersed in the game	1.9	2.0	1.2	1.0	1.1	1.0
I was fully focused on the game	1.9	2.0	1.4	1.0	1.6	2.0

Table 5.1: Mean and median of scores from immersion questions in post experiment questionnaire.

Finally, for preference of indicator an open ended question phrased *"Which of these conditions did you like best and why?"* was asked. 16 participants indicated they preferred the ambient condition, 11 preferred on-screen, and 3 preferred audio. Out of the participants that preferred ambient 7 of them mentioned that they enjoyed the indicator because it was less intrusive and less distracting to the game.

Participant 14: *"I liked the ambient lighting condition best as I used my peripherals to see the light, which did not interfere or distract me from the game itself. I was able to indicate what to do without directly looking away from the boxes."*

Participant 17: "The ambient lighting. It was less distracting."

Participant 28: "The ambient light because it was very easy to find the required block while not taking up screen real-estate unlike the on-screen notifications (indicators)."

Participant 18: *"I like the condition of off-screen (ambient) lighting best because I could see the light in my peripheral, I didn't automatically focus on it like with the sudden on-screen lights."*

5.6 Limitations

To better test the effects of ambient and on-screen indicators for their ability to alert a player and assist with location of targets, we believed it would be better to isolate indicators on its own. However, as a result ecological validity was reduced as most video games are played with audio.

We should have noted participant ages, if participants had previous experience in first-person video games, and if participants had any visual or hearing impairment that would affect the experiment. Such information may have helped to understand why that one participant was an outlier.

By asking the participant to wear the headset only for the audio condition we may have introduced a threat to internal validity. The testing environment should have been the same across all conditions. As such, a better method would have been to ask the participant to wear the headset the entire time and only play sounds during the audio condition.

Randomization instead of counterbalancing did not offer an even distribution for ordering, as such order effects may have occurred. The frequency of orderings is listed in the table below (table 5.2). A Latin square design would have been more appropriate.

Order	Frequency
1-3-2	7
1-2-3	1
2-3-1	8
2-1-3	7
3-2-1	2
3-1-2	5

Table 5.2: Frequency of order appearance for Audio (1), on-screen (2), ambient (3).

5.7 Discussion

Although we expected the visual indicators to outperform audio we did not foresee how much better they would be in terms of the variables measured. The results show that audio is a poor performer as a directional indicator in this task. However, a sound clip made specifically for directional indication may have performed better but as mentioned before this would not be representational of a typical video game.

We expected ambient light to have lower immersion ratings compared to on-screen indicators due to its novelty and being a separate system. However, it seems that adoption of the ambient light system was quick and did not disrupt immersion any more than on-screen indicators.

There was a slight preference for ambient light relative to on-screen indicators but these preferences may shift more strongly towards ambient light if personal configurations are available to users. Participant 9 stated: *"...perhaps lower brightness since it was jarring when the light popped up"*. The independence ambient light indicators offer compared to on-screen ones allows for a wider range of potential improvements.

Halo and Wedge [1, 2] are considered state-of-the-art off-screen location visualization techniques. However, they are made for navigating a 2D space. That being said, our experiment, as well as many video games, have essentially mapped a 3D space onto a 2D representation when considering damage indicators. The reason why we do not use Halo and Wedge is because they are not prevalent in video games. Moura et al. [51] looked at 21 high-budget 3D video games (known as AAA titles) to explore navigation aids, none of the games used Halo or Wedge. This is most likely because of the amount of screen space required for Halo and Wedge to be effective in addition to convention.

Ambient lighting outperforming on-screen indicators in reaction time is an important result. It suggests that ambient lighting solutions could be considered over on-screen notifications when developing systems that have the purpose of getting a user's immediate attention. For LightPlay's purpose, a faster reaction time means that we can notice real-time events such as being damaged, quicker.

Overall, ambient lighting was able to perform as well or better than on-screen notifications, while returning screen real-estate and potential configuration flexibility to the user.

Chapter 6

Experiment Two

In this experiment, we compared total performance time, error rate, and perceived workload, between on-screen and ambient light colour-coded notifications in a first-person camera view video game environment. We measured total time as opposed to separating into reaction and selection time because of the nature of the task; this will be further explained later on. We hypothesize that by minimizing possible selection time in our total time we will see a significantly faster total time in ambient compared to on-screen. This is based off our finding from experiment one that showed ambient light could offer faster reaction time compared to on-screen.

6.1 Participants and Apparatus

We recruited 15 participants for this study, using posters posted around the University of Waterloo. 11 of the 15 participants had also completed experiment one, and participants' age was not collected; more details will be provided in the limitations section. The posters specifically mentioned that participants must be 18 or older, and must not have epilepsy because of the potential seizure risk. Remuneration was $10. Participants were given control of a keyboard connected to the computer running the experiment.

6.2 Tasks

Game Environment

We used the same video game environment in experiment one, and kept all controls and limitations the same. The only thing that was changed was the task and its implementation. We used notifications (convey event) in this experiment instead of indicators (convey direction). As mentioned in the software implementation for experiment two, the notifications will utilize the entire space allotted, for on-screen this means the entire edge along the display, and for ambient this means all 103 LEDs (Figure 4.6).

Primary Task

The primary task was used so that participants did not anticipate the appearance of a notification. This task was similar to the secondary task of the previous experiment. However, this time one of the 16 white boxes would be highlighted indicating it is a current target. The participant had to find the current target without any visual or audio indicators. Once the correct target box had been clicked a new random target box would be highlighted and the previous target would be unhighlighted (Figure 6.1 & Figure 6.2).

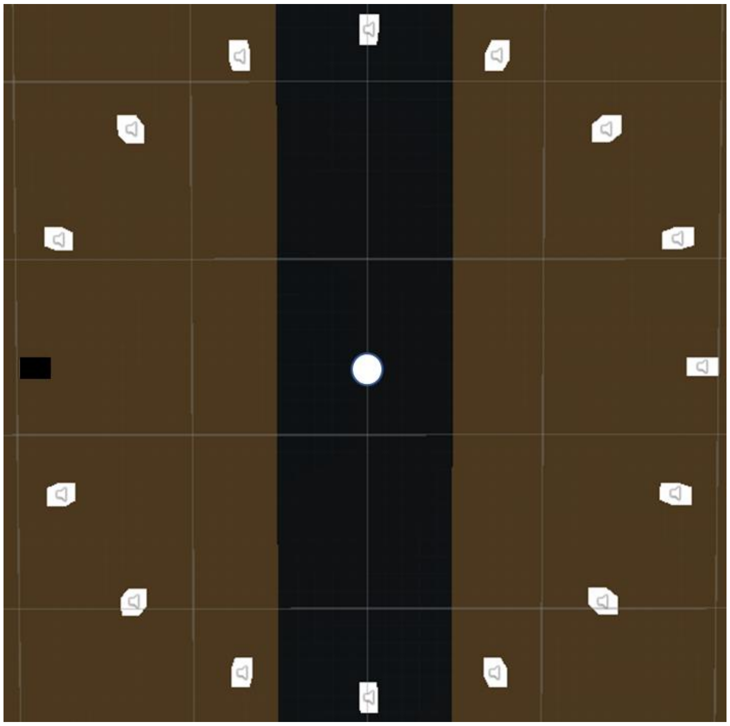


Figure 6.1: Aerial view of environment. Player (circle) is surrounded by potential target boxes (squares) with the current target highlighted by black for the primary task (middle-left box).

Figure 6.2: First-person view with visualization of what the notification would have looked like in the ambient condition (due to Covid-19 we could not get a picture).

Secondary Task

The participant would continue the primary task for a random amount of time between 3 to 6 seconds until a notification appeared that was randomly either: red, blue, or green (Figure 4.6 & Figure 6.2). Once the notification appeared the participant selected the corresponding colour on the keyboard (red = left key, green = up key, blue = right key), these keyboard keys were also covered with colour labels for easier identification. Any incorrect key presses were recorded as errors. The notification stayed on until the participant pressed on the correct key. After the correct key had been pressed the notification would turn off and the next trial would start again with looking for highlighted targets. Each condition had 30 trials.

6.3 Design and Procedure

This was a within-subjects design with two conditions: on-screen and ambient light. Each participant completed the primary and secondary task with each of these notifications. The condition order was randomized, resulting in 8 participants in condition one and 7 participants in condition two.

Due to the nature of the task, total time could not be split into reaction and selection time like experiment one. The entire time it took from the appearance of the notification to when the participant pressed the correct corresponding key was recorded as total time.

The ambient lighting system and tasks ahead were explained to the participant. Before each condition participants were introduced to the upcoming notifications by both the researcher and an instructional screen. After each condition participants were given the NASA-TLX to fill in. Finally, after the study participants were given a questionnaire. The study lasted approximately 30 minutes.

In summary: 2 Conditions x 30 trials per condition = 60 data points per participant

6.4 Results

The first two trials from each condition were removed to account for learning (6.7% of raw data). A Kolmogorov-Smirnov test determined that the data was normally distributed and a Mauchly’s test of sphericity indicated that the assumption of sphericity was not violated. We used repeated measures ANOVA (α =.05). The test showed no significant difference between the ambient and on-screen condition for total time (Figure 6.3). All notches on box plots indicate a 95% confidence interval.

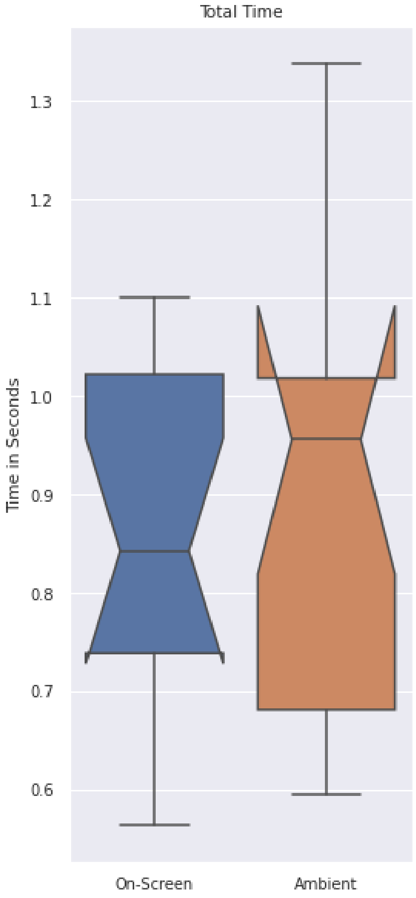


Figure 6.3: Reaction time by condition.

Target selection errors

The on-screen condition had a mean target selection error percentage of 7.5% with a median of 3.2% while the ambient condition had a mean target selection error percentage of 7.4% with a median of 3.2% (Figure 6.4). A Wilcoxon-signed rank test showed no significance between the conditions.

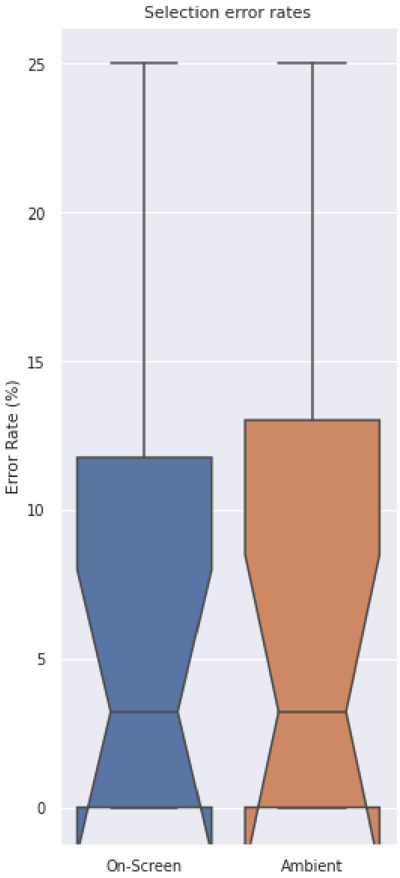


Figure 6.4: Selection error rate by condition.

Perceived Workload

Results from the NASA-TLX indicated no significant differences between on-screen and ambient light indicators (Figure 6.5). Both conditions scored below neutral across all categories for perceived workload.

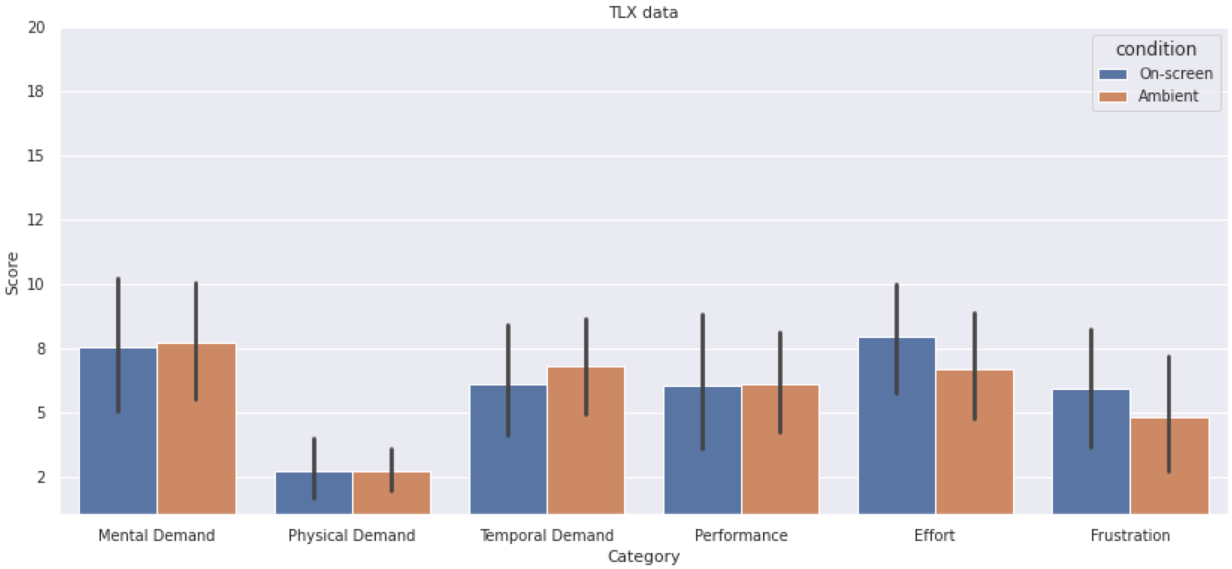
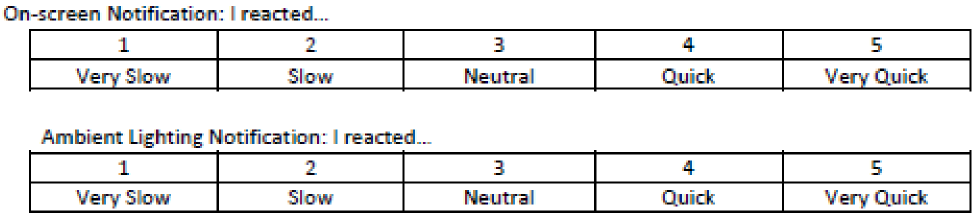


Figure 6.5: TLX data by category and condition.

Questionnaire Results

The post experiment questionnaire included ratings on perceived reaction time, immersion, and open ended questions on preferences. The immersion portion of the questionnaire was the same as experiment one (Figure 6.6 & 5.12). Overall, the ratings were similar between both conditions.



On-screen Notification: I reacted...

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

Ambient Lighting Notification: I reacted...

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

Figure 6.6: Question on perceived reaction time by condition.

In the questionnaire participants were asked *"Which condition did you enjoy the most? What made it enjoyable for you?"* 10 of the 15 participants indicated they enjoyed the ambient light condition more, with one participant indicating no preference. In particular, multiple individuals talked about how the ambient light condition offered a less distracting and natural experience.

Participant 7: *"I preferred the ambient condition because it was more pleasing to the eye and was less distracting. It allowed me to focus primarily on the main squares game"*

Participant 2: *"Ambient light, it felt more natural and immersive"*

Participant 9: *"the ambient one. The lights were not directly under the purview of my eye which made it easy to notice enough but was not too much of a glare"*

A follow up question to "*Which condition did you find allowed you to be the most immersed and why?"* was asked, "*For the condition you did not find as immersive, what changed would you make to make them more immersive for you?"* Results indicated that both on-screen and ambient lighting could be adjusted to fit users' personal preferences.

Participant 2: *"For on-screen light, maybe if area where the light pops up could be decreased and also it could be more integrated with the game."*

Participant 10: *"The regular lighting [on-screen] felt more harsh and somewhat unrealistic, while it felt like the ambient light was easy on the eyes"*

Participant 4: Referring to ambient light - *"Slightly softer lighting to make it less jarring when it's active"*

Participant 12: *"reduced intensity of ambient light - slightly too bright, defined shape or location of off-screen indicator"*

Although gamma could be adjusted in attempts to accommodate for brightness preferences of on-screen notifications, ambient light notifications offer a higher range of brightness adjustments independent of the host display.

6.5 Limitations

Having 11 of 15 participants from experiment one complete this experiment may have also been a threat to validity. However, the time between the two experiments was around four weeks and as such participants were less likely to remember experiment one when completing experiment two. Although learning effects are not likely as the tasks under analysis are different, preferences in the questionnaire may not be as representative as two separate experiments. Even though the indicators in experiment one were different from the notifications in experiment two, participants may have judged a condition based off a combination of both experiments instead of just experiment two. In addition, we should have noted participant ages.

While the HUD we visualized on the screen is not overly dense and is from a real instance, it could have impacted performance. On-screen notifications had slight overlaps with portions of the HUD (notification on top of HUD item). However, HUDs and overlaps with notifications are common in video games.

6.6 Discussion

The experiment showed that ambient light performed just as well as on-screen notifications in conveying colour-coded information to a user while again returning screen real-estate and potential configuration flexibility to the user.

Although experiment one indicated that reaction time is faster for ambient lights, this benefit did not cause a significant difference when considering total time in the second experiment. This may be because of our inability to effectively perceive colour in our peripheral vision [3, 30] thereby requiring participants to glance more directly towards the notifications before coming to a selection decision. It may also be the case that the time it takes to cognitively process decisions such as colour identification and selection significantly outweighs the time it takes to just notice the appearance of the notification. As such, the benefits from experiment one in reaction time may not have transferred over to this experiment.

Chapter 7

General Discussion

We outline uncaptured potential benefits and reflect on system limitations.

7.1 Uncaptured Potential Benefits

With the ambient lighting system users will be able to configure their own settings (i.e., brightness, colour). As such, performance gains along with system preferences have the potential to improve over what is suggested by these experiment results. An initial configuration task would help optimize settings for the user, such as a high brightness level. Optimizing on-screen settings may achieve performance gain but it may cause unwanted setting changes to the host display. In addition, settings such as brightness are limited by the host display while an independent ambient lighting system could provide a larger range. A system with automated adjustments based off the performance of the individual could further be explored.

7.2 System Limitations

Complexity of Information Conveyed

There is an inherent lack of information complexity available from ambient lighting. Information such as numerical notifications would be conveyed more effectively on screen. However, we believe that a mixed system approach would remedy such a situation. By utilizing ambient light to grab attention and on-screen notifications/indicators for dense data, there is potential to create a system which is effective at capturing user attention while offering complex information.

Another potential issue would be overlapping indicators for objectives that are behind each other. Although, many video games do not represent these overlapping targets with any distinctive indicators, for instance damage indicators would not convey information of multiple enemies shooting from the same location. However, if there is a need for distinction Perteneder et al. [12] found solutions such as using colour-codes in addition to physical separators in order to display alerts that would have otherwise covered each other (Figure 7.1).

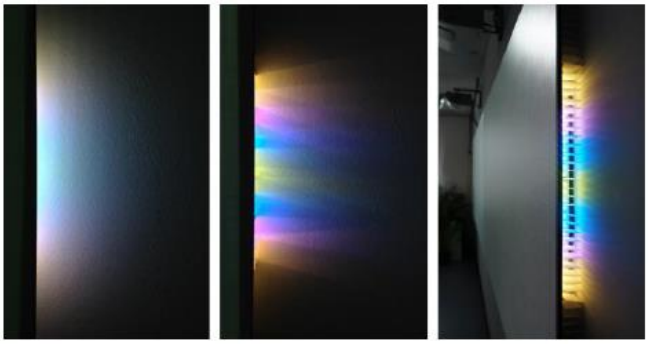


Figure 7.1: Separators for ambient light system implemented by Perteneder et al. [12].

Screen Size Generalization

We cannot generalize our results across all screen sizes (i.e. tablet, mobile). As screen sizes of displays shrink or users physically move further away from devices, indicators move away from the periphery and closer towards central vision. As mentioned before, in our experiments participants are between 50 to 80 centimeters away from the monitor, allowing indicators and notifications to be seen in a viewing angle between 19 to 24 degrees. These ranges of angles are within the near peripheral (Figure 7.2).

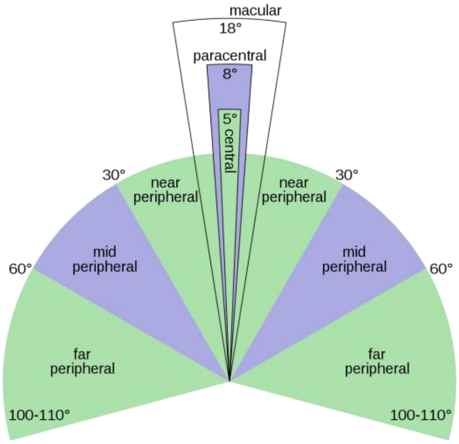


Figure 7.2: Viewing angles for central and levels of peripheral vision [42].

In addition, rod cells in the eyes that detect movement, along with cones that detect colour vary as the viewing angle changes. As such, certain devices that are fitted with ambient light indicators may not receive the same benefits as screens like monitors. For instance, Sparkle [11] used tablets for their implementation of ambient light indicators while Perteneder et al. [12]

utilized a large smart board; further research on performance across screen sizes could be explored.

Developer Cooperation

For LightPlay to be used with video games developers will need to supply information to map objectives and enemies to the system. Although difficult to adopt at first we believe that support for LightPlay as a video game accessory would provide players with a more effective, novel, and accessible experience, and as such would be commercially enticing.

Chapter 8

Conclusion and Future Work

We explored the viability of an ambient light system to display indicators and notifications in video games, as a replacement for on-screen methods. In particular, we compared reaction time, selection time, error rate, perceived workload and user preference, between on-screen and ambient light indicators and notifications in a first-person camera view video game environment.

Our first experiment shows that ambient light indicators provide 17.5% better reaction times while also performing at least as well as on-screen indicators across all other tested metrics. Our second experiment demonstrates that ambient light notifications perform as well as on-screen ones. In addition, participants seemed to prefer ambient lighting for the tasks.

Our work suggests further explorations into ambient light indicators across multiple devices with different screen sizes. As we have listed there are many potential applications for video games, such as different methods of coding additional in-game information.

LightPlay could also be applied to games with a top-down camera view that are often used in real-time strategy games such as *Starcraft* and *League of Legends*. Information such as identifying off-screen enemy locations for team members could be conveyed through an ambient light system as opposed to on-screen.

In particular, we believe that ambient light’s application for accessibility in video games is a vital area that should be explored. An ambient light system could allow people with accessibility issues to play or better experience certain video games.

Overall, LightPlay has shown the potential of ambient light systems to reduce occupation of screen real estate and allow users greater configuration flexibility for video game indicators and notifications. We believe that these results can assist designers and researchers in creating meaningful video game peripherals to enhance player experiences.

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Appendices

Appendix A: Post study questionnaire for experiment one

Appendix B: Post study questionnaire for experiment two

Appendix A: Post study questionnaire for experiment one

Base answers off second task only! Where you look and click boxes

Questionnaire

1. Rate the conditions on what you thought let you navigate the quickest to the slowest.

Audio Only: I could navigate…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

On-screen Notification: I could navigate…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

Ambient Lighting Notification: I could navigate…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

2. Rate the conditions on what you experienced to be the most immersive to the least immersive.

Audio Only: Rate on the scale.

I was no longer aware of my surroundings while I was playing.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was immersed in the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*

Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was fully focused on the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

On-screen Notification: Rate on the scale.

I was no longer aware of my surroundings while I was playing.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was immersed in the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was fully focused on the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

Ambient Lighting Notification: Rate on the scale.

I was no longer aware of my surroundings while I was playing.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was immersed in the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was fully focused on the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

***Participants were given enough space for fill their answers for the questions below**

1. How did the three conditions feel different from one another? Which of the conditions was most different from the others? Why?

2. Which of these conditions did you like best and why?

3. Which characteristics of the audio, on-screen, and ambient light indicator (colour, size, brightness/volume, etc.) would you have changed to improve your experience? Why?

Appendix B: Post study questionnaire for experiment two

1. Rate the conditions on what you thought your reaction time was when the indicator came up

On-screen Notification: I reacted…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

Ambient Lighting Notification: I reacted…

1	2	3	4	5
Very Slow	Slow	Neutral	Quick	Very Quick

2. Rate the conditions on what you experienced to be the most immersive to the least immersive.

On-screen Notification: Rate on the scale.

I was no longer aware of my surroundings while I was playing.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was immersed in the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was fully focused on the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

Ambient Lighting Notification: Rate on the scale.

I was no longer aware of my surroundings while I was playing.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was immersed in the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

I was fully focused on the game.

-3	*-2*	*-1*	*0*	*+1*	*+2*	*+3*
Strongly disagree	*Disagree*	*Slightly disagree*	*Neither disagree, neither agree*	*Slightly agree*	*Agree*	*Strongly agree*

***Participants were given enough space for fill their answers for the questions below**

3. Which condition did you find allowed you to be the most immersed and why?

4. For the condition you did not find as immersive, what changes would you make to make them more immersive for you?

5. Which condition did you find allowed you to quickly understand which color was being shown? If conditions felt the same just write “N/A”.

6. Which condition did you enjoy the most? What made it enjoyable for you?