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The Influence of Intrinsic Perceptual Cues on Navigation and Route Selection in Virtual Environments

# The Influence of Intrinsic Perceptual Cues on Navigation and Route Selection in Virtual Environments.

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# ABSTRACT

The principle aims of this thesis were to investigate the influence of intrinsic navigational cues in virtual environments and video games. Modern video games offer complex environments that may reflect real world spaces or represent landscapes from fantasy and fiction. The coherent design of these spaces can promote natural navigational flow without the requirement for extraneous guidance such as maps and arrows. The methods that designers use to create natural flow are complex and stratified utilising principles rooted in urban architectural design and navigational cues that are intrinsic to real-world wayfinding scenarios. The studies presented in this thesis analysed not only these commonly used architectural cues but also the potential for the reinforcing of these cues by the addition of lighting, visual and auditory cues. The primary focus of this thesis was a systematic and quantitatively rooted analysis of the impact lighting has on navigation and the levels at which variance in lighting makes a quantifiable difference to navigational choices within a virtual environment. The findings of this thesis offer clear guidance as to the influence that lighting has within virtual environments and specifies the thresholds at which the inclusion of guidance lighting begins to affect navigational choices and the levels that players become conscious of these cues. The thesis also analyses the temporal thresholds for the detection of changes in contrast, hue and texture within an environment. The relationship of other intrinsic cues such as the potential reinforcement or cue competition effects of both audio and other visual cues, for instance motion are quantitatively analysed. These data were reflected in the form of a series of heuristic design principles that augment those that underpin architectural and environmental design considerations by for instance suggesting levels of saliency for lighting cues or reinforcing existing cues via supporting audio guidance.

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# LIST OF ABBREVIATIONS

2D – Two dimensional

3D – Three Dimensional

SR – Stimulus Response

CGI – Computer Generated Imagery

FMV – Full Motion Video

HUD – Heads Up Display

GUI – Graphical User Interface

VE – Virtual Environment

FPS – First Person Shooter

RPG – Role Playing Game

MMORPG – Massively Multiplayer Online Role Playing Game

RTS – Real Time Strategy

QTE – Quick Time Event

VSTM – Visual Short Term Memory

UDK – Unreal Development Kit

# 1 CHAPTER ONE: INTRODUCTION

The video games industry - sometimes described more broadly as the digital entertainment industry (Bateman, 2007) – has since 2003 (D. Smith, 2004) generated greater revenues than the film industry, and is now worth over $100 billion (US) annually (DaSilva, 2016). From initial commercialisation in the early 1970's (Kent, 2002) to the present, the games industry has evolved from being a novelty or curiosity to a mainstream entertainment medium. The image of video games consumers being male adolescents is no longer the case, with video games being a very common pastime for people both male and female of all ages and across all continents (McDonald, 2017). Many advancements in the development of computer hardware and its associated processing speeds have been directly driven by the demands of the games market, graphics processing cards being an important technology that would not exist in their present form if it were not for the requirements of the gaming community (Donovan, 2010). The same is also true for the development of screen technologies, the current market for large ultra-wide monitors and 4k televisions is largely being driven by the demands of gaming rather than office use or consumption of traditional video-based media (Bethell, 2017).

Whereas artistic traditions such as sculpture, painting and theatre have had millennia to develop and even cinema has had over a century to mature and hone its craft, games have only existed for less than half of the time that cinema has and have become barely recognisable when compared to the crude offerings of the early 1970's. Figure 1.

**Figure 1. A comparison of video game graphics and game characters: Gun Fight (Midway, 1975) and The Last of Us 2 (Naughty Dog, 2017)**

The principles of game design are evolving rapidly, and the design challenges faced by modern designers require deep knowledge of design techniques that make their titles fun and compelling. As games have gotten larger and more complex, strategies for communicating the goals, aims, interactions and narrative have developed to meet the requirements of a more demanding audience. In order for the narrative of a title to flow in the manner the designer intended, the player must progress through the world in a structured and often essentially linear manner (S. Rogers, 2010; Schell, 2013). The methods employed by games designers that enforce these behaviours have shifted as video games have evolved from clear and obvious instructions either as text or as graphical pointers to subtle and subliminal nudges in the form of geometry, lighting, contrast and colour among many other techniques that guide the eye of the player (LaViola Jr, 2010). Despite these methods now being commonplace, the academic literature relating to this field in particular the effects of lighting is sparse (El Nasr, Niedenthal, Knez, Almeida, & Zupko, 2006; Knez, 2001; Knez & Niedenthal, 2008). This thesis seeks to explore the design knowledge required to inform decisions of how lighting in video games and similar virtual spaces can be employed to direct players by reinforcing path preference. Quantitative experimentation to ascertain which cues work at particular thresholds has not been undertaken. The work contained in this thesis seeks to address these issues, by the implementation of a suite of experiments that take aspects such as movement, spatial arrangement, contrast, audio cues and in particular real time lighting. The studies seek to identify how compelling each of these elements is in isolation, and when these cues are used in conjunction, whether cue competition exists and if so, the prioritisation of that cue competition.

Through a series of interlinked quantitative experiments based on cognitive models of human navigation, this cross-disciplinary thesis explores the nature and effectiveness of lighting and related intrinsic navigational cues in video games. It primarily focuses on mainly intrinsic, visual, and often subliminal cues used by designers to draw player's attention and motion towards areas of interest or through a game level, and explores areas of cue competition, thresholds and hierarchy.

An overarching aim of this thesis was to reflect the outcomes and evidence generated by these studies into a framework of design guidelines or heuristics that form the basis of an evidence-based approach to building intuitively explorable virtual environments.

## 1.1 BACKGROUND

Virtual Environments (VEs) from the perspective of this thesis are interactable three-dimensional computer generated spaces. These environments may be viewed either on a 2D screen or via a virtual reality headset; offering the viewer a stereoscopic three-dimensional and more immersive view of the virtual world. Such virtual environments while requiring a visual component usually have an associated audio component. They may even offer tactile feedback via the use of haptic controls, although in common usage haptic feedback is limited to little more than the mere vibration of a games controller or similar input device (Bala, 2016).

Current VEs offer rich, detailed environments; this detail enhances the believability of an environment. Held (2014) proposes that the strengths and advantages of VEs is that a strong sense of presence is evoked by the VE. Presence in these terms being defined as a subjective experience of feeling present in a particular environment (Baumgartner et al., 2008), while being physically present elsewhere. This theory can be correlated with Dalton's (2003) findings that in the statistical analysis of human movement in architectural spaces, it was demonstrated that there was little difference between directional choices made by people in either virtual on screen navigational tasks or real world navigational scenarios. This suggests that navigation in virtual environments that afford a strong sense of presence may yield results close to their real world counterparts.

### 1.1.1 VIRTUAL ENVIRONMENTS AND VIDEO GAMES

Virtual Environments are now commonplace (McDonald, 2017); a key driver for graphics processing hardware development and the primary usage of virtual environments is in video games. In purely financial terms, the video games industry has for more than a decade been the world's most financially successful entertainment industry (Nguyen, 2007). Video games are also arguably the most complex form of digital media, integrating the aesthetic traditions of cinema with the complex interactive narrative (Schell, 2013). The content that they contain crosses over animation, music and sound design to encompass elements from sequential art through the creation of three-dimensional worlds for players to explore. The immersion that modern games provide and the interaction required incorporates a blend of cognitive, perceptual and motor skills. The synthesis of these skills in relation to the game challenges come together to form a game-play gestalt (Lindley & Sennersten, 2008).

It is well documented that the processing power of computing devices increases at an exponential rate (Waldrop, 2016). Over the course of just a few decades, the graphical processing power of personal computing devices has allowed games developers to move from producing simplistic, almost abstract flat shaded three-dimensional environments to rich, complex worlds, with shading and lighting algorithms that are approaching photo-realistic quality. *Figure 2*

*Figure 2.* **Comparison of early games graphics (Sphere, Virtuality 1994) with current generation graphics (The Division, Ubisoft, 2014) and Star Wars Battlefront (Electronic Arts, 2015)**

As these virtual worlds have grown in scale and complexity, they have required a corresponding development of navigational guidance (Moura & El Nasr, 2015). Navigational instruction in video games can be as simple as having either text or graphical elements overlaid on top of the depiction of the virtual world, and designers utilise a very broad range of both graphical elements and guidance techniques to ensure the player does not become lost.

Embedded or intrinsic navigational guidance are now commonly used by game designers to suggest a path or direction to a player. Beyond simple architectural structure, or affordances such as doorways, ladders or stairs, designers utilise a very broad range of design features to aid player navigation these include lighting, colour, shading, sound and motion. These topics are explored in depth later in this chapter.

Once a navigational aid is implemented in a game title, it is often juxtaposed with and cross-influenced by other competing navigational modalities and therefore it becomes very difficult to specify precisely how influential any specific given cue is. For instance, many modern games now utilise lighting to guide the player through the environment (Mitchell, 2008). *Figure 3*, *Figure 4*. Despite this being commonplace, there is very little current literature that investigates in any depth; how, why and at what thresholds players make decisions based upon a variety of stimuli. It is commonly assumed that lighting does indeed act as a visual cue (Baron, Rea, & Daniels, 1992; Knez, 2001), but does that work in isolation? For instance, can an audio cue take precedence over clear visual guidance? (Wolfson & Case, 2000)

The role of the lighting designer is now commonplace within games design studios (Betancourt, 2017; Calahan, 1996; Lehtinen, 2010), but the guidance methods employed by those designers are largely intuitive or based on the experience of what has been used previously under similar circumstances (Birn, 2006). This thesis aimed to further the understanding of the influence such cues have.

*Figure 3.* **An example of guidance lighting. (Alan Wake, Remedy Games 2010)**

*Figure 4*. **Subtle shading differences in the foreground grasses draw the eye towards the house. (The Elder Scrolls Online, ZeniMax Online Studios, 2014)**

### 1.1.2 SPATIAL NAVIGATION

The ability to navigate spatially is fundamental to both animal and human survival. Without the ability to cognitively build and retain spatial information the simplest navigational tasks would be essentially impossible (O'Keefe & Nadel, 1978). Tolman (1938) theorised that the mental representation is stored as a cognitive map, encoding the spatial data to allow for later recall and decision-making. The manner in which these maps are encoded and stored within the hippocampus has been studied extensively in both rats and later in humans by utilising Functional Magnetic Resonance Imaging (fMRI) techniques (Burgess, Maguire, & O'Keefe, 2002; Maguire, Burgess, & O'Keefe, 1999; O'Keefe & Nadel, 1978). Ongoing research into the understanding of how these cognitive maps are created includes a host of stimulus-response (SR) experiments that have led to a broad knowledge of the area of navigational choice making. However, there is a paucity of research into the influence of perceptual cues on navigational choices in virtual environments.

Perceptual cue is a very broad term, and the research presented in this thesis focuses primarily on the visuospatial navigational choices produced by the introduction of changes in lighting conditions in VEs. This data can then be cross-correlated with changes to the audio environment or to the architectural nature of the VE, for instance, simple elements such as visual distance or door widths (Norman, 1988). Although there is extensive research investigating the emotional effects of music and sound (Juslin & Laukka, 2003 Nacke, Grimshaw, & Lindley, 2010), there is little in the literature concerning the effects of audio stimulus with regards to navigational choices within a VE or games context. That which does exist does not remain particularly relevant to current sophisticated games technologies (Wolfson & Case, 2000).

The main research goal was to determine which environmental cues have a measurable influential effect on the navigational choices and to ascertain if a cueing hierarchy was in force. The secondary research goal was to determine the thresholds of change required to influence navigational choices made by participants. Additional to this was an analysis of the lack of perceptual awareness to subtle variations in the environment. Although it was central to the research that variance in light and colour can influence player navigational choices, it was also proposed that environments with gradually changing colours, textures and contrast variants may not even be perceived by participants.

## 1.2 EXPERIMENTAL FRAMEWORK

The studies within this thesis use a broadly quantitative approach to understanding the effectiveness and hierarchical nature of intrinsic navigational cues – rationales for the overarching and specific experimental approaches are covered in detail in the methodology section of this thesis. These are cues that are embedded within a virtual environment and include structural and architectural, distal landmark cues and more subtle elements such as the use of lighting and sound. A secondary goal was to determine whether subtle changes in perceptual information such as changes of luminance or hue in light sources have an impact on the choices made when navigating a virtual space.

These studies analyse the effects of cue competition between navigational choices related to architectural structure or the influence light and shade or the nature of the response to audio stimuli. The frameworks developed isolate individual variations in an environment such as the location of a positional audio stimulus between variants of the apparatus. The development of A/B variants of an apparatus allows for differences in stimulus-response (SR) between participant groups to be measured and compared.

Dynamic changes in a video games environment are frequently used to attract player attention (El Nasr, Vasilakos, Rao, & Zupko, 2009); dynamic lighting can emphasise a focal point, and coupled with motion, the designer can draw the player's attention to specific points in a virtual space. These changes can be subtle and offer guidance that is potentially at sub-perceptual levels. As detection of gradual value shifts in lighting is uncommon (Arrington, Levin, & Varakin, 2006), it was therefore theorised that broad changes in visual elements such as the colour and pattern of textures within an environment could be altered and yet not be consciously observed. These factors relate directly to the thresholds of perception of changes in lighting cues. A framework was created to study this issue, this apparatus applied gradual changes to the textures of an entire environment.

These studies aimed to address this under-researched area, where the discipline of game design and the human factors of navigational choices meet from a cognitive psychological perspective. This cross-disciplinary research aimed to offer insights into the structuring of navigational cues, the balance between the architectural aspects and the use of additional intrinsic guidance, the reinforcement of player direction and the thresholds at which elements such as lighting become competing factors. These are known issues within the field of games design (Mitchell, 2008), but despite the common usage of these navigational guidance techniques, there is little quantitative data to inform the designer.

## 1.3 NAVIGATION IN VIDEO GAMES

> *"**Navigation** is the most common VE task, and is consists of two components. TRAVEL is the motor component of navigation, and just refers to physical movement from place to place. WAYFINDING is the cognitive or decision-making component of navigation, and it asks the questions, "where am I?", "where do I want to go?", "how do I get there?", and so on."* (LaViola Jr, 2010)

VE navigation, specifically in video games is an underexplored topic in academic literature. Moura and El-Nasr (2015) explored the methods used by developers to assist navigation, via a study of 22 games that the primary author had recently played. Their review, in turn, was largely based upon retrospectives and overviews from professional designers such as Nerukar and Rogers (2009; 2009) and covered many of the commonly utilised methodologies at the time of its publication. A more recent review of embedded and more subliminal intrinsic methodologies is discussed by Brown (2015) in which he details the design methodologies utilised by designers at the games company Naughty Dog (Lemay, 2014). This chapter analyses the history, development and state of the art in games navigational guidance. It represents the most thorough investigation of this topic to date.

## 1.4 HISTORICAL CONTEXT

From a navigational perspective, video games have developed from simple two-dimensional pixelated single screen titles through angular and repetitive block-based 3D to a complexity and variety that comes close to photorealism. *Figure 2*, *Figure 5*. Augmented and virtual realities offer deeper immersion (E. J. Arthur, Hancock, & Chysler, 1997). as the worlds created have become larger and ever more complex, games designers have needed to ensure that their worlds remain navigable (Moura & El Nasr, 2015).

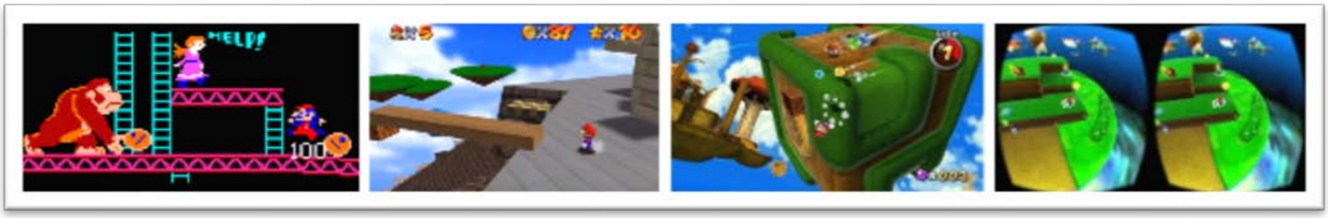

***Figure 5.*** **The progression from 2D, through 3D to complex VR spaces. (Nintendo, 1981-2017)**

The first generation of commercial video games titles utilised a screen resolution of only 336x240 pixels, (Kurtz, 2004) these pixels could only be either black or white, with no greyscale.

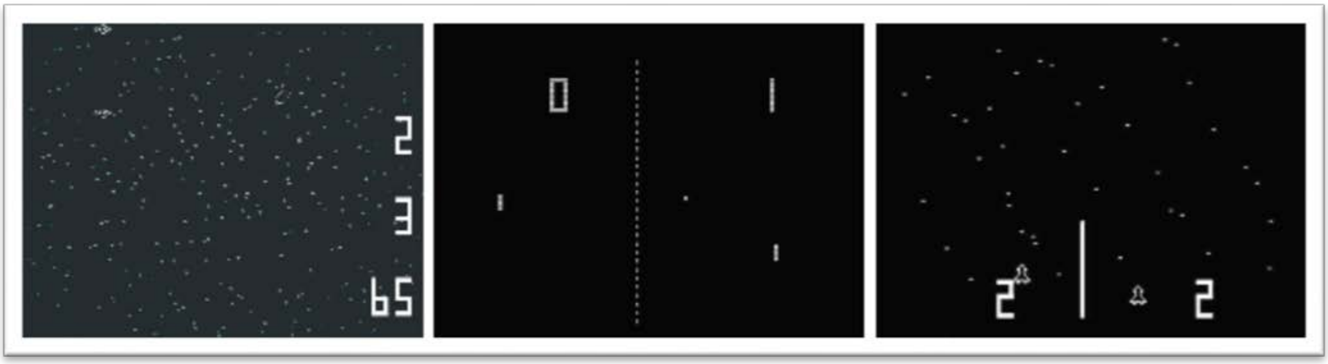

***Figure 6.*** **(Computer Space Syzygy-Engineering, 1971 Pong Atari, 1972, Astro Race, Taito, 1973)**

All of the in-game action of these first generation video games took place within the defined area of the screen [*Figure 6*]. It was not until 1974 that any scrolling of the screen was introduced. Simple scrolling of the game space expanded the play area of the game beyond a single screen; even then, this scrolling was purely linear and did not involve any parallax motion. The first game to introduce this technique was Speed Race (Taito 1974) followed quickly by Moto-Cross (Sega, 1976) which introduced rudimentary sprite scaling in order to provide a three-dimensional effect to the track. Despite these incremental graphical advances, games of the Golden Age of video games - defined by Whittaker as 1978 to 1986 (2004) - seldom deviated from these stereotypical examples. As processing power developed, games machines introduced colour graphics at increasing resolutions. Many arcade video games of this era evolved as standard tropes, driving games, single screen shooters such as Space Invaders (Taito, 1978), scrolling shooters such as Defender (Williams Entertainment, 1981), and maze games like Pac-Man (Namco, 1980). *Figure 7*.

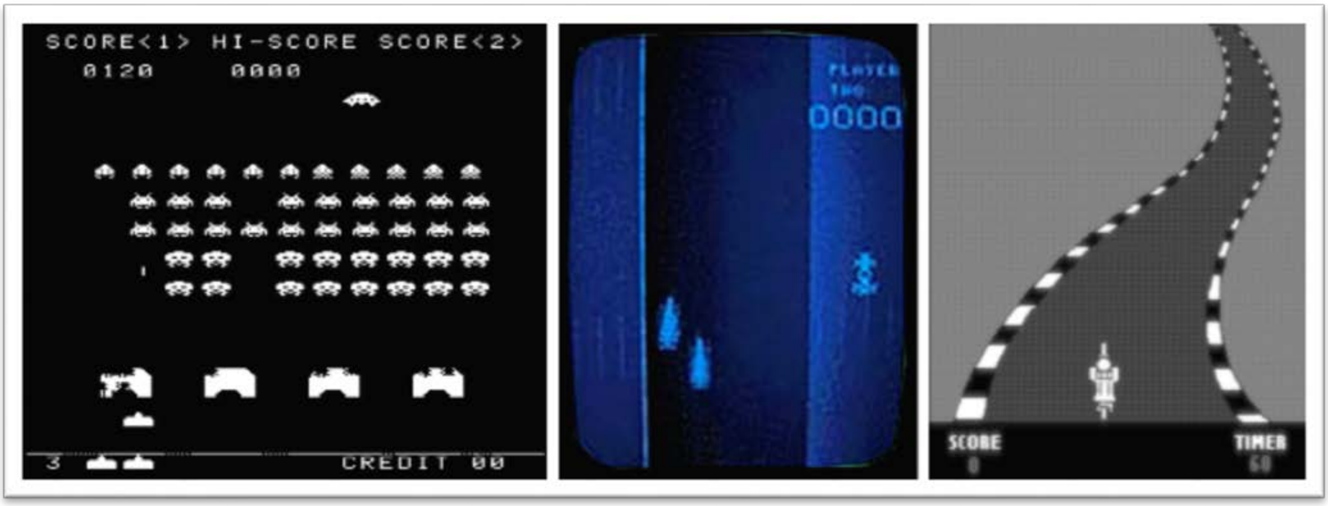


***Figure 7***. **Space Invaders (Taito, 1978), Speedrace (Taito, 1974), Motocross (Sega, 1976)**

The exceptions to these rules were vector graphics games that as their name suggests utilised a vector line drawing method of displaying their images. In these cases, it was possible to define simple line representations of objects and scale these using 3D vector mathematics to create very rudimentary first person 3d games such as Battle Zone (Atari, 1980) and Star Wars (Atari 1983). A feature that arcade games of the Golden Age have in common is that they do not require any complex player navigation and were frequently constrained to either a single 2d screen or a simple linear action.

## 1.5 THE HOME COMPUTER MARKET AND TEXT BASED ADVENTURES

Video games in the home were at first simple recreations or minor variations of the same existing tropes developed for the arcade, usually either built into a fixed firmware device such as the first generation console the Magnavox Odyssey (Magnavox, 1972). Second generation consoles such as the cartridge based Atari VCS (Atari, 1977). In 1979, the title Adventure was developed by Warren Robinett (Atari, 1979) this title is recognised as being the first graphically based adventure game and was loosely based upon the text-based Colossal Cave Adventure, which was developed by Will Crowther (1975). Colossal Cave Adventure was not only the first text-based adventure game but also the first game distributed across the nascent internet known at the time as Arpanet. Colossal Cave Adventure was, however, limited to being played in research labs on very expensive hardware, despite this, it is considered by games historians to be the precursor to the adventure game genre (Dickey, 2006). The home video games console is at the time of writing recognised to be in its eighth generation with devices such as Xbox One X (Microsoft, 2017) and PlayStation 4 Pro (Sony, 2017). However, to investigate the history of computer games through the lens of only console gaming would miss an area where innovation has been consistently possible due to a more open development ethos; the home computer allowed for experimental creativity in a much broader manner and without the constraints of console development.

During the early nineteen eighties, there began a market in home computing, that while initially aimed at serious applications such as word processing or accountancy, soon began to witness the development of video games that were a diversification from those offered in the arcade and even the home games console. Amongst these games were text based adventure games. Games of this type became immensely popular and included the Zork series of games (Infocom, 1981) which coincided with the release of more affordable mainstream home computing platforms from manufacturers such as the US-based Commodore and Atari and the UK-based Sinclair. The main factor that all of these titles had in common was that they allowed for free roaming around the digital environment. While these environments did not have any graphical elements, they did require a cognitive map (Tolman, 1948) of the game space in order to navigate successfully, in practice; many players resorted to drawing the game space onto paper with a view to streamlining their experience. Games such as the Wizardry series (Sir-Tech, 1982) contained graph paper in the product packaging in order for the players to draw the maps for themselves. *Figure 8*. With these exceptions, navigation within games remained straightforward, the navigational methods used in the aforementioned tropes being core to most games with the introduction of other game mechanics on top to differentiate the game titles.

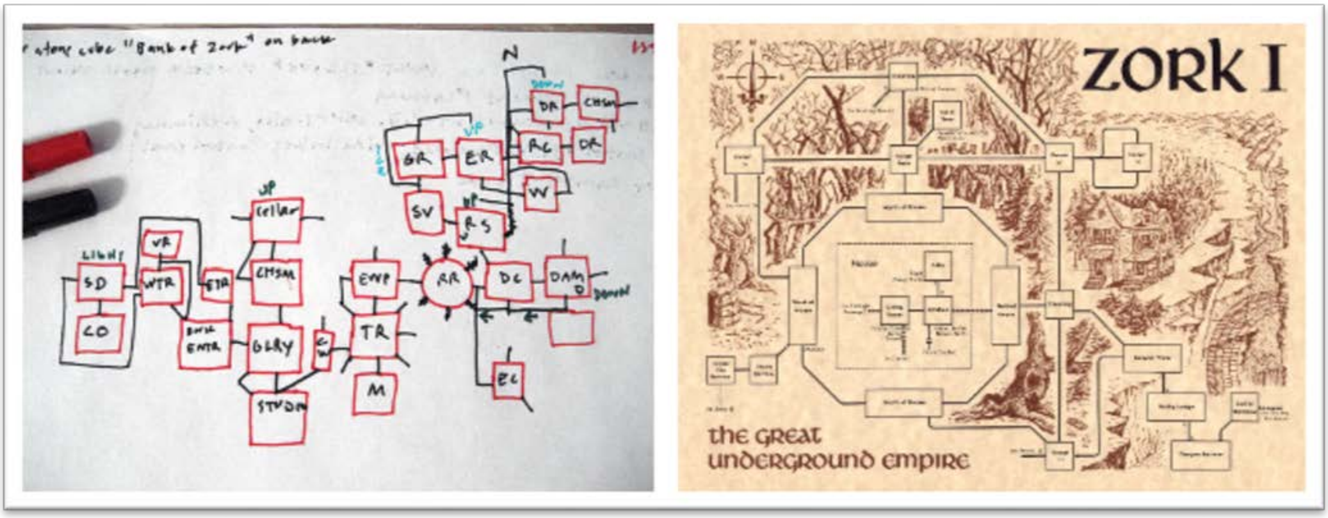


***Figure 8.*** **Sketch maps of text-based adventure games**

## 1.6 AUXILIARY NAVIGATIONAL CUES

Auxiliary navigational cues are defined as cues that stem from elements external to the games' environment; they are either part of the Graphical User Interface (GUI) or the Heads Up Display or HUD.

A GUI is specifically the interface element of a game; it can, therefore, be defined by the fact that it affords user interaction via direct manipulation of the graphical elements on the screen such as icons and other visual indicators. This is distinct from the HUD, which is composed of the non-interactable graphical items that offer additional information to the player such as health and mana bars, ammunition counts or navigational aids such as compasses. In practice, the term HUD is often used a generic shortcut to describe both the GUI and HUD components of video games. Further to these systems, other player navigational tools may be embedded into the title in the form of separate screens such as maps. Again, these are frequently described as being part of the GUI. It is, in fact, possible for games to utilise navigational cues that are external to the audiovisual component of the title entirely, such as haptic feedback in the form of vibration or 'rumble' from an input device such as a joypad, however these types of cue are considered to fall outside of the scope of this review.

### 1.6.1 CUT SCENES AS NAVIGATIONAL CUES

Cut scenes are non-interactive elements of video games used for exposition, direction and foreshadowing of events; they may introduce new story elements, introduce characters and associated dialogue or introduce the player to new mechanics. Pacman is considered to be the first game to introduce a separate cutscene external to the main gameplay screen (Games Radar, 2010), with its simple animations of Pacman chasing the ghosts. *Figure 9*.


***Figure 9.*** **Pacman chasing ghosts – the first example of a video game cut scene (Namco, 1980)**

In other instances, video or animated cut scenes are utilised to inform players of upcoming objectives, the first game to utilise video specifically for cut-scenes and not as in game video such as in Dragon's Lair (Cinematronics, 1983) was Bega's Battle (Data East, 1983) scenes of this nature are often referred to as FMV (Full Motion Video) Sequences. *Figure 10*.


*Figure 10.* **Examples of cut scenes from Bega's Battle (Data East, 1983)**

As rendering power has increased, in-game cut scenes (either video or pre-rendered CGI footage) have largely been superseded by in engine run-time scenes that are rendered in broadly the same graphical style as the main game (Hancock, 2014). These scenes usually exclude the graphical user interface or similar overlays as demonstrated below in an example from Grand Theft Auto 4 (Rockstar, 2008). From a navigational perspective, cut scenes frequently demonstrate to the player the route they should take to the next objective, often in the form of fly through animations or indicating to the player the next goal that they should seek.

Cut scenes are frequently used to foreshadow a major element of gameplay that may aid navigation, such as the location of levers that open doorways to new areas of the environment in Tomb Raider (Core Design, 1996). *Figure 11*.

*Figure 11.* **Cut sequence linked to a character action – A lever opens door in Tomb Raider (Core Design, 1996)**

Cut scenes as a navigational cue are still common through many genres of game, despite their breaking of flow and player immersion (Dutton, 2011); they do provide focus on the specific goals that the designer has placed in the game for the player to discover. *Figure 12*.

***Figure 12.*** **Cut Scene leading to in-game action – Grand Theft Auto IV (Rockstar, 2008)**

### 1.6.2 ON SCREEN DESTINATION GUIDANCE TEXT

Setting the goals for the player can also be handled in some instances as a straightforward text overlay in the form of a subtitle. Navigation cues of this kind are not the most elegant solution but are very clear and unambiguous. In the case of Shenmue (Shenmue, Sega AM2, 1999), the use of on-screen text as descriptors for locations such as shops was related to the lack of texture memory available to the designers when creating titles for the Sega Dreamcast (8 Mb in the Dreamcast – compared to 8Gb in the PlayStation 4) (Fahs, 2010). However, the use of on-screen text to set goals for players is still employed in many titles that also offer well-constructed intrinsic guidance; this applies to, for instance, Alan Wake (Remedy Entertainment, 2010) which uses on-screen text goals despite utilising other subtle guidance systems (Lehtinen, 2010). *Figure 13*.


*Figure 13.* **Examples of On Screen guidance text from Shenmue (Sega AM2, 1999) [left] and Alan Wake (Remedy Entertainment, 2013) [right]**

### 1.6.3 NAVIGATIONAL POP-UP DIALOGUE BOXES

A further related manner in which text-based navigational information is provided for players is via the use of pop-up dialogue boxes. *Figure 14*. A dialogue box may contain the text of a conversation with a non-player-character (NPC) (Ellison, 2008) or provide instructions derived from reading a map, manuscript or similar. In other cases, they may be displayed following the activation of trigger points in the game world. Commonly, such pop-up boxes simultaneously pause in game action while they are active.


*Figure 14.* **A pop-up dialogue, offering navigational instruction. Fallout 3 (Bethesda Game Studios, 2008)**

On-screen text either as subtitles or as pop-up boxes are perhaps the most blatant and obvious kind of navigation cue to be found in video games (Ellison, 2008), they offer direct instructions, but are distinctly separate to the general gameplay of a title. In practice, games designers aid and direct navigation within complex game worlds by employing many other more subtle techniques.

### 1.6.4 MAPS, MINI-MAPS AND AUTOMAPS

#### 1.6.4.1 MINI-MAPS

Once video games had expanded beyond the area of a single screen, navigational demands required the development of a visual overview of the play area. These small graphical representations became known as mini-maps. Mini-map navigation systems were first introduced in the maze based racer arcade game Rally-X (Namco, 1980) [*Figure 15*] this map was a simple blue rectangle with coloured dots representing the player, NPC vehicles and checkpoints and did not contain a representation of the environment. Expanding upon the concept Defender (Williams, 1981) showed the entire main window of the game miniaturised to fit in an embedded rectangular window at the top of the screen. *Figure 15*. The mini map also clearly showed the nature of the player's ship, the enemies and the astronauts to be defended. While initially crude, these maps were the precursors to many similar variants that are utilised in many different game genres to this day.

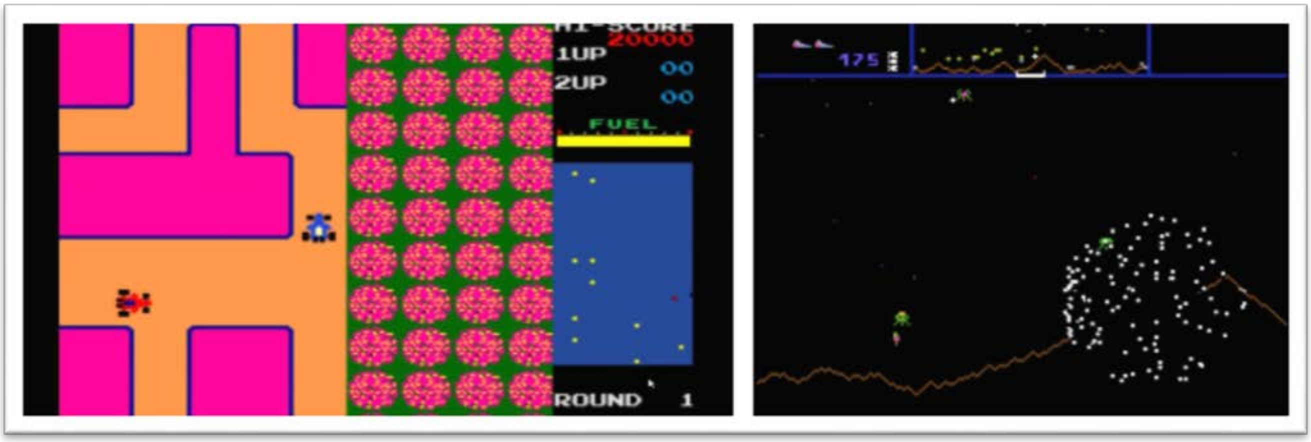


*Figure 15.* **Two of the earliest examples of mini-maps. Rally X (Namco, 1980) [left] and Defender (Williams, 1981) [right].**

The basic mini-map is commonly used in a wide variety of games from real-time strategy games to Massively Multiplayer Online Role Playing Games (MMORPG). As these systems developed, further features were added to complement gameplay, including an unexplored area masking system - similar to the blind mechanic of the board game Battleship - that has become known as 'fog of war' (Adams, 2014). *Figure 16*. The fog of war system, masks unexplored areas of the map as part of the games exploration mechanics. It also has the additional benefit in larger and more complex games of informing the player that a zone is unexplored and therefore reduces the occurrence of unintentional backtracking.

***Figure 16.*** **Fog of war as represented by the black area of the minimap - Total Annihilation (Cavedog, 1997) [left] - Command and Conquer 4 (DICE, 2010) [right]**

### *1.6.4.2 AUTOMAPS*

The development of three-dimensional navigable spaces in video games began with a project entitled Maze War that was developed at NASA Ames Research Centre in 1974. While this project was limited to expensive research machines, it is considered by games historians to be the first 3D exploration game and also (despite the lack of a true aiming mechanic), the progenitor of the first-person shooter (FPS) (Arsenault, 2009). Although never commercially released in this form, Maze War also introduced a very basic minimap [*Figure 17*], as an aid to navigation only, six years prior to Namco's Rally-X. The intervening decades saw multiple methods for rendering three-dimensional environments. However, beyond the drawing of simple vector lines, the complex calculations required to render filled, let alone textured polygons impacted frame draw rates to such a degree that it precluded successful development of playable games titles.

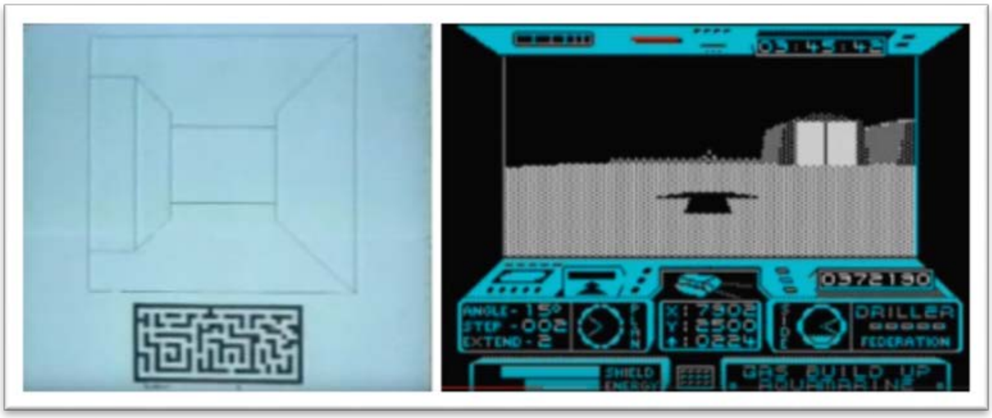

*Figure 17.* **Early experimentation with vector and filled 3D: Maze War (Ames Research Centre, 1974) [left] and Driller (Major Developments, 1987) [right]**

Games began to move from two dimensions to three as soon as the available hardware allowed. Solid drawn 3D graphics had appeared in titles such as Driller (Major Developments, 1987) [*Figure 17*] on the Sinclair ZX Spectrum, but with frame draw rates as low as two frames per second, the interaction was limited. Wolfenstein 3D (id Software, 1992) was one of the first titles to offer textured albeit pseudo-3D graphics utilising a rendering technique known as ray casting. With games of this scale and complexity, the requirement for inbuilt mapping became more of a necessity. Wolfenstein 3D despite having a large and complex level layout with a large amount of repetition did not have a mini-map or map of any kind. It is commonly noted in reviews of this title that this led to the player becoming disoriented and lost (Hatfield, 2009) indeed beyond memorising the layouts of rooms and their contents, there was no intrinsic guidance evident in the game.

As pioneers in the field of first-person action games, id Software addressed many of the criticisms made by reviewers of Wolfenstein 3D in the development of their next title - the following year they released Doom (id Software, 1993). Doom was one of the first games to introduce a variant of the mini-map referred to as an automap. *Figure 18*. The job of the mini-map is to represent the play area including terrain graphically and to represent the population of elements such as enemies or points of interest. By contrast, the auto-map represents an automatically updating top down and often-abstract version of the local area of play in a game. These types of maps often allow for interactive input from the player; clicking enables the navigation within the map view itself. This intractability means that auto-maps are a form of graphical user interface (GUI) making them distinct to their overlaid mini-map counterparts that form a part of a games' heads up display (HUD).


***Figure 18.*** **Wolfentstein3D (id, 1993) [left] had no mapping of any kind. Doom (id, 1993) [middle] was among the first titles to introduce an automap [right]**

### *1.6.4.3 'PHYSICAL' MAPS*

Abstracted map systems in some regards break the immersion of a game by cutting away from the main game interface. In order to present map data in context, games such as Far Cry 2 display their maps as part of the physical world of the game in the form of props. *Figure 19*. Such maps can be as complex as required to fit the narrative. Therefore, allowing in some instances for sketch-maps to act as clues rather than as direct representations. An example of this is illustrated below from Uncharted 3 Drake's Deception (Naughty Dog, 2011). Figure 20.


***Figure 19.*** **A realistic representation of a compass and map - Firewatch (Campo Santo, 2016)**


**Figure 20. An example of a sketch map from Uncharted 3: Drake's Deception (Naughty Dog, 2011)**

### 1.6.5 GPS

A more modern extension of the utilisation of maps in games titles comes in the form of an in-game GPS device; many games such as Grand Theft Auto V (Rockstar Games, 2013) incorporate a variety of mapping techniques as well an overlaid GPS system as part of the graphical user interface overlay. *Figure 21*. In other titles that attempt to be more realistic and immersive such as Far Cry 2 (Ubisoft Montreal, 2008) a physical representation of a GPS device is incorporated; these GPS units may be a handheld object or a device attached to a vehicle. *Figure 22*.


***Figure 21.*** **Mapping systems in Grand Theft Auto V (Rockstar, 2013) City Map [left] GPS [middle and right]**

***Figure 22.*** **Use of in-vehicle GPS in Far Cry 2 (Ubisoft Montreal, 2008)**

### 1.6.6 QUEST-MAPS

A specific type of map that has become commonly used in a very broad range of games but in particular Role Playing Games (RPGs) has become known as the quest map (Adams, 2014). Quest maps as with the types of mini-map utilised in real-time strategy games such as the Command and Conquer and Total Annihilation series display the terrain and invariably utilise the similar fog-of-war system to obscure unexplored areas. On top of this map data, the quest map adds various icons to aid the player in the discovery of characters, locations and objects pertinent to the unfolding story. As can be seen from the images below, the quest map has become ubiquitous in this genre of game, and therefore, the maps of multiple titles bear a large number of similarities to each other. A common visual language for some of the icons or markers in these quest maps has evolved [*Figure 23*, *Figure 24*] with exclamation points repeatedly utilised to indicate characters offering available quests. Beyond the exclamation point, each title will offer a variety of bespoke markers that indicate the other desirable locations on the map (Pepe, 2012). However, while these icons may vary from title to title, the similarities in design afford a sense of familiarity for players of games in this genre.


***Figure 23.* The use of Quest Maps in; Aion (NCsoft, 2008), World of Warcraft (Blizzard, 2004), RuneScape (Jagex, 2001)**

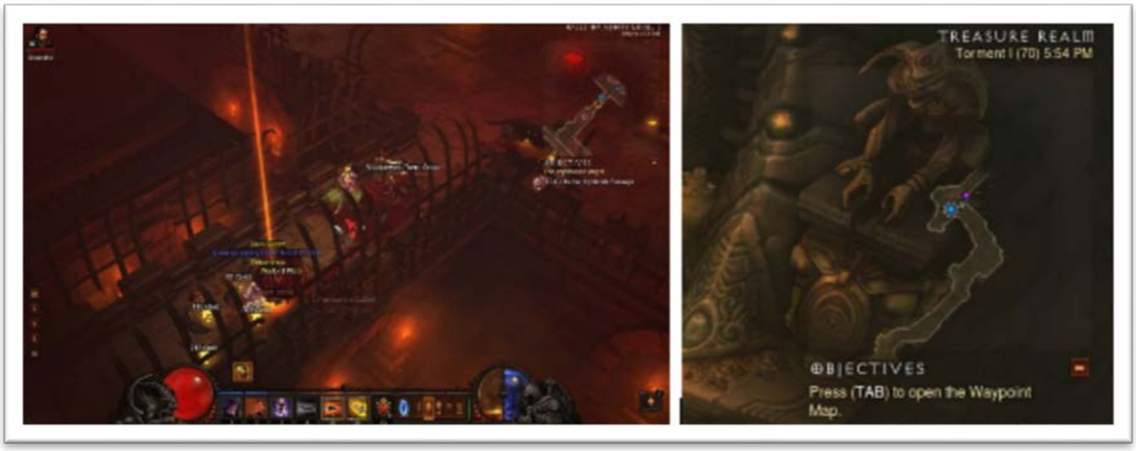


***Figure 24.* Quest Map in Torchlight II (Runic Games, 2012)**

## 1.6.7 TELEPORT MAPS

The concept of the quest map is expanded upon in certain titles such as RuneScape (Jagex, 2001) to incorporate a teleport map. As its name infers, this map allows for a different type of navigation within the game world. Teleportation of some kind is very common to Role-playing Games but is usually a self-contained in game mechanic such as using spells or objects to open portals sometimes from point to point but more frequently to return to a central hub such as a town. Runescape builds upon this concept and allows players to use this specific interface to move from one location to another. *Figure 25*. Similar systems are also used to make progress across the large world space of games such as Fable 3 (Microsoft, 2010).

***Figure 25.*** **An example of a Teleport Map from RuneScape (Jagex, 2001)**

## 1.6.8 OPEN SPACE MAPS

Dependent on the scale of the world, maps within games can be extremely complex systems. However, most mapping systems found in games involve the navigation of discreet worlds. Maps may vary from the size of a few streets to the scale of a city or county. Large-scale maps usually limit exploration to two dimensions. Games in which the player can navigate between worlds are therefore entirely different in nature and scope to maps designed to navigate what is, in essence, a large plane. One of the more complex of these three-dimensional mapping systems can be found in the Elite series, first developed in the original Elite (Acornsoft, 1984). *Figure 26*.

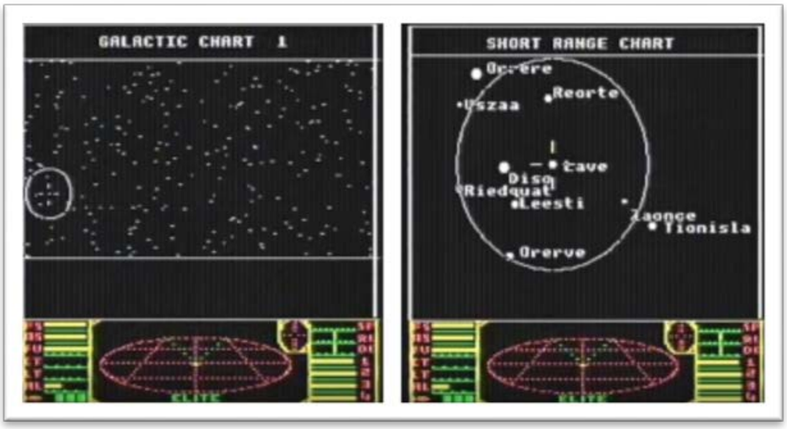


*Figure 26.* **Two-dimensional galactic maps in Elite (Acornsoft, 1984)**

While only containing 2048 planets Elite (Acornsoft, 1984) was groundbreaking in its day given the memory restrictions of 8-bit computers. Navigating these systems required a complex (at least at the time of development) mapping system, a series of eight galactic charts each of which had 256 planets. A short-range chart would then display the local planets that could be visited and traded with (in this title the use of the term planets and star systems was interchangeable as the navigation system did not differentiate between the two). Navigation within a star system was then managed by the flight radar/mini map at the lower quarter of the screen. These mapping systems have necessarily evolved as space exploration games have become more complex and ambitious; the latest in the Elite Series, Elite Dangerous (Frontier Developments, 2014) allows players to visit over 400 Billion star systems, each containing planetary systems based on the best available scientific understanding of planetary formation. This single galaxy is navigable by a 3D representation with selected systems having routes that link to each other in a web-like structure. *Figure 27*. Individual Star Systems are then graphically represented showing all of the associated moons and major asteroid belts. Final navigation is handled in the same manner as the original Elite, but in this instance, when travelling at relativistic velocities, displays the local planets in the same radar system as the ship-to-ship radar. *Figure 28*.

*Figure 27.* **A three-dimensional galactic map in Elite Dangerous (Frontier Developments, 2014)**

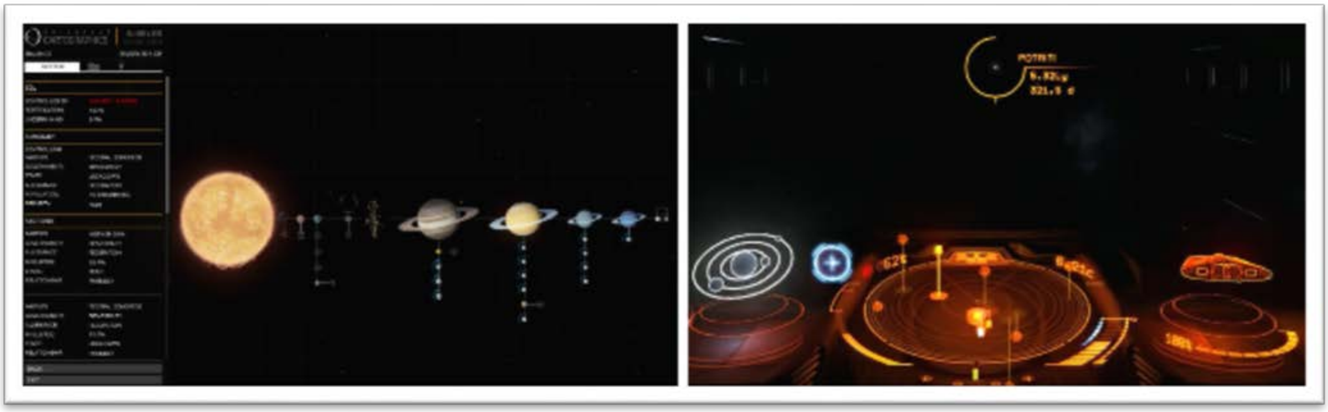

*Figure 28.* **Two-dimensional star system chart [left] and three-dimensional navigation system [right]: Elite Dangerous (Frontier Developments, 2014)**

### 1.6.9 COMPASSES

While mini-maps will display goals in a discrete segment of the main map, compasses point in the general direction of a location in the environment. Goals on a mini-map will always be shown in a fixed and absolute manner whereas the compass is useful for displaying their relative location. The term compass in gaming parlance is not restricted to the representation of a real compass in the game, although this is often the case, many titles such as Firewatch (Campo Santo, 2016) and DayZ (Bohemia Interactive, 2013) utilise a map and compass in combination to allow for virtual orienteering. *Figure 29*.

***Figure 29.*** **The use of representations of physical compasses. As an intrinsic prop: DayZ (Bohemia Interactive, 2013) [left], a compass as a HUD object in Walking Dead Survival Instinct (Terminal Reality, 2013) [right]**

Other titles such as Walking Dead Survival Instinct (Terminal Reality, 2013) have incorporated representations of traditional compasses overlaid as a HUD component. More commonly, the compass is integrated into the design of the HUD such as in Rise of the Tomb Raider where the compass is graphically represented in the top right of the screen and is in keeping with the graphical style of the HUD overlay. *Figure 30*.


***Figure 30.*** **A compass represented in a HUD graphical element in Rise of the Tomb Raider (Eidos Montreal, 2015)**

This integration into the graphic style of the game and its user interface design is evident in games such as Sly Cooper Thieves in Time (Sanzaru Games, 2013) which integrates a compass-style quest-pointer into its reticule design. *Figure 31*. Gears of War 2 (Epic Games, 2008) uses a similar approach in this case a goal-compass surrounds the reticule, indicating the direction of the nearest wounded comrade.

***Figure 31*. Compasses as an element of the in-game reticle: Sly Cooper Thieves in Time (Sanzaru Games, 2013) [left] and Gears of War 2 (Epic Games, 2008)**

Other games have taken the concept of the compass a stage further - integrating a compass pointer like representation in a semi-abstract fashion. For example, Shadow of the Colossus (SCE Japan, 2005) in which, when the protagonist holds his sword aloft and a ray of light is cast from it representing the compass direction which the player needs to follow to the next waypoint (Mielke & Rybicki, 2005). *Figure 32*.

***Figure 32*. The ray of light reflected from a sword used as an in-game compass: Shadow of the Colossus (Sony Computer Entertainment, 2005)**

The compass is rarely used in isolation it is invariably used as an adjunct to other systems, such as the markers on a mini-map. Compasses offer the ability to point towards goals within a game when they are either too distant or are currently not visible to the player.

## 1.7 INDICATORS, ARROWS, MARKERS, GLYPHS AND ICONS

### 1.7.1 INDICATORS

The navigation of many games that do not use a mapping system is often controlled by the level layout. In its most crystallised form, the player has no control of their motion through the game and simply has to react to onscreen events. One of the earliest and simplest implementations of this style of game is Dragon's Lair (Cinematronics, 1983) where the player simply has to watch for items in the game to flash white and push the joystick in the corresponding direction. *Figure 33*. The term Quick Time Event or originally, Quick Timer Events was coined by Yu Suzuki the director of the game Shenmue that utilised many such events without its game play. The term QTE subsequently became common parlance in gaming circles to describe such events (T. Rogers, 2011). Despite the simplicity of this method of gaming, it has continued to be employed in contemporary titles such as Resident Evil 4 (Capcom, 2004) and The Walking Dead series (Telltale Games, 2012) and has become known as a Quick Time Event often abbreviated to simply QTE. QTE's invariably use an onscreen icon to indicate which button the player must press to continue although; in some cases, the input required is of a more complex nature such as manipulation of a motion sensing joypad.

***Figure 33.*** **Two examples of direction indicators for Quick Time Events (QTE). One of the earliest examples from Dragon's Lair (Cinematronics, 1983) [left ] and a more recently in The Walking Dead (Telltale Games, 2012) [right]**

A variation on this concept of gameplay overlaid on cinematic style visuals was the development of an entire sub-genre of shooting game known as the 'rail shooter' where all navigation is removed from the player, and their only task is to shoot the numerous enemies that present themselves. Often these enemies themselves have a visual attraction method similar to the movement cues in the Cinematronics games for instance in House of the Dead a brightly coloured sprite is used as an indicator of the correct aim point. *Figure 34*.


***Figure 34.*** **An overlaid attraction / aim point, similar in nature to a Quick Time Event cue. House of the Dead (Sega, 1996)**

### 1.7.2 ARROWS (AUXILIARY)

One of the more readily recognised methods of indicating the direction that should be travelled is the inclusion of arrows pointing towards a goal, even when there is only one direction of travel in titles such as Metal Slug (Nacza Corporation, 1996). *Figure 35*.


***Figure 35.*** **Simple use of directional arrow navigation cue: Metal Slug (Nacza Corporation, 1996)**

While this could be considered an obvious method by which to guide a driver, and is in fact utilised in many commercially available satellite navigation systems from companies such as TomTom and Garmin, [*Figure 36*] this is not a system that is in common use in open world driving games.


*Figure 36.* **Arrows in common usage in satellite navigation systems.**

The reason for this is that in 1997 Sega patented the system of having floating arrows pointing in the desired direction of travel (Takeshi Ando, Kazunari Tsukamoto, 1998) and therefore only Sega games such as Crazy Taxi (Sega, 1999) and Jet Set Radio (Sega, 2000) have legitimately utilised this system. *Figure 37*. A similar system was implemented in Simpsons Hit and Run (Radical Entertainment, 2003) this led to Sega suing Fox Entertainment, Electronic Arts, and Radical Entertainment for an undisclosed sum. (Staff, 2010).


*Figure 37.* **Examples of floating arrows as an aid to navigation in driving games: Crazy Taxi (Sega, 1999) [left] and Simpsons: Hit and Run (Radical Entertainment, 2003) [right]**

As can be seen below [*Figure 38]* Sega made extensive use of arrows in such title as Jet Set Radio in which not only do arrows point in the direction of the goal, but variants in colour also point to individual objectives or antagonists.


***Figure 38.* Multiple floating navigational arrows: Jet Set Radio (Sega, 2000)**

A variation of using arrows to indicate direction is utilised in BioShock Infinite (Irrational Games, 2013) in a manner that falls somewhere between being an element of the HUD and is bordering on being an intrinsic element of the game. While the graphic for the directional arrow is clearly alien to the overall aesthetic, although it blends with the texture space of the rest of the floor plane, it is in the form of graphical overlay and therefore is considered an auxiliary navigational cue. *Figure 39* ].


*Figure 39.* **Navigational arrows in BioShock (Irrational Games, 2013)**

### 1.7.3 FLOATING ICONS

Some methods of indicating goals have become standard across multiple connected genres of game. As discussed in the quest map section earlier, the exclamation point has become the standard form for a quest indicator (this is sometimes supplanted by a question mark, although the purpose is usually the same). This exclamation point not only indicates the location of a quest but also in many instances the NPC providing that quest. Within the game world, the NPC may also have a floating icon above its head, which indicates that it has information or a quest. An extension of this that is frequently seen in fantasy quest based games from MMORPG (Massively Multiplayer Online Role Playing Games) to dungeon crawler titles such as Torchlight (Runic Games, 2009) is the profession-indicator – a floating icon above a character's head that simply indicates the nature of the NPC. For instance, the Merchant may have a bag of coins above his head or an alchemist may have a potion bottle above his head. *Figure 40*.

The use of these symbols for indicating quests has become so embedded in these genres that Defence of the Ancients (DotA) takes this one stage further to indicate quest goals themselves in situ with large exclamation marks hovering around them. *Figure 41*.


***Figure 40.*** **Examples of floating icons from Torchlight II (Runic Games, 2012) [left] World of Warcraft (Blizzard, 2004) [right]**


***Figure 41.*** **Variants of the standard Quest Marker in ArcheAge (XL Games, 2013) [left] and Defence of the Ancients (DotA) (Valve Corporation, 2013) [right]**

## 1.7.4 WAYPOINT MARKERS AND QUEST MARKERS

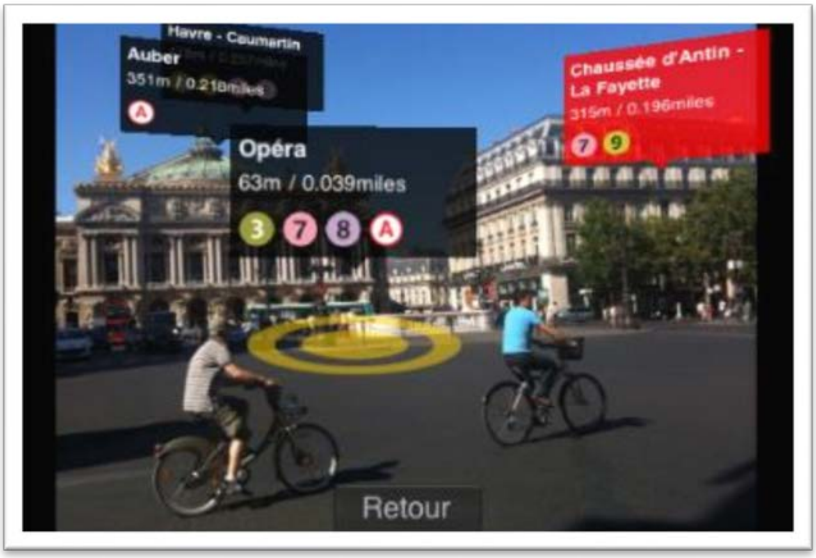


*Figure 42.* On-screen markers in augmented reality Metro Paris Subway (Presselite, 2013)

In open world games, it is common to use on-screen markers that draw visual attention to the position of the next waypoint or quest destination. *Figure 42*. These vary from game to game in their implementation, for instance in Mass Effect (Bioware, 2007), [*Figure 44*] they only appear when in close proximity and are otherwise displayed as coloured points on the mini-map. *Figure 43*. Whereas in Dishonoured 2 (Arkane Studios, 2016) they are permanent guides to the quest goal with the addition of a countdown timer in which the player must complete the task. *Figure 43*. The Elder Scrolls V: Skyrim (Bethesda Game Studios, 2011) takes yet another approach, utilising a uniform icon for its quests throughout the game and not only displaying the quest marker as an overlay on the environment but also using the same icon within its inbuilt compass.

*Figure 43.* **Quest markers embedded in the on-screen compass in The Elder Scrolls V: Skyrim (Bethesda Game Studios, 2011) [left] and permanent on-screen quest goal marker icons in Dishonoured 2 (Arkane Studios, 2016) [right]**

*Figure 44.* **Examples of distal and proximal waypoint markers in Dead Rising 4 (Capcom Vancouver, 2016) [left] and Mass Effect (Bioware, 2007) [right]**

## 1.7.5 QUEST TRAILS / PATH MARKERS

While quest markers may offer a distal cue to the player, other titles have opted for a system that is more closely related to a breadcrumb trail, sometimes referred to as quest lines; these abstract artefacts offer very clear player guidance in a form that is difficult to miss. For instance, Dead Space 2 (Visceral Games, 2011) draws paths of different colours to indicate a variety of different goal types. *Figure 46*. Fable 2 (Lionhead Studios, 2008) utilises a more ethereal particle effect to draw a hovering path to the next suggested goal. *Figure 45*.


*Figure 45.* **Example of a quest trail in Fable 2 (Lionhead Studios, 2008)**

*Figure 46.* **An example of a quest path marker in Dead Space 2 (Visceral Games, 2011)**

## 1.7.6 CHARACTER OUTLINES AS GUIDANCE

Characters within games could be used to overtly guide the player by using animation, and audio cues indicate that the player should follow, however, the location of both player characters and non-player characters are frequently essential information for navigation from a player perspective. The location of characters, be they friend or foe, particularly if the game has no mini-map is often indicated by the use of glowing outlines that can compensate for figures being obscured by geometry or a lack of light. In Left 4 Dead (Valve Corporation, 2008) the player works as part of a team of four at all times. Whether the other three characters are controlled by AI or another player is irrelevant to the fact that team survival and cooperation is imperative to the gameplay and therefore being able to see characters at all times is core to this. Often characters will need direct help from other players and being able to visually perceive their peril is a main mechanic within the game. Similarly, being able to locate enemies in The Last of Us (Naughty Dog, 2013) is linked to the sound they make, and this audio signature is visualised in a spatially diegetic manner in the game by displaying a glowing outline around each enemy. *Figure 47*.

***Figure 47.*** **Character outlines either indicating the location of team members, Left 4 Dead (Valve Corporation, 2008) or enemies The Last of Us (Naughty Dog, 2013)**

## 1.8 SUMMARY

Auxiliary navigational cues can be defined as any navigational cue or guidance afforded the player that is not a natural part of the game world. In this sense, despite the guidance lines used in Deadspace being present in the environment, they appear to the viewer as an unnatural overlay. As such, they are perceived as a graphical addition to the game's HUD rather than being a feature of the game world. Cues of this nature are always overt; they are designed to be noticed and acted upon by the player. Occasionally cues of this type will even interrupt gameplay for the player to effectively process them, i.e. pop-up dialogue boxes. In other cases, they may force the player in a particular narrative direction, as is the case for Quick-time Events. Auxiliary navigational cues are extrinsic to the game worlds; they are not explicitly designed to feel either grounded or realistic in nature.

## 1.9 IN GAME NAVIGATIONAL MODALITIES

Within many titles, there are influences on player navigation through the game environment that may be rooted in the game's mechanics as opposed to being a navigational overlay or as will be discussed in the next chapter the intrinsic and subtle cues built into the game world.

### 1.9.1 CHARACTER BASED ABILITIES

Characters within games may be able to move in a variety of ways beyond simply walking on a two-dimensional surface. The speed of motion is seldom uniform, more often being a variable, particularly when the player is using a game controller with analogue control sticks. Variation in the speed of navigation will change the manner in which the environment is perceived. The speed of a character's walking or running is not the only factor that will alter the manner in which an environment is explored. Characters may also have the ability to climb surfaces and make jumps of varying types. Although limited largely to non-realistic games and in particular 2D platform games, the double jump (Games Radar, 2010) was first seen in Dragon Buster (Namco, 1984) is was also utilised in games such as Team Fortress 2 (Valve Corporation, 2007). In this case, it is reserved as the special ability of the Scout class character. Essentially a double jump gives the player the ability to jump again when already in the air.

Jumping in video games seldom follows natural physical laws, for instance, being able to turn in mid-air is common as is the ability to wall jump. Wall jumping enables the character to propel itself upwards by repeatedly bouncing off walls; while being introduced in earlier titles, this became a core feature of Super Mario 64 (Nintendo, 1996) and was required to explore and reach many areas and items. An extension of these jumping abilities that again plays fast and loose with the laws of physics is the rocket jump where a character utilises a ballistic device like a rocket launcher and by aiming at the ground is propelled skyward via the recoil of the device. This mechanic was first introduced in Doom (id Software, 1993).

Beyond these physics-defying abilities, many characters have the ability to fly, swim, demonstrate a range of acrobatic abilities and of course operate items and vehicles that allow for further range of motion and increased speeds.

Characters may also manifest abilities that allow them to enter areas that other characters may not. For instance, it is common in roleplaying games that characters belonging to the thief class have abilities such as being able to pick locks and therefore are able to open doors other players cannot, a further ability that is common to thieves is that of detecting and disabling traps that may slow or stop other players. In other cases, extremely strong characters may have the ability to remove a door or push through walls. These types of abilities whether they are magical, scientific or technological in nature can vary extremely widely between titles and are only really limited by the designer's imagination. Characters may develop new abilities via the acquisition of technological or magical objects or simply evolve new abilities as the game progresses. In all cases, these abilities offer the player broader navigational choices. When coupled with level design, a game designer can influence the paths a player will take and open up previously unexplorable areas of a level by the introduction of a new player ability.

#### 1.9.1.1 CHARACTER POSTURE AS A NAVIGATIONAL CUE

In titles such as Rise of the Tomb Raider (Crystal Dynamics, 2015) and Grand Theft Auto V (Rockstar Games, 2014) goals and points of Interest (POI's) are indicated by the third person avatar turning their head to look at the specific point in space. The gaze direction of others is known to draw visual attention (Downing, Dodds, & Bray, 2004). Therefore this method of visually pointing is intuitively understood by the player. This technique is taken a stage further in LA Noir (Rockstar Games, 2011); using a technique Rockstar term 'Optimised Character Movement' (Alexander, 2010) the avatar of the currently controlled character will dynamically draw the player to the POI by augmenting the player input.

### 1.9.2 VEHICLES

Vehicles are a mainstay of entire genres of video games; they offer a variety of methods to open up new modes of travel and navigation. Characters may have access to any kind of vehicle, from the standard road, air and sea craft to more esoteric items such as jet packs, flying carpets or animal based transport such as Dragons. There is a huge variety in this area, and the limits of these modalities are only limited by the constraints built into the world by the designers.

Beyond opening up areas for exploration, vehicles can also directly influence navigational choices, for instance in LA Noire (Rockstar Games, 2011) the vehicles aid in navigation directly by having an automatically preferred route to the goal, the player can deviate from this path deliberately, but if not directly deviated from the car will steer as if on auto pilot.

## 1.9.3 DEVICES

As previously mentioned in the discussion on jumping, devices can be used by players to enable broader exploration of the game space. The rocket jump is only one of many such device-based abilities that are used in video games. Objects that aid the motion of the character are employed extensively. Examples of device or object-based movement aids include simple ropes as used in Uncharted 4 (Naughty Dog, 2015), grappling hooks as employed in Batman Arkham City (Rocksteady Studios, 2011), or even magical umbrellas that allow the character to fall at a controlled rate as in the platform game Lemmings (DMA Design, 1991). *Figure 48*.


***Figure 48.*** **Use of devices as aids to movement and navigation from left to right. Ropes as lassos in Uncharted 4 (Naughty Dog, 2015), grappling hook in Batman Arkham City (Rocksteady Studios, 2011) an Umbrella in Lemmings (DMA, 1991)**

## 1.9.4 TELEPORTS AND PORTALS

A variety of in-game mechanics can allow characters to teleport from one location to another. Many roleplaying games such as Torchlight (Runic Games, 2009) will give the player the ability to create magical portals using in the case of Torchlight a magical scroll. In other titles, this may be a spell cast directly by a magic user, these portals in many games including Torchlight will allow the player to teleport back to a central hub, in the case of Torchlight this is the main town. Portals of this nature are usually single use; allowing transport to the central hub and return to the point of casting, completing the cycle and removing the portal.

Portal (Valve, 2007) makes extensive and elaborate use of the player’s ability to teleport between visible locations by the utilisation of a ‘portal gun’ that links one part of the play space to another.

*Figure 49*. Portal takes a mechanic that in other titles is a method of travel and builds puzzles around the concept that incorporate the use of momentum and gravity allowing the player to travel through the environment in unexpected ways (Dudley, 2011).

***Figure 49.*** **The use of teleportation portal in games Torchlight II (Runic Games, 2012) [left] and Portal (Valve, 2007) [right]**

## 1.9.5 KEYS, PUZZLES, ENEMIES AND BOSSES

It is common in video games that in order to enter a specific new area, or complete a level of a game, a puzzle must be solved, a key must be found, or a specific character often referred to as a 'Boss' (Tokuyoshi, 1983) must be defeated in order to progress in the game. *Figure 50*. In many respects, these elements are broadly similar in their outcome. Once solved, found or defeated they perform roughly the same purpose. Despite their initial hindrance, problems of this nature eventually provide access to additional explorable spaces. Therefore, conversely, they can be considered aids to navigation of the game world.

***Figure 50.*** **The first example of a 'Boss' in a video game: Phoenix (Taito, 1980)**

## 1.10 INTRINSIC NAVIGATIONAL CUES

Whereas HUD and GUI elements are clearly overlaid on top of the game world that the player interacts with, many other factors in an environment can influence player navigation; these cues may be visual or auditory or in rare cases even haptic. They can be gratuitous in nature and in some cases cease to be navigational cues and actually force navigational choices upon players. At the other end of the spectrum, these cues can be very subtle and work in a combined manner that is barely perceptible to the player.

### 1.10.1 MAPS (INTRINSIC)

While maps are a very common component of modern games, certain titles may not; despite being, large open worlds offer any kind of HUD/GUI mapping. Some instead rely on static in world maps, whilst this is uncommon, this is the case with Minecraft (Mojang, 2011), in which a map is a constructed and usually static object in the world. *Figure 51*.

***Figure 51.*** **The creation of static maps in Minecraft (Mojang, 2011)**

Similarly, Alien Isolation (Sega, 2014) requires the player to find their goals and current location by visiting a series of fixed computer terminals located in the environment. *Figure 52*.


*Figure 52.* **Computer terminal based static maps in Alien Isolation (Sega, 2014)**

### 1.10.2 ARROWS (INTRINSIC)

Sega's patent [1.7.2] only applies to floating arrows that are clearly part of the game's HUD. Therefore, games such as Team Fortress 2 (Valve Corporation, 2007) are able to use arrows as signage indicating to the player the flow of a level or new goal. In other cases, the developers use objects in the game world as pointing devices. *Figure 53*, *Figure 54*. Therefore, while abstract floating arrows may not be readily available to developers, innovation in the use of pointers has led to a great many novel approaches of signalling towards objectives. In Everyone's Gone to the Rapture (The Chinese Room, 2016) the direction of the next quest goal is indicated by a glowing ribbon of 'spirit energy'. Similarly, in Journey (thatgamecompany, 2012) floating strips of cloth flock together and flow towards the goal. *Figure 55*.

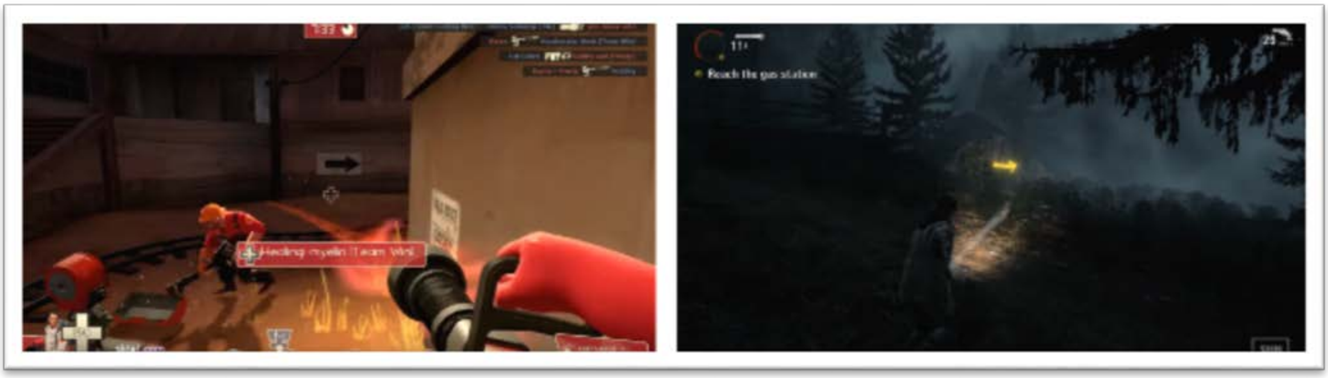

*Figure 53.* **Intrinsic arrows in Team Fortress 2 (Valve Corporation, 2008) [left] and Alan Wake (Remedy Entertainment, 2012) [right]**


*Figure 54*. **Arrows displayed on boards in Left 4 Dead 2 (Valve Corporation, 2009)**

***Figure 55.*** **In Everyone's Gone to the Rapture (The Chinese Room, 2016) the direction of the next quest goal is indicated by a glowing ribbon of 'spirit energy' [left]. Similarly, in Journey (thatgamecompany, 2012) floating strips of cloth [right]**

### 1.10.3 LADDERS, ROPES AND OTHER CLIMBABLE OBJECTS

The term affordance is often used by games designers to describe a physical object or piece of geometry either intrinsically interactive or so positioned as to appear to be interactive (McBride-Charpentier, 2011). Examples of these affordances include ladders, ropes, simple protrusions in rock faces or indeed any geometry that by its very nature indicates how the player can interact with it in a manner that precipitates exploration. *Figure 56*, *Figure 57*.


***Figure 56.*** **Climbable objects, allowing vertical exploration of an environment. Ladders in Donkey Kong (Nintendo, 1981 [left], ropes in Limbo (Playdead, 2010) [middle] and chains in Ico (Team Ico SCE, 1998) [right]**

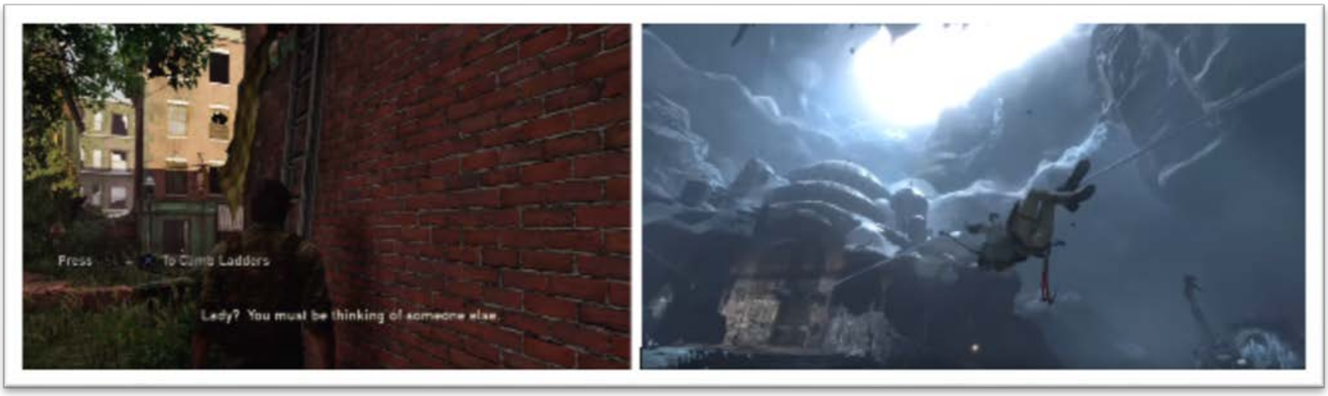


***Figure 57.*** **Complex climbable objects: Movable ladders in The Last of Us (Naughty Dog, 2013) and rope traverse in Rise of the Tomb Raider (Eidos Montreal, 2015)**

### 1.10.4 AFFORDANCE BY ASSOCIATION

Affordance by association is used extensively in the Assassin's Creed series (Ubisoft, 2007). A particular instance of this that is repeated throughout the series is that of birds' nests or roosts, or even simply their droppings may indicate locations from which players can make what is termed a 'leap of faith'. Essentially, this allows the player to perform a dive that should prove fatal only to 'miraculously' land in a hay cart or pile or convenient pile of leaves. What differentiates these affordances is the fact that they are only identifiable by the addition of a subtle cue that is otherwise a natural part of the environment. *Figure 58*.


*Figure 58.* **Bird nests and droppings indicate points where 'leaps of faith' can be made in the Assassin's Creed series (Ubisoft, 2007)**

### 1.10.5 DOORS, DROPS AND DYNAMIC EVENTS

The inverse to climbable objects that open up new areas of exploration are game elements that close off access to previously visited areas. This is very common in linear games where the designer is attempting to keep the player heading in the direction intended. Closing a door and making it impossible to open again is one method that is frequently employed, these doors may initially seem unlikely, but in the real world, security doors often have similar mechanisms. Further methods of blocking passages back to previously visited areas can include variations on; rock falls, explosions, fire, or water washing away a bridge. These dynamic events physically alter the environment to make backwards travel impossible. A simpler and very effective way of stopping backtracking in games where the character does not have the ability to scale great heights is simply to have a character drop down to a lower level that offers no climbable path to the point above.

### 1.10.6 SWITCHES, LEVERS AND INTERACTABLE OBJECTS

Access to new areas of a level may involve interacting with objects in the scene that in turn open a door, raise a platform or call an elevator. These objects may, in turn, require other collectable objects to activate them such as a crank handle. In effect, objects of this nature are simply an analogue of a key, but their unique nature can add interest to an otherwise mundane task. Interactable objects of this kind are often included to break up otherwise monotonous exploration, but also can lead to a heightened sense of drama and tension as the animated sequence resolves itself. *Figure 59*.

***Figure 59.*** **Switches Levers and interactable objects**

## 1.10.7 TEXTURE COLOUR AS A NAVIGATIONAL GUIDE

In 2008, Electronic Arts released it parkour-based action title 'Mirror's Edge' the game has a unique and striking aesthetic that was nominated for an AIAS (Academy of Interactive Arts & Sciences) award for 'Outstanding Achievement in Art Direction'. The game omits the usual maps, pointers and overlays in deference to a guidance mechanic built into the texture design (Bogost, 2008). The colour pallet for the city is primarily white with blue as the ambient shadow colour, the game then adds starkly contrasting dark red shaded objects to the scene, and it is these objects that form the goals, guidance and interactable objects throughout the free running space. *Figure 60*. At the time of release, this method of player guidance was innovative; it remains the clearest example to date of this approach to path marking.

*Figure 60.* **Mirrors Edge (Electronic Arts, 2008) Red Paths**

This method of highlighting via the colour of textures or the use of materials has been adopted by several titles and as it has become more commonly used, its subtlety has also increased. For instance, Uncharted 3's implementation of this concept was only slightly less visually obvious than Mirror's Edge in the particular shading and distinction of the highlighted geometry in this instance Naughty Dog chose to use a bright golden yellow shade throughout the game. *Figure 61*.

*Figure 61.* **Uncharted 3: Drake's Deception (Naughty Dog, 2011) yellow paths**

More subtly, Rise of the Tomb Raider (Crystal Dynamics, 2015) uses white highlights often in the form of worn paint to delineate its paths. Similarly, Uncharted 4: A Thief's End (Naughty Dog, 2016) again highlights in white in a subtle manner that blends with the underlying art style of the textures and does not appear as distinct or separate as the technique is employed in previous games in the series [*Figure 62*].

*Figure 62.* **Subtle use of white textures indicate climbable routes in Rise of the Tomb Raider (Crystal Dynamics, 2015) [left] and Uncharted 4 (Naughty Dog, 2016) [right]**

Whereas the games discussed above are subtle with their use of texture, colour and shading to define a path, or suggest affordances in the level design, Portal (Valve Corporation, 2007) defines clear paths to exits using clear colour coded signage to indicate whether the exit is open or closed *Figure 63*. Colour coding the line to the exit, blue if closed or orange if open. These guiding lines form a major part of the puzzle and narrative design of the game and although clearly included as navigational cues are an intrinsic component of the general aesthetic of the game. It is the affordances offered by integrating the navigational cues in this manner that allow the game to be playable without any kind of HUD or other kind of graphical overlay.

*Figure 63.* **Coloured routes to open or closed exit door in Portal (Valve Corporation, 2007)**

### 1.10.8 ART STYLE AS DELINEATOR

In Team Fortress 2 (Valve Corporation, 2007) all of the maps in the game are split into two distinct zones for the two opposing teams. As these maps are frequently labyrinthine and the player does not have a map of the play area, the designers differentiate between the two sectors by the use of discrete art styles. The most obvious difference is simply the colourisation of the textures, denoting the team colours, either Red or Blue. Beyond this, there are numerous subtle differences between the models used, the quality of the lighting and general wear and ageing of the two zones. *Figure 64*. This is despite in some of the levels, the actual physical layout of the environment being broadly a mirror image of the opposing team's base (Hellard, 2007).

***Figure 64.*** **While keeping the same geometrical spacing and door scaling, distinct differences in architectural style and colourisation differentiate the Red base from the Blue base in Team Fortress 2 (Valve Corporation, 2007)**

A further extension of this colourisation of environments is exemplified in War Thunder (Gaijin Entertainment, 2012) the title takes the general concept of team colours but allows the player to assign unique colours to factions. This colour assignment in a multiplayer context is only made visible to the individual player who assigned them.

### 1.10.9 ENVIRONMENTAL DEGRADATION AS DELINEATOR

Many games differentiate discrete areas of their worlds by the use of various types of deterioration of the environment. This can simply be sectors that have been left untended or conversely been recently renovated; they may be simply the differences in poor regions contrasted with those that are more affluent. This technique is used in the Grand Theft Auto series of games, often to inform the player that have veered on to the 'the wrong side of the tracks'. As can be seen in the images below [*Figure 65*] from Grand Theft Auto V there are distinct differences between neighbourhoods while the game retains a clearly defined art style. This kind of differentiation can be used as a navigational aid in a variety of ways from segmenting of a map to working in a similar manner to landmarks discussed previously.

***Figure 65.*** **Clear distinction between zones by environmental degradation in Grand Theft Auto V (Rockstar Games, 2013)**

### 1.10.10 STEPPING STONES

Repeated scattered objects in a scene add a point of visual interest that designers describe as stepping-stones. These repeated forms are intended by the designer to influence player navigational choices by offering enough difference from the rest of the environment to suggest a direction of travel (Pangilinan, 2010). These objects are often not intrusive and whilst blending naturally with the underlying scene, breaking up the preferred path as would natural stepping-stones. This is illustrated below in two examples from The Last of Us (Naughty Dog, 2013). *Figure 66*.

*Figure 66.* **The use of repeated seemingly incidental geometry as stepping stones in The Last of Us (Naughty Dog, 2013)**

## 1.10.11 VARIATION IN HEIGHT

As previously mentioned variations in height can close off areas from backtracking, however, it is commonly accepted that upward variations in height in a level, introduced by stairs, steps or simple raising of the floor plane encourages player movement in that direction, this may be to allow for a better vantage point. Changes in elevation also vary the environment and encourage exploration (Galuzin, 2011). *Figure 67*.

*Figure 67.* **Variations in height coupled with stepping stone geometry: Uncharted 4 (Bethesda Game Studios, 2015)**

### 1.10.12 MOTION

Moving and or animated objects on a screen will naturally draw the eye of a player toward either a goal or a point of interest (Itti & Baldi, 2009). Games designers encourage both gaze direction and exploration by utilising elements of seemingly unimportant or natural motion to draw the player's gaze to the point of interest or in the desired direction of travel. A large variety of stimuli are used in this manner, one of the more commonly used examples of this is the motion of flame, this can be in the form of lanterns, flaming barrels, or burning objects. For instance, Left 4 Dead (Valve Corporation, 2008) uses both the motion and simultaneous illumination offered by flames, commonly flaming oil barrels. Similarly, Bioshock (2K Games, 2007) draws the player's attention repeatedly with the use of cascading water. *Figure 68*.

***Figure 68.*** **Motion and contrast used to draw the gaze of the player. Running water in Bioshock (2K Games, 2007) and a flaming oil barrel in Left 4 Dead 2 (Valve Corporation, 2009)**

### 1.10.13 BIRDS

A subtle method of guiding visual attention that has been used by both Valve and Naughty Dog is to use the motion of flying birds to draw the player's gaze towards a focal point. In the example below from Uncharted 4, a bird of prey flies towards the mountain that is the mission objective. In Half-Life 2, crows are used to draw the player's attention towards a Combine Hunter stationed on a rooftop. *Figure 69*.

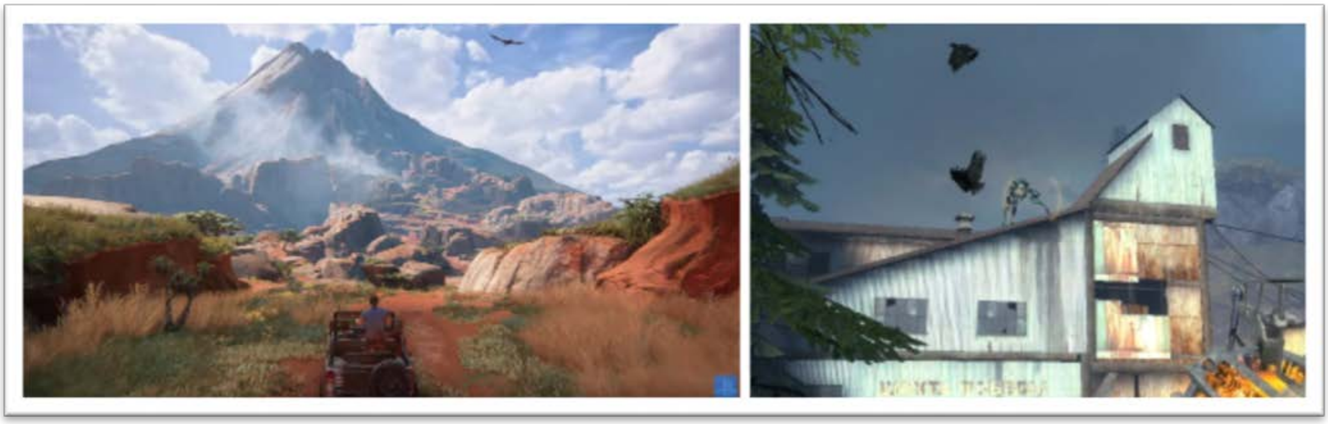

*Figure 69.* **The motion of birds flying across a scene draws the player's eye to a focal point. Uncharted 4 (Naughty Dog, 2016) [left] and Half-Life 2 (Valve Corporation, 2004) [right]**

A further example that is used more explicitly as indicating a point of interest is exemplified in Red Dead Redemption (Rockstar Games, 2013) in which, the circling of vultures above bodies draws the player to a pre-scripted narrative event in an otherwise open world environment. *Figure 70*. The scale of the vultures makes them specifically useful as a distal cue, while the circling motion is for the species a normal behaviour where carrion is present. The benefits for the developer in the utilisation of this and similar attention-grabbing animations is that they do not require an unnatural overlay, instead relying on naturally occurring phenomena such as fauna to move in such a manner as to be the clear nexus of the scene. Frequently, animations of this kind are combined with associated sound effects and camera motions to increase the importance of the movement.

*Figure 70.* **Vultures circle above a carcass in Red Dead Redemption (Rockstar Games, 2010)**

## 1.10.14 PICKUPS

Pickups also commonly referred to as 'power-ups' in games dating back to the power pellets and fruit that would appear in Pacman (Namco, 1980). *Figure 71*. Pickups are a standard inclusion in a very wide range of titles; these pickups may restore health and often mana (spiritual or magic energy), increase a characters shields or armour or offer ammunition or weapon upgrades. In other cases, such as in the Sonic the Hedgehog Games (Sega, 1992) the pickups are simply a collectable that is intrinsic to the gameplay- in the case of Sonic the Hedgehog, the rings offer protection from losing a life and gaining 100 adds a life.


***Figure 71.* Pick-Ups and Power-Ups: Power Pills in Pacman (Namco, 1980) [left] Rings in Sonic the Hedgehog (Sega, 1992) [middle] Health packs in Team Fortress 2 (Valve Corporation, 2007) [right]**

Whichever purpose they serve, pickups are frequently designed to be clearly visible, brightly coloured and often animated. As they are useful to the player, they are therefore desirable to collect and therefore may encourage deeper exploration of a level. In some instances, the layout of pickups such as health or ammunition packs can be designed with the intention of the player being guided in a particular direction in order to collect the pickups that line the trail. *Figure 72*. This is in comparison to some of the other techniques discussed somewhat heavy-handed, but as the trail itself proffers beneficial effects, it can be a powerful lure to players.


*Figure 72.* **An obvious trail of health pick-ups in Unreal Tournament 3 (Epic Games, 2007)**

## 1.10.15 BREADCRUMBS AND BLOOD TRAILS

Many games use a breadcrumbs style feature to draw the player through the level; these ‘breadcrumbs’ can be represented in a wide variety of forms; footprints, for instance, offer a visual clue that something has moved through the environment and could be followed. Vehicle tracks could potentially offer the same guidance. A commonly used visual guide is in the form of blood trails, these have been used effectively in titles such as Doom 3 (id Software, 2004) and Outlast (Red Barrels, 2014). *Figure 73*.

*Figure 73.* **Blood trails in Doom 3 (id Software, 2004) [left] and Outlast (Red Barrels, 2014) [right]**

The Witcher 2 (CD Projekt RED, 2011) takes the principle a stage further giving the character a feature in the form of a sense specifically designed to detect blood trails; this sense is represented by a switch to a high contrast graphical style in which the blood trails are represented in a bright orange hue. *Figure 74*.

***Figure 74.*** **Highlighting of blood trails in The Witcher 2 (CD Projekt RED, 2011)**

### 1.10.16 FOLLOWING NON-PLAYER CHARACTERS

Characters in video games can influence navigational choices in many different ways, dialogue, facial expression and gesture can clearly indicate to a player narrative information that may affect navigation. Non-player characters may indicate a new way to interact within the game space, for instance climbing up to a better vantage point (Ellison, 2008). Whereas many games may only use the non-player character to indicate a gaze direction and small movement at a crucial moment to allow for the player to catch a specific animated action, other titles utilise the following mechanic extensively as part of the ongoing narrative and particular the general navigational path. The Last of Us (Naughty Dog, 2013) utilises multiple characters at different points in the game to pull the player into the game world at a pace that is in time to the underlying narrative. *Figure 75*.


***Figure 75.*** **Typical NPC guidance text from: Grand Theft Auto V (Rockstar Games, 2013) [left], Half-Life 2 (Valve Corporation, 2005) [middle], The Last of Us (Naughty Dog, 2013) [right]**

The subtlety of NPC guidance in current generation games titles is in stark contrast to the egregious manner in which The Legend of Zelda: The Ocarina of Time (Nintendo, 1998), utilised a character of Navi the Fairy which would interrupt the gameplay in order to instruct and influence the player's navigation directly. *Figure 76*. This interruption was deemed intrusive and annoying by many reviewers of the game, and the character has become infamous for its ability to annoy the player. (Bateman, 2007; Lovett, 2008)


***Figure 76.*** **Navi the Fairy in The Legend of Zelda: The Ocarina of Time (Nintendo, 1998)**

## 1.10.17 LANDMARKS AND WEENIES

### 1.10.17.1 LANDMARKS

Landmarks within a scene are often used to distinguish a particular area and aid navigation by defining a specific point in a level (Vinson, 1999a). Landmarks do not necessarily have to be unique objects; they only need to be unique in context to that particular area. A diner on a street corner as in Grand Theft Auto V (Rockstar Games, 2013) may with the exception of a single sign texture, be a reusable piece of geometry distributed around the large open world. In some instances, where a title makes a particular point of utilising landmarks by which to navigate, these items will be of more of a unique nature. For example, in the image below from Fallout 4, (Bethesda Game Studios, 2015) two unique structures at different scales allow for player navigation on differing scales. The Minuteman statue is used for more localised navigation whereas the Red Rocket Truck Stop - while similar in principle to the more generic diner in GTA V - distinguishes itself with a unique and eponymous sculpture. *Figure 77*.

***Figure 77.*** **Distinctive diners in Grand Theft Auto V (Rockstar Games, 2013) and Fallout 4 (Bethesda Game Studios, 2015)**

### 1.10.17.2 WEENIES

The term 'weenie' was coined by Walt Disney; it is used to describe the eye-catching and imposing structures that can be seen at a distance. A weenie in common American parlance is a derivation of the term wiener that in turn relates to the home of the development of a particular type of sausage in Vienna (Wien) Austria. Disney appropriated the term to define something that people are drawn to after he noted that if he walked around his home carrying a small sausage aloft, his dogs would follow it endlessly and give it their full attention. He realised that when designing his theme parks (starting with Disney Land in California in the early 1950's), he could use distinct landmarks as a guidance aid for visitors to the parks and by utilising maps supplied. By locating these structures, the visitors would always have a fixed point by which they could navigate. *Figure 78*. Games designers such as Jesse Schell (Schell, 2013) who have previously worked for Disney as 'Imagineers' a term they use to describe their theme park designers have continued to use the term within video games development in the same manner.

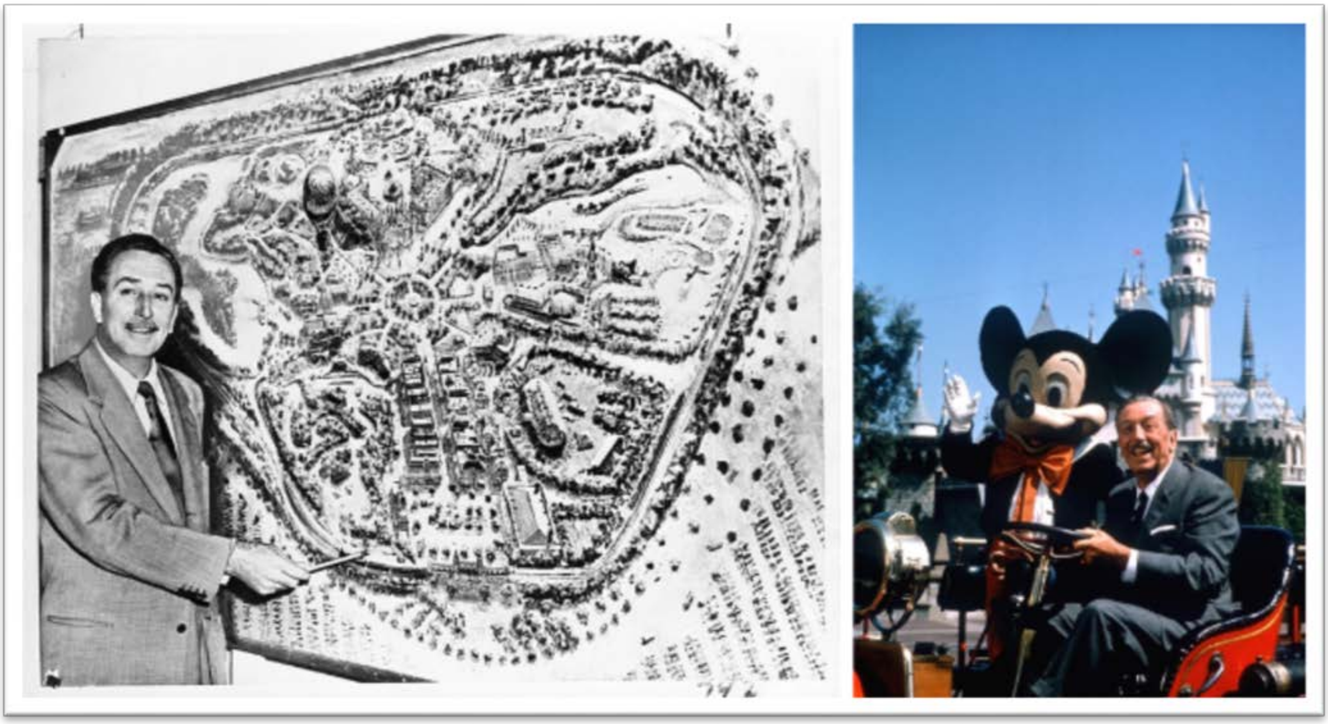

***Figure 78.*** **Walt Disney presenting his plans for Disney Land [left] and driving in front of one his self-described 'weenies.'**

Although weenies are quite obviously landmarks in their own right, what distinguishes a weenie from a standard landmark is usually its scale and often its incongruity. The object or structure needs to be distinct and quite obvious, and visible from great distances. In open world games, these structures can simply be a straightforwardly obvious point of navigation as in titles such as Fallout 3 (Bethesda Game Studios, 2008) or Journey (thatgamecompany, 2012) where the player will not be told directly that the 'weenie' is the goal of the mission. In other titles such, particularly in The Last of Us (Naughty Dog, 2013), the use of landmarks as quest goals is explicit and referred to heavily in the in-game dialogue. *Figure 79*, *Figure 80*.

Weenies due to their nature as distant objects allow for players to decide between perusing long term and short term goals, in effect the long term goal is always visible and the short term goals, therefore, can naturally take precedence while having the player always have the larger goal both in mind and in view (S. Rogers, 2009).

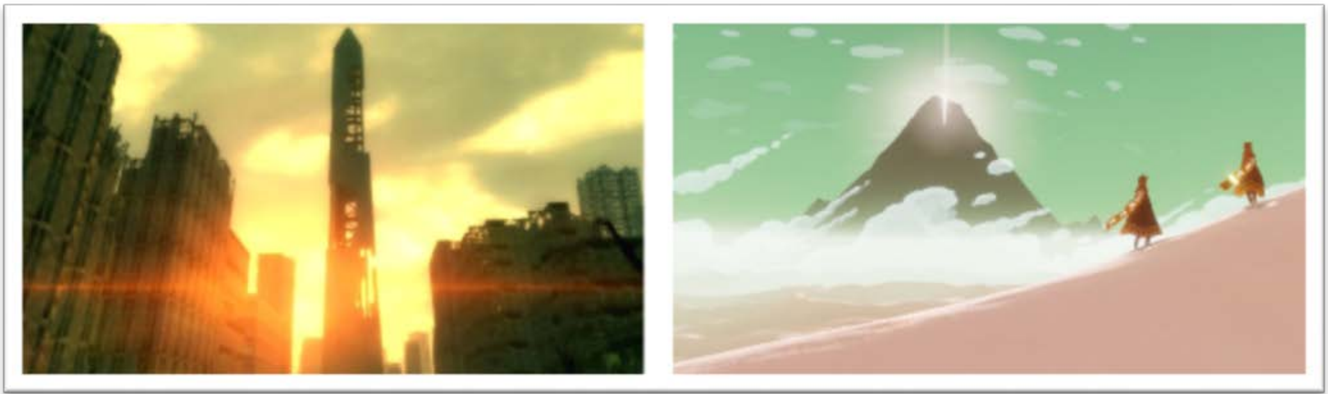

***Figure 79.*** **Examples of Weenies: Tenpenny Tower in Fallout 3 (Bethesda Game Studios, 2008) [left and the Mountain in Journey (thatgamecompany, 2012)**


*Figure 80.* **Weenies in The Last of Us (Naughty Dog, 2013) are frequently pointed out by the NPC's**

#### *1.10.17.3 TRIANGULATION POINTS*

Beyond the use of unique weenie style structures, the inclusion of three or more large distal cues or points of reference can allow for triangulation within a game world (P. Arthur & Passini, 1992). These objects assist the player in developing a cognitive map of the world. The use of triangulation points affords the player similar orientation information as would an in-game compass.

### 1.10.18 COMPOSITIONAL TECHNIQUES

The compositional techniques common to other media such traditional art or film including the structure the position and motion of cameras and the framing that this affords are utilised by game designers (Birn, 2006). However, within a video games context, it is often not easy to specifically compose a precise image unless the segment of the game takes place as a video sequence or similar cut scene. At all other times, when the player is in control, the designer is forced to take into account the fact that the player is in motion, can be crouching, standing, walking or even jumping and then have to compensate for a dynamically moving camera. For these reasons, it is uncommon for game designers to adhere strictly to these rules.

### 1.10.18.1 FRAMING AND ARCHES

A compositional technique used to draw both the eye of the player and in turn, the player's motion is the use of framing. Often combined with changes in contrast, where the brighter area beyond the frame gives the viewer a natural guide. These techniques are used extensively in video games. Framing of this nature can be created by objects, both natural and architectural, can highlight important new scenes or objects and combined with lighting can offer strongly contrasting points of interest. In the development of Uncharted 2 (Naughty Dog, 2009), the designers specifically utilised the shapes that objects such as trees make to create arches, their assumption being that players have a natural tendency to be drawn through apparently natural portals (Pangilinan, 2010). *Figure 81*.

***Figure 81.*** **Examples of arches and natural framing in The Elder Scrolls V: Skyrim (Bethesda Game Studios, 2011) [left] Uncharted 2 (Naughty Dog, 2009) [middle and right]**

### 1.10.18.2 NEGATIVE SPACE

The term negative space usually refers to the space between or surrounding the focal point(s) of a composition. Use of negative space in a games scene can form a non-specific guide to the player for instance in the image below. The tunnel walls and the detritus on the ground provide guiding concentric rings and guiding lines that draw the eye to the centre of the image. The midpoint of the image holds no specific information for the player, this being obscured by the use of depth fogging. However, this use of negative space still draws the player along the tunnel. Limbo, (Playdead, 2010) uses negative space extensively, where the foreground is in silhouette with the exception of key elements such as the main character's eyes. *Figure 82*.


***Figure 82.*** **Examples of negative space in Left 4 Dead (Valve Corporation, 2007) and Limbo (Playdead, 2010)**

### *1.10.18.3 GUIDING LINES AND CAMERA ANGLES*

One of the more commonly used compositional techniques used in traditionally produced art is the use of subtle lines that guide the viewer toward a focal point in an image; invariably this focal point will also be an area of high contrast. As it can be seen in the illustration below [*Figure 83*], the lines along the edge of the path as well as the flow of leaves in the trees curve gracefully towards the central figure. The figure itself is darker than the lighter fogging behind it and is drawn further forward by both the contrasting red against blue as well as a deeper saturation of colouring between the figure and the pale grey-blue/green background.

***Figure 83.*** **An example of guiding lines in an artistic composition.**

These self-same techniques are used throughout all visual media from photography to film to video games. Video games unlike pre-composed media such as film require that the guiding lines work in conjunction with the position of the camera. As can be seen in the image below [*Figure 84*] from Uncharted 4 (Naughty Dog, 2016), the scene has been specifically crafted to make the goal extremely distinct. The narrow wall that the character approaches the area from allows for the precise focus of the camera. The lighting against the goal is bright and distinct; there is an area of bright and contrasting colour in the form of a red flag in a predominantly muted brown/green scene. Lines including a conveniently positioned affordance of the telegraph wire point directly at the goal. Should the player be too keen to simply take a running jump at the goal, the level designers have also incorporated a small barrier that breaks the direction of movement while still emphasising by shadow and contrast the correct path to take.

***Figure 84*. Example of guiding lines implemented in Uncharted 3 (Naughty Dog, 2011)**

Good camera positioning and framing in modern video games are not accidental; early 3D video games made many mistakes with camera positioning. For instance, confusing the player by flattening 3D surfaces consisting of uniformly lit repeating textures. *Figure 85*. In Tomb Raider (Core Design 1996) it was possible to not only lose the sight of the space in front of the player avatar but to lose sight of the avatar herself as she ran behind walls and other geometry.

*Figure 85.* **Camera movement issues occluding the player character in Tomb Raider (Core Design 1996)**

In Resident Evil (Capcom, 1996), due to the use of static cameras, it was possible due to poor camera positioning to either lose track of the character or to have the character attacked by a previously unseen opponent. Resident Evil also repeatedly broke the 180-degree rule of cinematography by switching to the opposite side of an imaginary wall; leading to navigational confusion for the players (Hvorup, 2016). *Figure 86*.

*Figure 86.* **NPC's in between the camera and player character in Resident Evil (Capcom, 1996)**

### *1.10.18.4 CAMERA MOTION AS A NAVIGATIONAL CUE*

Beyond cameras simply tracking the player, a technique that is commonly used in third person perspective titles where the camera follows behind the player's avatar is a spline based camera motion that is triggered at a particular location. This is an intrinsic cue, as it does not break the gameplay; it simply shifts the camera angle during normal play to allow emphasis to be placed on the structure and layout of the scene. This emphasis offering visual clues as to where to proceed. The first game to implement this technique was The Legend of Zelda: The Ocarina of Time (Nintendo, 1998), but this is perhaps best exemplified by the dramatic and precise use of camera motion in Ico (Sony Interactive Entertainment, 2001). *Figure 87*.


***Figure 87.*** **Early examples of dynamic camera motion that indicates the direction of navigation. The Legend of Zelda: The Ocarina of Time (Nintendo, 1998) [left] and Ico (Sony Interactive Entertainment, 2001) [right]**

## 1.10.19 LIGHT AND CONTRAST

The use of lighting as a navigational aid in video games predates the ability to dynamically affect light and shadow afforded by modern game engines. The earliest 3D games on systems such as those on PlayStation 1 did not use any true lighting or shadows. As can be seen from the image below from Tomb Raider (Core Design, 1996) the shadows are created by a process called vertex shading, this offers simple shading across individual polygons based upon the colourisation of individual vertices. Lighting and shadow are inferred in these early 3D titles, but they could not, given the processing power available deliver accurate results. For instance, the shadow cast by the Lara Croft character is simply an extra shaded polygon that follows with the character. As the blending is additive, the result is a shadow on top of an already existing shadow. This applies to most shadows in games of this era; however, whereas the lighting in Tomb Raider often fails to differentiate surfaces adequately, the lighting in titles such as Crash Bandicoot (Naughty Dog, 1996) shows clear delineation of the path. The designers at Naughty Dog had quickly realised the importance of clearly defined paths and performed what they called the 'squint test' (S. Rogers, 2010) in order to ensure that the route the player was meant to follow was always the brightest and most obvious element on the screen. *Figure 88*.

***Figure 88.*** **Contrasting paths as player guidance. Poor lighting flattening textures: Tomb Raider (Eidos, 19977) and strong, clear paths in Crash Bandicoot (Naughty Dog, 1996)**

With increasing computational power, it became possible to improve the quality of in-game shadows; vertex shading is still utilised to offer a basic type of self-shadowing in many titles, although in many instances even this has been supplanted by multiple approaches to the generation of ambient occlusion.

Dynamic lighting and shadows in real time games are much harder to achieve computationally than methods that pre-calculate or 'bake' the lighting on to the game geometry. Shadow volumes go some way to addressing the problem of creating real-time shadowing in a virtual world (Crow & Crow, 1977). Dynamic per-pixel lighting was implemented without softening on to animated surfaces for the first time in Doom 3 (id Software, 2004). *Figure 89*. As engines have developed, so has the lighting quality, Half-Life 2 (Valve Corporation, 2004) introduced High Dynamic Range

(HDR) lighting that allowed for broad changes in contrast to be handled in real time. Whilst pre-baked, this technology enables players to experience the differences between indoor and outdoor lighting brightness with the on-screen graphics simulating the effect of pupillary dilation.

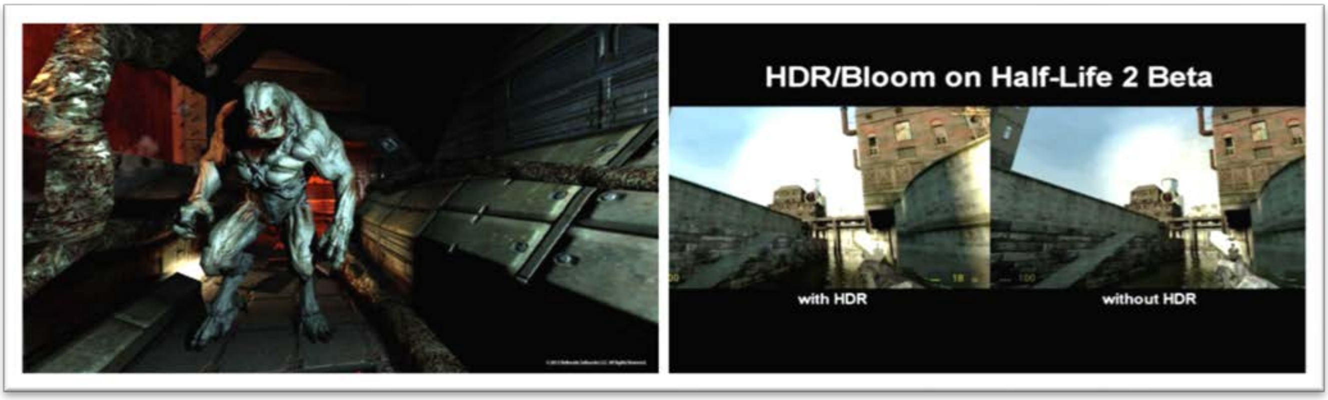


***Figure 89.*** **Dynamic per-pixel lighting in Doom 3 (id Software, 2004) [left]. Half-Life 2 (Valve Corporation, 2004) introduced High Dynamic Range (HDR) lighting [right]**

In 2008, the Source engine that had been used to create Half-Life 2 was utilised in the development of Left 4 Dead (Valve Corporation, 2007), a survival horror game that took place largely at night. This game utilised the techniques available at the time to pull the player into the game world using a wide variety of navigational cues, primarily these are in the form of lighting cues. Dark spaces end in lit openings using both framing and contrast encouraging exploration; important spaces will be strongly illuminated, often with either a flickering broken light or a burning barrel adding motion to the light source of a building or doorway. Goals in the form of buildings and in particular waypoints are extremely strongly illuminated. Left 4 Dead also handles lighting of scenes in a specific manner; light in the distance at the next junction will appear very bright by contrast to the surrounding shadows in which the player is standing. However, once the area has been entered, the overarching illumination of that area will gradually lower in intensity due to a fall-off of the light source. This allows for the next junction again to be illuminated in the same manner. In this way, the game allows players to always follow an illuminated path without having to increase the brightness of each subsequent light source continually.

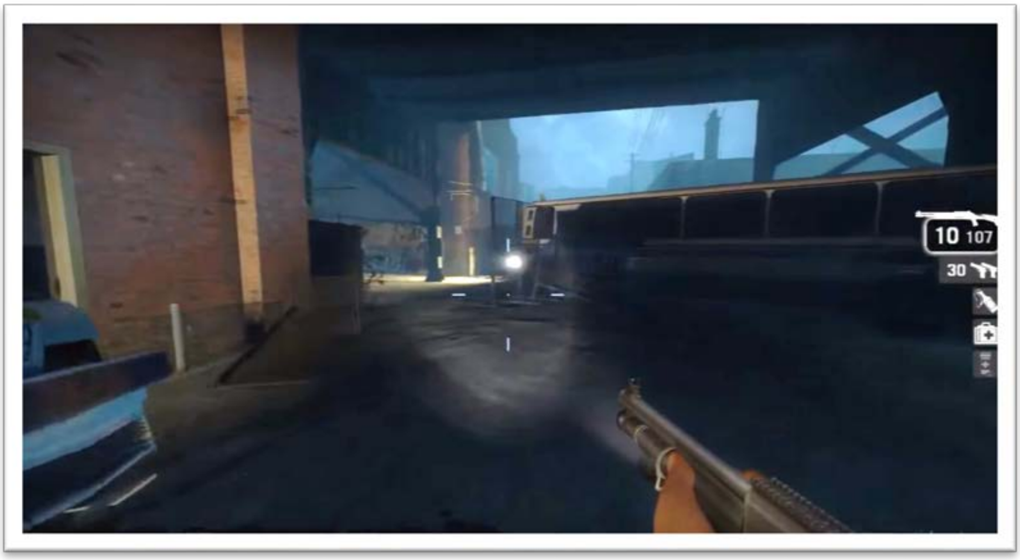

*Figure 90.* **Vehicle headlight as a focal point: Left 4 Dead (Valve Corporation, 2007)**

Many of the light sources in Left 4 Dead are at ground level, rather than being above head height, vehicle headlights are used extensively to provide a strong focal point with a long directional fall off. *Figure 90*. These headlights can either be pointing directly toward the character as an attraction or away from an area of darkness highlighting the required route. Due to the fact that these lights work as headlights do in the real world, the lighting has a natural quality that despite being very specifically controlled by the lighting designer does not manifest as being out of place or forced (Lundeen, 2009). *Figure 91*, *Figure 92*.

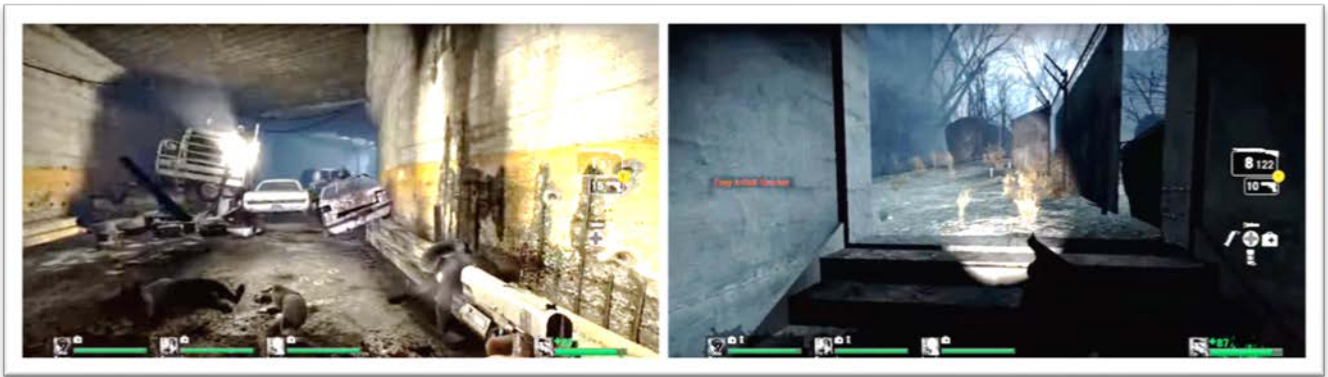

*Figure 91.* **Lighting combined with archways providing directional guidance in Left 4 Dead (Valve Corporation, 2007)**

***Figure 92.*** **Lighting of waypoint doorways strongly contrasting with surrounding lighting in Left 4 Dead (Valve Corporation, 2007)**

These techniques of using illumination to provide contrast and focus are now commonly used in many titles. Some such as Alan Wake (Remedy Entertainment, 2010) make the lighting of the game one of its primary mechanics with the 'darkness' of the game being the ethereal enemy and the torch the eponymous protagonist carries being required to make the 'darkness' able to take damage. According to the art director Saku Lehtinen (2010), the torch light and general lighting composition themes in Alan Wake were based upon scenes from The X-Files (20th Century Fox, 1993). *Figure 93*.

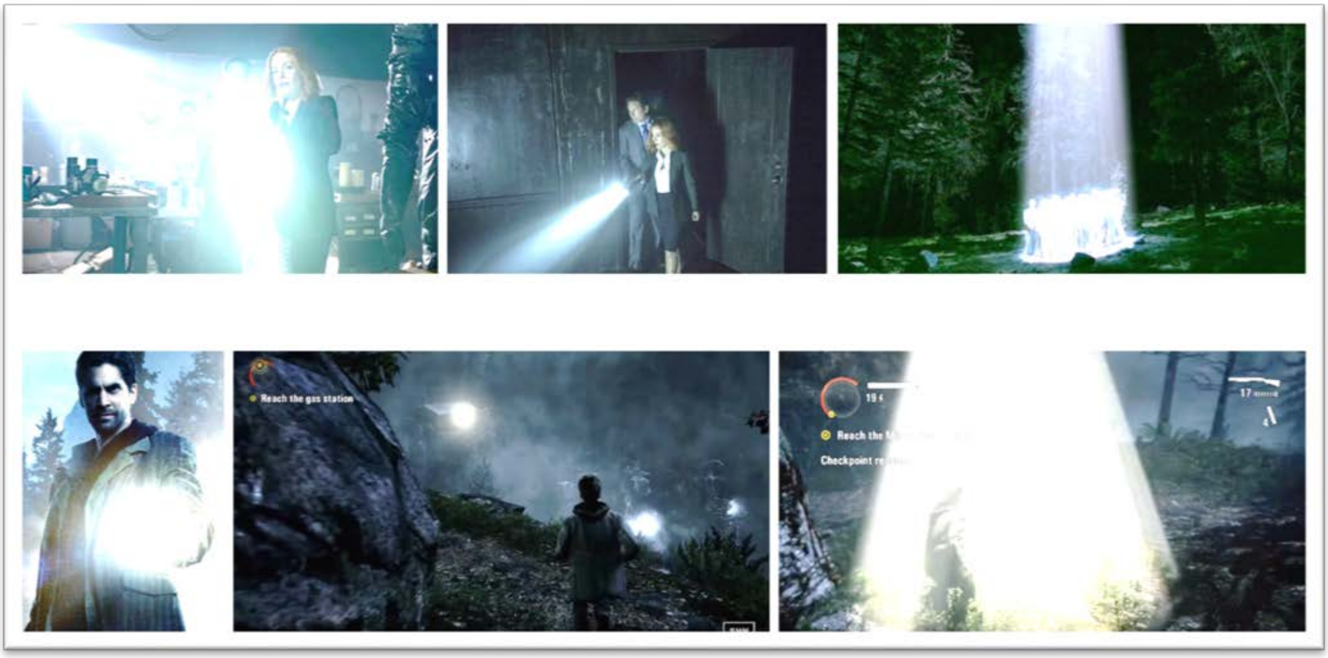


***Figure 93.*** **Lighting design concepts from The X-Files (20th Century Fox, 1993) [top] were used in Alan Wake (Remedy Entertainment, 2010) [bottom]**

The game uses many similar guidance techniques discussed above in Left 4 Dead but also incorporates beams of light produced by street lighting, helicopter lights and a lighthouse to spotlight upcoming areas of interaction. *Figure 94*.


***Figure 94.*** **The use of distal lighting as a form of weenie in Alan Wake (Remedy Entertainment, 2010)**

## 1.10.20 SILHOUETTES

A further manner in which lighting is used by games designers is to illuminate a key object or goal from behind in order to create a distinct silhouette. These techniques are again used effectively in both Left 4 Dead and Alan Wake the latter uses both fog and silhouettes cast in front of the fog to create areas of high contrast with the intention of drawing the player towards these new areas of visual interest. *Figure 95*.


*Figure 95.* **Examples of silhouettes designed to draw player attention: Left 4 Dead (Valve Corporation, 2007) [left] Alan Wake (Remedy Entertainment, 2010) [right]**

## 1.10.21 AUDIO GUIDANCE

Many titles offer the player specific guidance in the form of audio cues. These cues can be very specific in nature. For instance, a non-player character may be in voice communication with the player; this is distinct to the verbal guidance offered by a visible character, whilst ostensibly similar in nature, the visibility of the character is usually the main factor in the navigational influence towards a player. The player is generally instructed to simply follow the NPC. In cases of disembodied verbal instruction, this type of navigation cue needs to be attended, interpreted and acted upon independently.

Audio cues in the form of sound effects are used extensively to draw the player through an environment. This can be something as obvious as a telephone ringing, but in many instances is more subtle. For instance, the sound of water may rise in intensity as the player approaches and therefore act as a directional cue.

Music is used both as a narrative device, but also in multiple ways to convey information about a space; it can add atmosphere and ambience, specific styles of music setting additional context such as the time period the game is set in.

## 1.11 THE ILLUSION OF CHOICE

It is clear that the techniques implemented by video games designers and more generally by designers of all types of virtual environments draw upon a very broad range of techniques to guide players through complex three-dimensional spaces. However, it is not usually the case that these worlds offer unstructured travel and total freedom. Video game designers use these techniques to support an underlying narrative. These narratives can seem to the player to be complex and often give the impression to the player that they are forging their own path and creating their own story. For instance, the underlying design may allow for the branching of quests and opportunities to make discoveries in a non-linear fashion, but it is very common for these branches to lead to sequential narrative subplots. Therefore, most open world games that do have a coherent narrative merely give the impression that the player is driving the story.

In a 2016 lecture at the Game Developers Conference (GDC), Jim Brown of Epic Games (2016) elucidates upon the game designer's adoption of The Illusion of Choice or The Illusion of Decision (Cornford, 1974). Essentially, this paradigm suggests that individuals not only tend not to notice that their choices are restricted but also actually prefer to have a limit to the number of options:

> *Consider the difference between these two requests:*
>
> *Request 1: Pick a color: _____________*
>
> *Request 2: Pick a color: a. red b. blue c. green*
>
> *Both of them give the answerer freedom of choice, and they are both asking for about the same thing. But the difference is tremendous because for Request 1, the answerer could have chosen one of millions of different answers — "fire engine red, " "cauliflower blue, " "mauvish taupe, " "sky blue pink, " "no, you pick a color, "or just about anything, really* (Schell, 2013).

In game worlds, players are able to act based upon the rules and mechanics of the game, the actions and choices that they make can be constrained by the design of the game. The manner in which the player can is offered freedom to make choices in the game stems from whether the player is offered either agency or autonomy:

- Agency: The capacity to act in any manner possible and for that action to not be predetermined.
- Autonomy: Making decisions that are constrained by narrative, rules or limits of choice.

In practice, few games offer the player agency due to the lack of narrative that is a consequence of unlimited choice. Minecraft, for example, offers players the ability to create anything that they wish within the parameters set by the game. While this offers the player an affordance of agency, it does, however, mean that there is no underlying narrative within the title in the traditional sense (Sainsbury, 2013). In more conventional, narrative driven titles, the player is able to make choices based upon the options and constraints imposed by the designer. Brown (2016) states that offering an illusion of choice is actually preferred by game players. He provides the following explanations for this:

- The Paradox of Choice: Research has demonstrated that offering too much choice increases cognitive load, (Schwartz, 2004) and can become an unpleasant experience, and this can break what game designers deem the 'flow state' (Ranalli, 2008).
- The Availability Heuristic: Operating on the concept that if something can readily be recalled, it must be more important than something that is not so readily recalled. This leads to a familiarity with a concept or idea that becomes, in turn, preference or liking for that idea. This is similar to the concept of confirmation bias.

As Brown (2016) indicates, one of the main reasons that games can offer repetition of modes of engagement and tasks, and also why methods of play, navigational cues and modalities are effective from title to title, is in some part due to the availability heuristic; players have familiarity with these methods, and familiarity engenders liking.

> *Remember that no matter how open or linear a level is; the player is always on some sort of path from A to B – game theory actually revolves around getting a player from the point of origin to a goal. And it's totally fine if there's only one path – as long as we give players the autonomy to FEEL like it's the path THEY chose* (J. Brown, 2016).

It is therefore accepted that the most successful approach from a player engagement perspective is to respect the paradox of choice, to remove extraneous options such as multiple navigational choices, and therefore lower the cognitive load placed upon the player. The player perception that the limited number of choices available are now somehow more relevant offers both a heightened sense of autonomy and an increase in their personal enjoyment of the title (Schwartz, 2004).

It is frequently the case in open world games that dynamic events will steer the player in the direction of a goal. This is implemented in Grand Theft Auto 5, the player has an entire city in which they can roam, but the designers manipulate player guidance by introducing scripted events such as car crashes that will block a particular route pushing the player in the desired direction.

These principles and heuristics go some way to explaining the construction and layout of modern games, be they ostensibly open world or linear in nature; the options are constrained at all times for narrative reasons by the game designers.

## 1.12 SUMMARY

Video game designers over decades of playtesting and development have created titles that utilise a very broad range of guidance techniques. The complexity of geometry has evolved from simple repeated blocks to highly detailed and organic landscapes. Simultaneously, the implementation of lighting has moved from simple vertex shading to dynamic systems that mimic real world lighting effectively. As these processes and systems have evolved, the requirement for reliance on graphical overlays in the GUI has diminished. In some cases therefore, the GUI has been supplanted in by intrinsic navigational systems that subtly pull the player through the title. In practice, this is still rare and many games still use elaborate GUI based navigation systems.

Game designers when discussing their process frequently state that they draw upon principles derived from human cognitive psychology research (J. Brown, 2016; Pangilinan, 2010; Schell, 2013), they utilise these principles to engage their players. They understand how to avoid excessive cognitive load and, moreover they understand that the navigational choices that they present their players with can be constructed in such a way that they can present an illusion of choice despite the game actually maintaining a linear path or narrative.

The subtlety of intrinsic navigational devices has evolved to a state of maturity, the principles of using motion, architecture and lighting amongst many other techniques to draw the player's attention and encourages exploration. These principles cross-pollinate between titles while constantly encouraging innovation in design. However, despite many open world games now incorporating these ideas and concepts, the actual effectiveness of each method has not been studied in isolation, games designers and producers do not engage in such specific research, they build a level and test with a small number of people, adjust based upon small-scale play testing and iterate this model (Schell, 2013).

This chapter has shown that there is a drive to make in game navigational guidance more subtle and embedded in many titles. However, despite all of the techniques discussed in this chapter being commonly used, little academic research has been conducted into how elements such as gradients, motion, colour or simply lighting can affect navigation and whether these cues can act at sub-perceptual levels. This thesis concentrates on these specific issues and primarily on the effect, subtle lighting cues can afford navigation. Chapter Two contains sections on how light effects navigational choices, Chapter Three explores the principles of composition that coupled with lighting guide the eye. The remaining chapters of the thesis form a series of interlinked studies into the effect lighting has on navigation, how these effects can be either reinforced or reduced via additional intrinsic cues such as architectural or audio cues and the thresholds at which these cues become salient.

# 2 CHAPTER TWO:

# LITERATURE REVIEW

## 2.1 HUMAN SPATIAL NAVIGATION

### 2.1.1 NAVIGATION IN REAL AND VIRTUAL WORLDS

This chapter anlalyses the cognitive psychological perspectives that underpin the design of virtual worlds or video game environments with regards to influencing navigational choices. The human visuospatial system affords the ability to perceive abstract two-dimensional images as representations of three-dimensional worlds. The manner in which this perception functions, how these two-dimensional images are processed, and how navigation in these worlds correlates to real world choices and at what thresholds of visual difference such as contrast or brightness are key to understanding which visual aspects are most salient when building complex virtual environments such as video games.

### 2.1.2 CAUSATION, SPATIAL MEMORY AND COGNITIVE MAPS

Humans as with other animals develop the ability to navigate spatially as part of their natural development, babies as young as 4 to 8 months develop goal-oriented behaviours (Piaget & Inhelder, 1956) and begin to develop spatial schemas or mental representations of scenarios at roughly 18 months. These basic topological ideas are at this stage generalised offering the child only a broad understanding of their surroundings.

In the mid-20$^{th}$ century, a debate was ensuing concerning the manner in which spatial and navigational behaviours in animals could be said to be simple stimulus-response (SR) associations or instead that these responses demonstrated that deeper learning about an environment was taking place. For example, Skinner (1935) reasoned that animals learned via a series of reinforcing consequences and that their responses to particular stimuli built over time to become ingrained behaviours. This behaviourist approach to animal psychology did not address observed phenomena, a more observationally robust method of research (Tolman, 1938) led to the creation of theories which offer a more nuanced and neuroscientific observation of animals. Tolman (1938) was convinced that animals do not in fact just rely on simple SR associations to determine their spatial and navigational choices and were in fact highly adept at building mental representations of their surroundings a concept Tolman refers to as a cognitive map. Tolman believed that cognitive maps are a form of latent learning and are created automatically without the requirement of reinforcement stimuli.

An understanding of how these maps are coded and stored is evolving (Burgess et al., 2002), it has been clear since 1957 (Scoville & Milner, 1957) that the hippocampus has been integral to the storing and subsequent retrieval of spatial and episodic memory. These episodic memories are of a spatiotemporal nature and are distinct from verbal and narrative memory, which is stored in the neocortex. O'Keefe and Nadel (1978) built upon Tolman's cognitive map concept and expanded it based upon discoveries from a neurological perspective. They propose two distinct systems that define spatial abilities, terming these the 'taxon' and the 'locale' systems. The taxon system being associated with learning from orientation and guidance whereas the locale system is related to the construction and retention of cognitive maps. From the perspective of the taxon system, spatial information is not relevant, the orientation being governed simply by SR associations or by guidance learning where individual features in space are associated with a specific goal and the relationship between these two elements governs navigation. Therefore, accurate spatial navigation based upon a cognitive map was defined to be the preserve of the locale system. The locale system (O'Keefe & Nadel, 1978) allows for the updating of the cognitive map to allow for changes within an environment dynamically with exploration. Cognitive maps combine topological features and landmarks that remain stable in an environment or at least remain static for some considerable time (Pearce, 2009). Therefore, it is not possible to construct a reliable cognitive map based upon reference to a moving landmark (Biegler & Morris, 1993). Further investigation from a neurological perspective has supported these concepts and demonstrated the involvement of the hippocampus in coordinating spatial learning of this kind (Doeller, King, & Burgess, 2008).

### 2.1.3 NAVIGATIONAL CUE COMPETITION

The research into navigational cue competition suggests that spatial memory is not a unitary task and is an interrelationship of discrete brain structures (Biegler & Morris, 1993; Doeller et al., 2008; Pearce, 2009). fMRI studies (Caclin et al., 2011; Doeller et al., 2008) have both confirmed this hypothesis and demonstrated that humans can reconstruct and adapt cognitive maps dynamically to accommodate changes in the location of a goal in relation to fixed landmarks. This research suggested a complex relationship between brain regions primarily the hippocampus and the dorsal striatum that process and structure the information. These studies indicated that landmark-related learning obeyed associative reinforcement, whereas boundary-related learning is incidental in relation to a feature environmental margin. Navigational cue competition was a recurrent factor in navigational experimentation; these cues can affect the outcomes of tests by introducing factors that influence spatial cognition but also can affect outcomes in a temporal manner. According to Tlauka et al. (2011), much of the evidence for cue competition in the spatial domain could, in fact, be explained as a result of the taxon system being utilised.

An example of how the taxon system has been analysed in practice would be via the methods rats use to discover hidden platforms located in a Morris Water Maze task (Morris, 1981). Multiple studies have concluded that navigation in these environments can be explained by the association formed between the goal and surrounding landmarks, via viewpoint matching. An underlying novelty in shortcuts can be explained via this method of understanding (Morris, 1981, 1984).

## 2.2 THE ARCHITECTURAL PERSPECTIVE

In humans, the primary navigational stimulus is visual; navigation appears to be one of the primary functions of vision in the vast majority of animals (Golledge, 1995). The systems that humans as with many animal species utilise include: cue or landmark recognition; turn angle estimation, route linkage sequencing alongside various route plotting strategies including; dead reckoning, environmental simplification and shortcutting. In practice, these route plotting strategies are adaptive systems that interact with and adapt to the surroundings and impact the speed, method and direction of motion (Dalton, 2003). Routes may be perceived as longer or shorter dependant on whether they point towards or away from a primary reference point (Montello, 1997; Sadalla, Burroughs, & Staplin, 1980).

Space syntax (Hillier & Hanson, 1984) describes the emergence of complex spatial-navigational patterns, derived from the cumulative mapping of individual behaviours. Contingent with these behaviours, space syntax, sets out to define a set of discrete rules or principles (Dalton, 2003; Golledge, 1995; Peponis, Zimring, & Choi, 1990). Chief amongst these is a preference to maintain linearity when presented with divergent options. This preference for maintaining linearity is reflected in the fact that people will prefer to take a particular route between points A and B but a different route from points B to A. This finding is broadly correlated with Dalton's 'British Library Theory' (Dalton, 2001) which indicates that on average, people will instinctively prefer to take the longest leg of a known journey first choosing a different path from A to B than from B to A due to initial distances. *Figure 96*


***Figure 96.*** **People prefer to take the longest leg first, even when returning to a starting point.**

An important factor of Dalton's research is the fact that it is partly conducted within virtual environments displayed on a traditional monitor and Dalton notes that key navigational decisions are maintained from the real to the virtual worlds (Dalton, 2003). Further to these findings were similar principles relating to a preference for following paths that offer the longest line of sight, strategic visual elements such as landmarks and that people actively avoid backtracking or revisiting a previously explored area. This latter finding was shown to be especially true of people navigating a novel environment. O'Neill (1991) Golledge, (1995) and Dalton (2003) detail the navigational preferences exhibited within virtual environments which can be distilled to the following principles: (These principles are explored in depth in the following sections)

- Preference for taking the shortest path
- Preference for maintaining a linear path
- Preference for maintaining linear path despite gradient
- Preference for path with the farthest line of sight
- Preference to avoid backtracking
- Path with more turns perceived to be longer than an equal length path with fewer turns
- Longest leg first preferred to shortest leg initially
- Preference for curved paths over sharp angled turns
- Angle of exit routes from a junction relative to the entry

### 2.2.1 PREFERENCE FOR TAKING THE SHORTEST PATH

This distinct preference for the linear path is in contrast to a similar path to a known location that follows a still linear yet flowing or curved route. Subjects were shown to display preference to routes that minimised to the actual Euclidean distance between points by travelling through the middle of a route (Golledge, 1995). This preference for taking the shortest route correlated to the preference for maintaining a linear path; any given route between two points is shortest when described by a linear path.

### 2.2.2 PREFERENCE FOR MAINTAINING A LINEAR PATH

It has long been understood that humans display a distinct preference for maintaining linearity, Tolman (1938) suggested that the reason for this preference is that it offers a reduction in complexity in an otherwise complex environment. One reason for the propensity for maintaining linearity could relate to the limitations of working memory. Longer path choices would necessarily reduce the number of path options and consequently be more likely to be retained in working memory particularly if the number of junctions was kept to within what is often referred to as the magic number (Miller, 1956), this being nominally seven plus or minus two. Dalton (2003) suggested that direction of travel, so long as it approximates the general orientation of the ultimate destination, will show a strong conservation of linearity with minimal angular deviation.

### 2.2.3 PREFERENCE FOR MAINTAINING LINEAR PATH DESPITE GRADIENT

Chang et al. (1998) described an effect for maintaining linearity despite changes to the gradient. They discovered that it is not only a general trend for pedestrians to choose the shortest and axially simplest routes but also, that pedestrians who have a direction in mind and set their directions as soon as possible when embarking on a route. They concluded that while pedestrian decision behaviour in route choice is affected by their familiarity with an area, axial depth from routes between the major attractors and generators of movement in the area also appears to be implicated. Gradient transitions seem to have relatively little effect.

### 2.2.4 PREFERENCE FOR PATH WITH FARTHEST LINE OF SIGHT

Dalton, (2003) indicates that route choices are also often associated with the path that offers the furthest line of sight. Conservation of linearity is frequently associated with the preference for paths that offer strategic visual information; long sightlines allow for a route with more salient features be considered and in turn influence navigational preference.

### 2.2.5 PREFERENCE TO AVOID BACKTRACKING

Common to much of the literature was a distinct avoidance of deliberate backtracking (Moffat, Zonderman, & Resnick, 2001). In certain scenarios, no participant chose to backtrack i.e. return back down the previous path taken (Dalton, 2003). This suggests a very clear and distinct preference for exploring previously unexplored areas.

### 2.2.6 PATH WITH MORE TURNS PERCEIVED TO BE LONGER THAN AN EQUAL LENGTH PATH WITH FEWER TURNS

Cognitive distances are defined as cognitive representations of large-scale environmental routes that cannot be perceived from an individual vantage point but require movement through the environment for their comprehension (Montello, 1991). Jansen-Osmann & Wiedenbauer (2004) indicated a route-angularity effect, which is demonstrated when a greater number of turns along a route increases the estimated length. It is suggested that this effect is concurrent with increased memory load during navigation and that the number of turns is categorically encoded and significantly increases the perception of the length of each pathway (Hutcheson & Wedell, 2009). Due to this perception, in repeated studies, it has been demonstrated that participants showed a preference for the route with the fewest turns (Dalton, 2003; Golledge, 1995).

### 2.2.7 LONGEST LEG FIRST PREFERRED TO SHORTEST LEG INITIALLY

Experiments that seek to determine preference over initially long or short paths have led to clear evidence for a preference for taking the longest leg first, even to the extent of reversing the choices on return to ensure that again the longest leg is again taken first. This is potentially due to the fact that cognitive distances between reference points are not accurate calculations and are inferences of their subjective spatial relationships. When constructing a model of a path, proximal elements take priority in path assignment (Sadalla et al., 1980). As Golledge (1995) stated:

> *"This implies that in addition to the previously discovered asymmetry of distance perception among anchoring and other nodes) perceptions of the configuration of the environment itself (particularly different perspectives as one changes direction) may influence route choice. Thus, a route that seems shorter or quicker or straighter from one end may not be so perceived from the other end, thus inducing a change of route. The real question is whether the route selection criteria also change; from examining the actual paths taken and recording response times and other variables) it seems that they often do.(Golledge, 1995)"*

### 2.2.8 PREFERENCE FOR CURVED PATHS OVER SHARP ANGULAR TURNS

Golledge (1995) identified that people have a preference for taking a linear yet curved path rather than taking what he describes as a turn, despite the use of this non-specific term, Dalton (2003) validates these findings, demonstrating that participants chose curving paths over paths diverging by 90°

### 2.2.9 ANGLE OF EXIT ROUTES FROM A JUNCTION RELATIVE TO THE ENTRY

Similarly, to the preference for curved paths and maintaining linearity, Golledge and Dalton (2003; 1995) both demonstrated preference for opting for a shallower angle when presented with variant options.

### 2.2.10 GOLLEDGE'S RANKING OF ROUTE SELECTION CRITERIA

These distinct principles are effective from a design perspective and outline where architectural design decisions can influence navigation of a virtual space, Golledge (1995) also included other discrete criteria that were measured in this research that are either not specifically architecturally related or difficult to quantify in a specific manner. The table below lists the results of matching route types with routes chosen by his participants.

| **Criteria** | **Rank** |
|---|---|
| Shortest Distance | 1 |
| Least Time | 2 |
| Fewest turns | 3 |
| Most Scenic / Aesthetic | 4 |
| First Noticed | 5 |
| Longest Leg First | 6 |
| Many Curves | 7 |
| Many Turns | 8 |
| Different from Previous | 9 |
| Shortest Leg First | 10 |

***Table 1.*** **Ranking of Criteria Most Often Used in Route Selection.**

The most scenic/aesthetic route, in particular, is difficult to quantify in the absence of detailed imagery to balance against the other criteria. Of interest is the preference for taking the route first noticed, this is related to a further phenomenon in route selection termed 'First Perspective Alignment' (Carter, 2011; Tlauka et al., 2011).

### 2.2.11 FIRST PERSPECTIVE ALIGNMENT ISSUES

A distinct preference for maintaining linearity is common in human spatial navigation. It is also common that a memory of a specific location is recalled from the perspective that it was first encountered. This related closely to the findings of Carter and Tlauka (2011; 2011); perceptual guidance cues require that those cues amend spatial navigation. In order to have an effect this additional layer of the information above the purely spatial information, a decision based upon the balance not only between these two elements but also between the individuals innate desire to maintain linearity needs to be reached. Carter expanded on the linearity issue by the addition of a First Person Alignment effect:

> *"The First Perspective Alignment effect (FPA) refers to significantly more accurate judgments when participants imagine themselves in alignment with the very first experienced perspective, or direction of travel, within a novel environment than those that are misaligned or contra-aligned with the first perspective. This can occur despite extensive exploration of an environment with equivalent exposure to multiple directions. The FPA effect has been shown to be a strong and reliable.."(Carter, 2011)*

## 2.3 WAYFINDING

Wayfinding (Lynch, 1960) is a conscious method of spatial problem solving by which humans and animals navigate through a large scale space via the use of orientation and of landmarks, typically moving from one specific location to another. The underlying models of spatial knowledge employed by humans in wayfinding exercises is dependent on two types of navigational knowledge, referred to as procedural and survey knowledge, (Thorndyke & Goldin, 1983; Thorndyke & Hayes-Roth, 1982).

### 2.3.1 PROCEDURAL KNOWLEDGE

Procedural knowledge is referenced from a personal perspective via exploration of an environment, it is incomplete knowledge of the space and while allowing an individual to move confidently from one point to another, rerouting or shortcutting is not possible due to the limited nature of the information. In many instances, procedural knowledge is a mental representation of a single route through an environment. Estimations of distances along these routes may be accurate but lack other spatial detail. However, landmarks along the route will form an intrinsic part of this information and therefore a route can be described with reference to these landmarks (Allen & Kirasic, 1985). Memories of procedural route information are most clearly recalled from the viewpoint perspective that they are first encountered.

### 2.3.2 SURVEY KNOWLEDGE

Survey knowledge is formed from the extensive exploration of an environment after following multiple routes, leading to the development of a cognitive map; these maps are mentally represented from above, creating a broad topological representation of the area, similar to a physical map. This is the central differentiation of survey knowledge that it is externally referenced rather than the personally referenced procedural knowledge. Survey knowledge can be gained from sources other than personal exploration for instance from photographs or maps (Thorndyke & Hayes-Roth, 1982). It has been demonstrated while this is a clear adjunct to personal exploration, the quality of the knowledge acquired this way is representationally inferior to personally acquired knowledge due to misrepresentations of elements such as the position and orientation of specific landmarks (Goldin & Thorndyke, 1982).

The benefits of survey knowledge include an ability to reroute or shortcut if the primary route is closed for instance. This rerouting does not require direct prior exploration of the route, as its construction is inferred from relationships in the cognitive map.

### 2.3.3 ACQUISITION OF PROCEDURAL AND SURVEY KNOWLEDGE

Siegel and White (1975) described a 5 step model of navigational awareness, in this model, steps one, and two generate procedural knowledge, with steps three to five generating survey knowledge, the combination of both types of knowledge creating what was termed navigational awareness (Satalich, 1995). These steps were:

I. Landmark recognition: Objects are defined as landmarks due to their unique, distinctive qualities; these may be combinations of factors such as scale, material, or colour among others. Navigational salience is derived from these landmark objects particularly when they are located with reference to the potential for directional information. For instance, if a landmark is positioned at a fork between two paths.

II. Routes or Linkages: A route is defined as being the path between two landmarks A and B, routes may contain a series of landmarks between point A and point B. When route knowledge is being created, it will contain the two reference points and visuospatial representations of the positions of distances and landmarks along the route.

III. Primary Survey Knowledge: By broad and varied exploration of an environment, a cognitive map of landmarks, inter-object distances and other topological features are combined to give a level of understanding of the environment that can afford inferences of alternate routeing; this further allows for vector distances can be approximated.

IV. Secondary Survey knowledge: The use of maps, photographs and other visual representations of survey data can lead to a broad understanding of an environment, but lacks the granularity and specific vector knowledge that is developed via personal surveying.

V. Chunking of the Environment: Holding all spatial data as a single overview becomes cognitively strenuous, and therefore a degree of chunking of the data is necessary to relate information at different scales. A typical postal address is structured much as a mental visualisation of these scales may progress, giving firstly the country, then county, town and street before being specific of landmark or location in the form of an individual house or further still the location of the particular letter box.

### 2.3.4 WAYFINDING IN VIRTUAL ENVIRONMENTS

The design of virtual spaces can reinforce aspects that can make orientation easier. Within a virtual environment, both landmarks and initial orientation of the avatar can be aligned by the designer. There is an emerging consensus that cognitive maps of large environments are orientation specific. Therefore an alignment effect had been suggested in virtual wayfinding scenarios (Jansen-Osmann & Fuchs, 2006; Waller, Montello, & Richardson, 2002). Further study has demonstrated the alignment effect issue is also apparent in real world studies leading to both desktop and virtual reality wayfinding experiments yielding comparable results to real world scenarios (Waller, Beall, & Loomis, 2004).

From a video games perspective, Open world environments require some element of guidance; otherwise, the player would wander aimlessly. Even when primed with a goal, the cues required such as landmarks and topological features must be designed in a clear manner if they are to be of use to the player.

Darken and Sibert (1996) suggested that wayfinding can be separated into three categories:

- Primed search: Where the navigator knows the target location but has no other information.
- Naïve search: Where there is a target, but the navigator has no knowledge of the target location.
- Exploration: Where the navigator has no target.

Downs et al. (1973) defined wayfinding as a process that can be broken down into four steps:

I. Orientation: The process of determining the current specific location by the use of proximal objects, structures and their relationship to the target location.
II. Route Decision: Formulating a route that will lead to the desired destination.
III. Route Monitoring: Continual analysis of the chosen route in order to confirm that the bearing is still correct.
IV. Destination Recognition: Confirming the identification of the correct destination or that the destination is close by.

Successfully wayfinding within an environment, requires the acquisition of spatial knowledge; this can come in two forms (Siegel & White, 1975):

- Primary knowledge: Via direct exposure to and exploration of an environment
- Secondary knowledge: Via external information sources such as a map

These two forms of knowledge acquisition are key to the development of a cognitive map (Tolman, 1948). Cognitive maps themselves are an amalgamation of three distinct forms of environmental knowledge; landmark knowledge, route knowledge and survey knowledge (Siegel & White, 1975).

- Landmark knowledge is constructed from information about the specific features of a location
- Route knowledge is information about specific pathways that join two locations.
- Survey knowledge is usually regarded as two-dimensional relational knowledge based upon distances between known landmarks. It is considered to be stored as spatial relationships and distance estimations, being similar to a traditional map.

In practice in the real world, people use maps to wayfind using one of two distinct strategies, either a route strategy or an orientation strategy (Lawton, 1994). These strategies both require a cross-referencing of survey knowledge with either the route knowledge in order to choose an appropriate path or location knowledge which may come in the form of triangulation based upon known landmarks.

Lynch (1960) and Arthur (P. Arthur & Passini, 1992), Foltz (1998) suggested a set of design principles for the construction of successfully navigable virtual environments. Navigable, in this context meaning that information presented about the virtual space allows for the navigator to move from the point of origin to destination in conformity with Downs (1973) four step wayfinding theory:

1. Orientation: The process of determining the current specific location by the use of proximal objects, structures and their relationship to the target location.
2. Route Decision: Formulating a route that will lead to the desired destination.
3. Route Monitoring: Continual analysis of chosen route in order to confirm that the bearing is still correct.
4. Destination Recognition: Confirming the identification of the correct destination or that the destination is close by.

Within the context of wayfinding in an urban environment, and the design of environments that contain intrinsically navigable structures, Foltz (1998) proposes eight design principles that reinforce urban wayfinding:

1. Create an identity at each location, different from all others.
2. Use landmarks to provide orientation cues and memorable locations.
3. Create well-structured paths.
4. Create regions of differing visual character.
5. Don't give the user too many choices in navigation.
6. Use survey views (give navigators a vista or map).
7. Provide signs at decision points to help wayfinding decisions.
8. Use sight lines to show what's ahead.

The wayfinding literature broadly concurs with the navigational preferences discussed previously [2.1 & 2.2]; it also demonstrates that individuals are more capable of locating a particular goal when provided with good quality narrative descriptions than when simply provided with maps (Goldin & Thorndyke, 1982).

## 2.4 SEX DIFFERENCES IN VIRTUAL NAVIGATION.

Sex differences in visuospatial navigation are a commonly reported phenomenon (E. Arthur, Hancock, & Chrysler, 1997; Cutmore, Hine, Maberly, Langford, & Hawgood, 2000; Grön, Wunderlich, Spitzer, Tomczak, & Riepe, 2000; Lawton, 1994; Spence & Feng, 2010). It has been demonstrated by Grön et al. (2000) that the differences in navigational and spatial ability are not merely derived from gender stereotypical issues such as males preferring to play video games, but are rooted deep in the structural differences between the brains of the two sexes. From around eight years of age, children are able to demonstrate mature capability in contextual spatial orientation and exploration tasks (Keating, McKenzie, & Day, 1986; Overman, Pate, Moore, & Peuster, 1996). Children demonstrate few differences in their spatial abilities at this time. As the brain develops during adolescence, sex differences in spatial ability begin to develop (Klingberg, 2006; Sowell, Delis, Stiles, & Jernigan, 2001). Despite these structural differences *Figure 97*, multiple studies have demonstrated only minor differences in overarching spatial reasoning between genders; although it has been demonstrated that males and females do use differing strategies (Sneider et al., 2015). In multiple studies, the differences between age groups having a larger impact on an individual's spatial ability than sex (Sandstrom, Kaufman, & Huettel, 1998; Sneider et al., 2015).

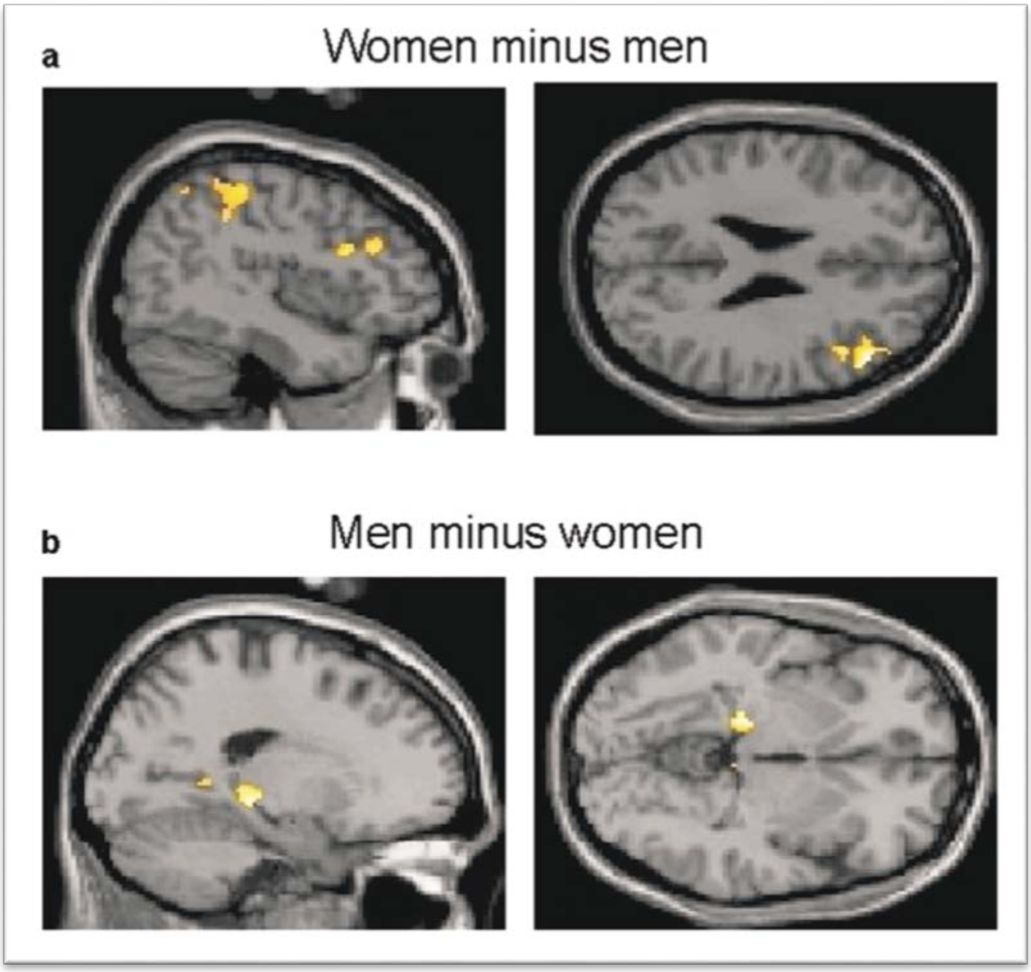


***Figure 97.*** **Gender differences in brain activity when solving a virtual maze. Grön 2000**

> *"The left hippocampal activity in the male group represented the neural substrate that enables men to process multiple geometric cues. Alternatively, the hippocampal formation functions in episodic memory thus, assuming a broader role of this area, male-specific hippocampal activity may reflect the males' reliance of on the use of episodic memory information in navigation. In summary, regardless of the specific underlying neuropsychological interpretation, left hippocampal activity in men and right frontoparietal activity in women reflect the gender-specific recruitments that differentiate male from female subjects in navigation."(Grön et al., 2000)*

## 2.5 THE VISUAL SYSTEM

Theories of how humans see and perceive evolved over the millennia as scientific understanding has matured. While a true model of human vision and perception remains incomplete, the sophistication of current models is in stark contrast to the prescientific models that preceded it.

Emission theory or the idea that visual perception is derived from beams of light being emitted from the eyes was a commonly held belief between 400BCE and as late as the 2$^{nd}$ century CE (Lindberg, 1981). The actual understanding of what light is and how it propagates is an ongoing area for physics researchers (Born & Wolf, 1999). Light can be created in a number of ways, often utilising precise emission systems born out of an era of ubiquitous electronics. From laser diodes to radio, the emission of photons or as electromagnetic waves is fundamental to how our technologies work. Of course, humans do not see in the vast majority of the electromagnetic spectrum; the human visual system has evolved to see only a very narrow slice through it; roughly 400nm-700nm wavelengths (V. Smith & Pokorny, 1975)

Much of the research that follows discusses reactions to virtual environments displayed on a variety of devices, therefore, it should also be noted that displays of different types do not produce a full spectrum image even in the wavelengths visible to us; the subset of colours that can be accurately represented is referred to as the gamut. *Figure 98.*

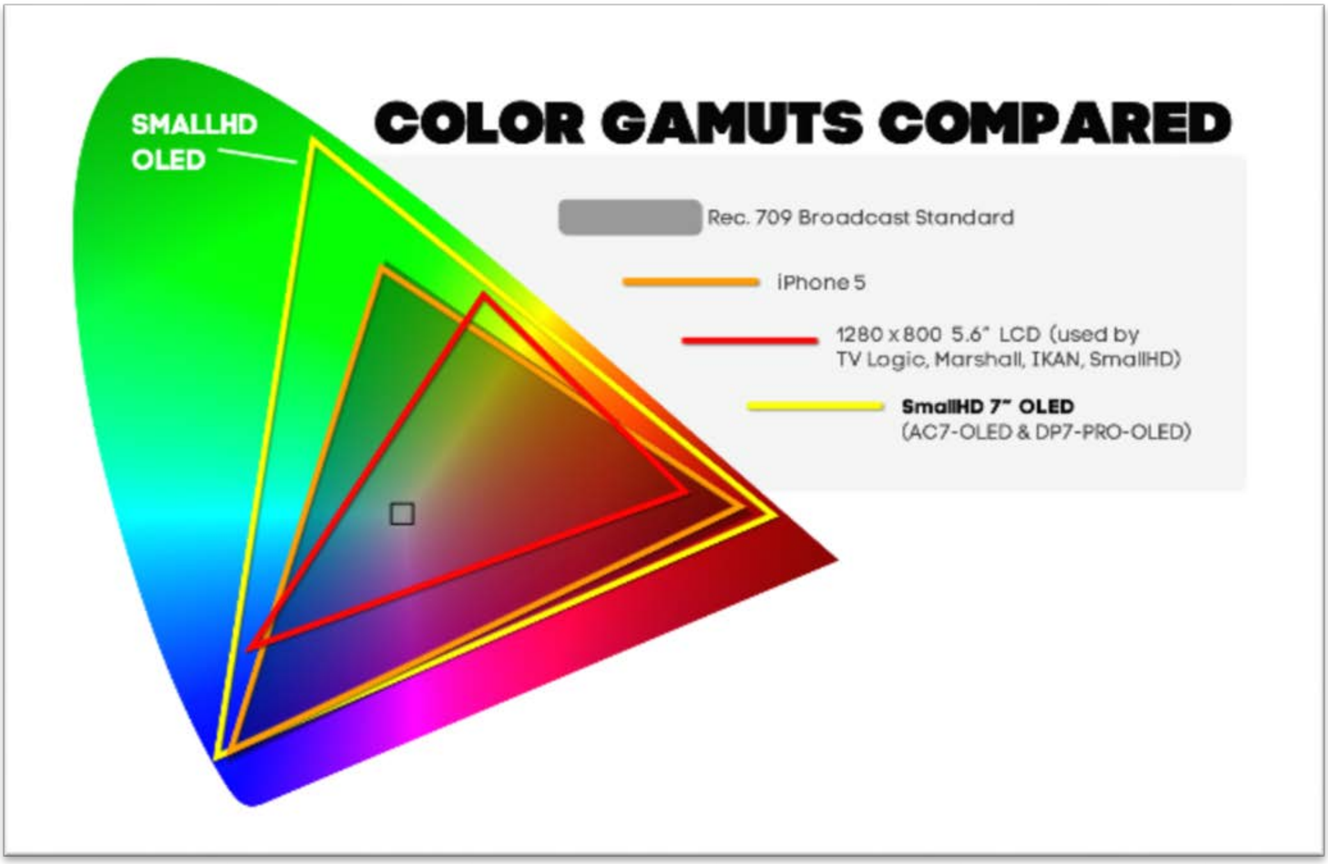


*Figure 98.* A sample of the colour gamut of typical display devices (PRWeb.com, 2012)

The human eye belongs to a grouping of eye types known as the camera eye; light passes into the eye via the cornea, pupil and lens, the lens allows for focusing of the light onto the retina that sits at the back of the eye. The retina consists of approximately 100-150 million individual photoreceptors; these receptors are of two distinct types; some 95% of the receptors are rod cells, these cells are extremely light sensitive, capable of detecting individual photons. They provide information in peripheral vision and are responsible for providing night vision. Rod cells do not provide any colour information. The remaining approximately 7 million cells are known as cone cells; these cones are predominantly found in the fovea centralis of the retina and come in three types allowing for trichromatic colour vision in humans. These cone cells are referred to as short, medium or long cones, these names referring to the wavelengths of light that they react to. In practice, these rods allow humans to distinguish frequencies of light that are described as red, green and blue (Regan et al., 2001).

Colour can be defined in two independent ways, firstly, in the manner described above, as a measurement of the wavelength of a photon. While it is true that these wavelengths then stimulate one of the three types of cone receptors in the human eye, any inference that colour is a specific perceptible thing even at this point of electrochemical interaction is debatable (Lotto & Purves, 1999).

Perception of a particular colour or even a shade of grey is a product not of the eyes or their related cones nor even the photopsins located within but is a complex contextualization of the data captured by the eye. The illusions in figures 8 & 9 [over page] demonstrate that the visual system does not see the retinal image - an image that arrives upside down and obscured by the blood vessels that feed the eye. Essentially, we perceive the world in a way that makes sense from an evolutionary perspective (Regan et al., 2001).

A capability to detect colour variation or movement in a wide variety of lighting conditions carries an enormous survival advantage. *Figure 99*. Therefore, brains process light-related data in the manner that is most evolutionally beneficial (Regan et al., 2001). Specific detection of a particular colour is subjective not only from an environmental perspective [*Figure 100*, *Figure 101*] but also neurologically and psychologically. This leads to famously imponderable questions such as whether any two individuals perceive any given colour in the same manner (Roberson, Davidoff, Davies, & Shapiro, 2005b).

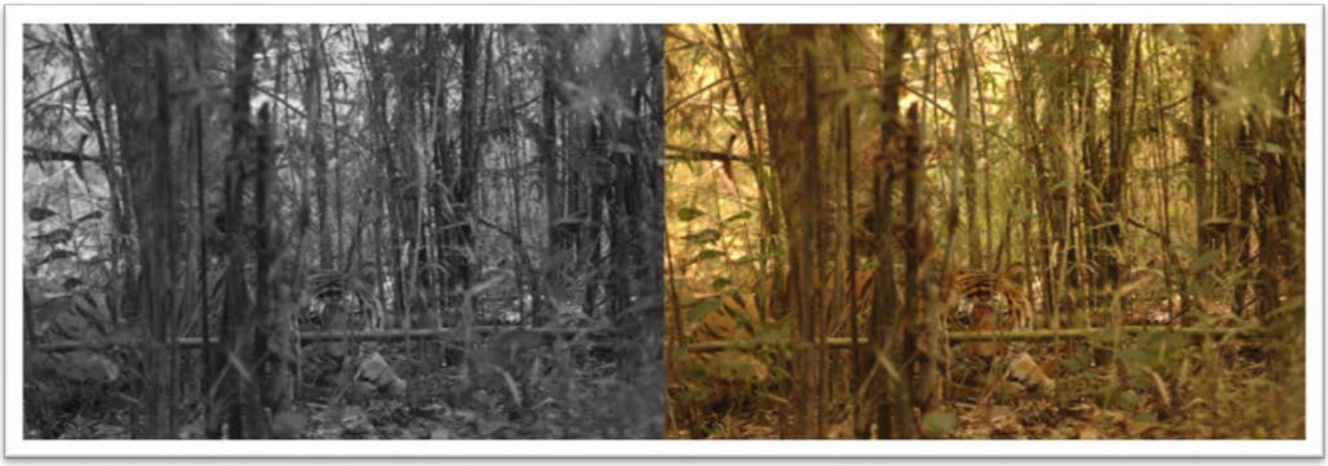

***Figure 99.*** **Demonstrating the evolutionary advantage of seeing in colour.**

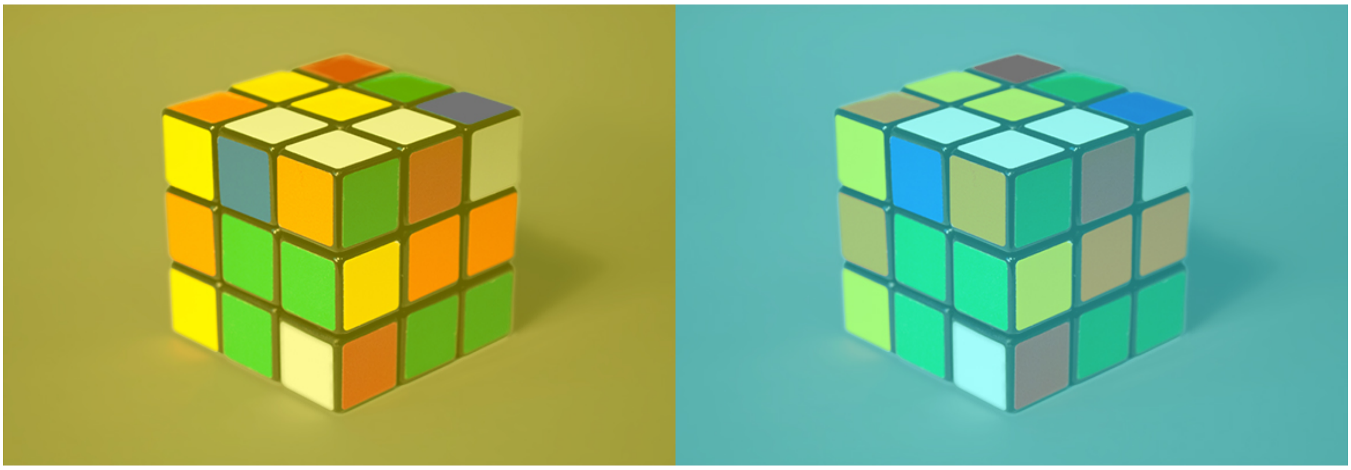

***Figure 100.*** **The "blue" tile on the top face of the left cube are the same RGB “colour” as the "red" tile on the top of the right cube yet are perceived as distinctly different colours due to context.**

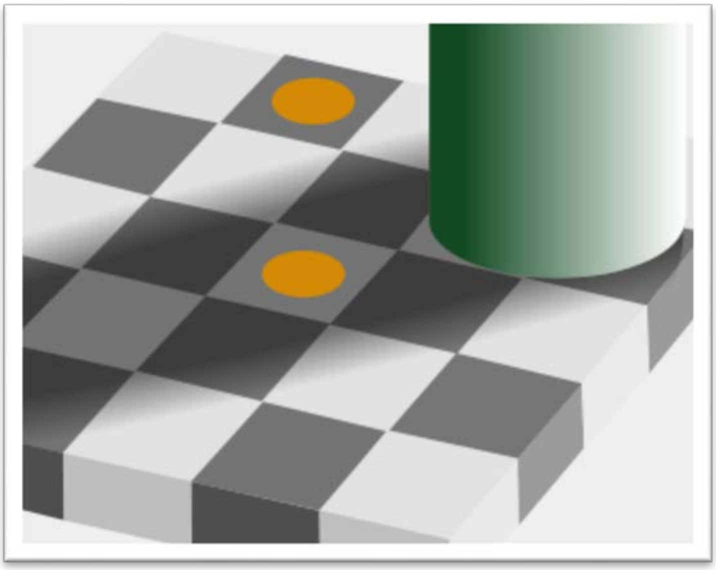

***Figure 101.*** **The two highlighted squares are the same shade of grey. (Adelson EH, 1995)**

## 2.6 VISUAL ATTENTION

Visual attention is a fundamental component of navigation in virtual environments and with video games being such a popular entertainment medium; many individuals have a great deal of experience of developing successful strategies for the exploration of virtual game worlds. With many players dedicating much of their leisure time to gaming, research has been undertaken that demonstrated that game players consistently outperform non-game players in tasks that measure fundamental aspects of visual attention (Boot, Blakely, & Simons, 2011; Green & Bavelier, 2003; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). Expert players demonstrated better performance in tasks that measured spatial distribution, resolution of visual attention and showed a superior ability for attending to multiple objects simultaneously.

Green & Bavelier (2003, 2006) sought to investigate whether this long-term exposure results in any modification of the players motor and / or perceptual skills. In a broad range of stimulus-response experiments, Green and Bavelier demonstrated that such an effect was present and that video game playing enhances attentional resources, in particular in tests which utilise the Eriksen Flanker Task (Eriksen & Eriksen, 1974). *Figure 102*

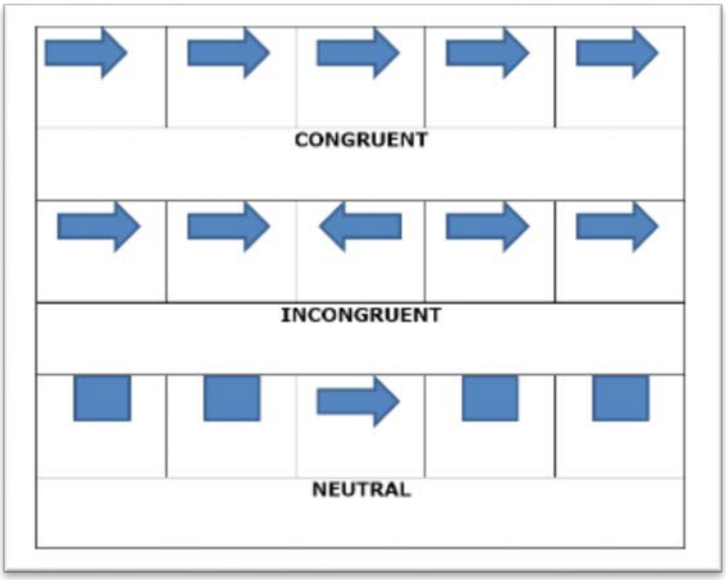


***Figure 102.*** **Typical Eriksen Flanker Task problem.**

The Eriksen Flanker Task is a set of response inhibition tests that assess the participants' ability to suppress responses to out of context stimuli. The central target is flanked by a number of non-target stimuli that can be in one of three states:

I. Congruent: the flankers will offer the same stimulus as the target and may be identical
II. Incongruent: the flankers will offer an opposing stimulus often being the reverse of the target
III. Neutral: the flankers do not resemble the target

In contrast to the above findings (Green & Bavelier, 2003, 2006), the field of perceptual learning also referred to as brain training or memory-training systems, purport to develop skills in for instance mathematics, or have been utilised as treatments for conditions such as ADHD. In these cases, despite the implicit intent to demonstrate a net beneficial effect in perceptual learning that would generalise to other tasks other than those identical to the trained task itself, the evidence is broadly negative (Melby-Lervåg & Hulme, 2013):

> "that memory training programs appear to produce short-term, specific training effects that do not generalise. Possible limitations of the review (including age differences in the samples and the variety of different clinical conditions included) are noted. However, current findings cast doubt on both the clinical relevance of working memory training programs and their utility as methods of enhancing cognitive functioning in typically developing children and healthy adults."

Despite the term attention being used extensively in the psychological literature, it remains that there is no single unified definition (Wolfe & Horowitz, 2004). Whether the brain processes incoming visual data in a 'top-down' or 'bottom-up' manner is addressed clearly by Tsotos (1990).

Tsotos demonstrates that from a complexity level, this is very much a top-down process; the fovea centralis draws the vast majority of information in a visual search. Similarly, the brain's processing of this information optimises the resources that are dedicated to optical data; suggesting an attentional mechanism that exploits prior knowledge about the world and constructs a representation that cognitively makes sense of the world based upon integrated models. In this top-down process, visual elements are revealed in order of importance. These models still do not address the criteria for selection of stimulus or focus of attention (Monahan & Lockhead, 1977; Treisman & Gelade, 1980). The issues of hierarchy of stimulus, attention and its relationship to working memory are discussed in the following section.

## 2.7 CHANGE BLINDNESS

Stemming from the fact that human visual processing is an evolved system is the manner in which change within an environment is detected. In order to understand why it might be that humans are poor at determining certain types of change in surroundings, it requires that the manner in which visual data is processed is understood.

It is a feature of the way that the human eye perceives colour and light intensity via two independent types of cell that the intensity of light particularly in the peripheral vision is predominant to any colour information that is registered largely in the fovea centralis. The colour detecting cones also require significantly greater stimulus in order to deliver a signal to the brain.

It has been demonstrated that humans cannot detect even abrupt isoluminant colour changes in parallel, whereas small luminance changes are readily detected (Theeuwes, 1995), colour changes may be detected at the periphery of vision, but only if accompanied by a luminance change.

Human working memory (Baddeley & Hitch, 1974) is not restricted to matters of short-term memory; it is concerned with dealing with attention given to tasks that require monitoring. The manner in which the details of a scene are stored is understood to be coded in the visuospatial sketchpad *Figure 103* and related semantically to long-term memories for instance to previously defined or remembered objects (Baddeley & Hitch, 1974). It is due to the way in which the brain creates shorthand associations for inputs that, although the broad sense of what is being perceived is coherent, the granularity or finer detail is lost.

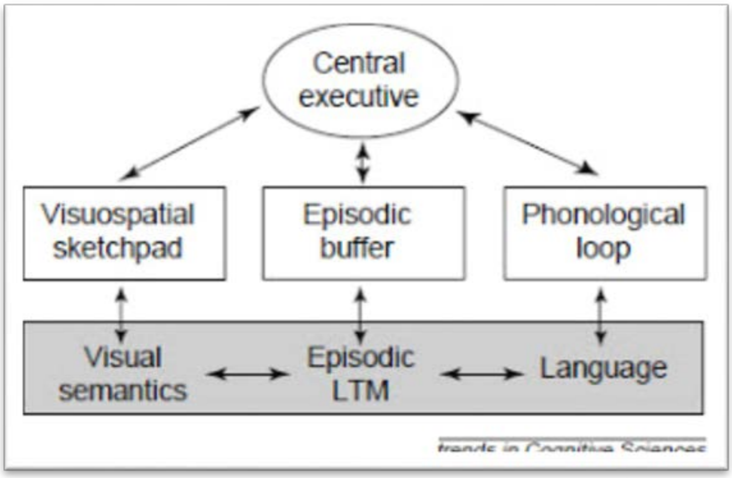


*Figure 103.* **Baddeley and Hitch's working memory diagram (TiCS)**

From a neurological perspective, the fact that these interweaving systems appear to operate in a semi-autonomous manner can be related to the method by which storage and processing of different types of sensory data are handled independently within the structure of the brain (Baddeley, Logie, Bressi, Sala, & Spinnler, 1986). *Figure 104*.

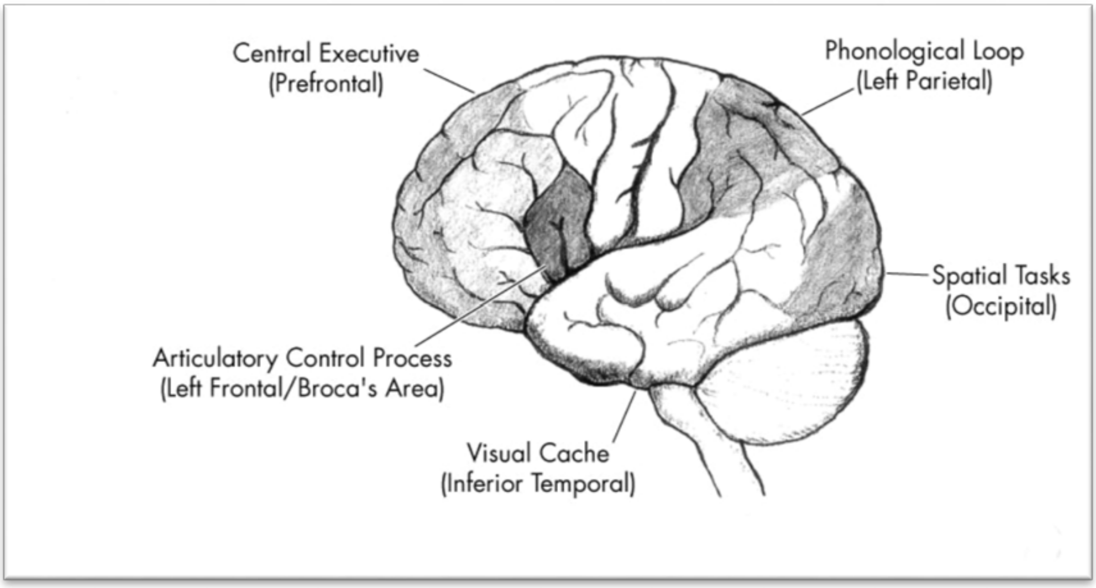


*Figure 104.* **Baddeley 1986 How brain regions map to the working memory model.**

Change blindness (Pashler, 1988) is a phenomenon that appears to relate directly to the manner in which visual data is captured, processed and stored by the brain. A range of types of change blindness have been shown to exist, the most extensively researched are saccadic change blindness (Grimes, 1996) where the eye moves abruptly from one object to another, skipping over entire aspects of a scene that are not the main focus (Simons & Chabris, 1999). The flicker paradigm introduces change between two images but inserts a blank image between the two main images (Pashler, 1988). A clear demonstration of inattentional blindness and its relation to working memory is presented in the basketball counting exercise (Simons & Chabris, 1999) in which two teams of basketball players pass balls to each other. While the viewer is counting the passes the white team makes, a man dressed as a gorilla walks into the centre of shot beats his chest and walks off. Despite this being completely obvious to anyone watching and not counting, the majority of first-time participants fail to spot the gorilla. The inattentional blindness demonstrated in this study has implications that relate to the changes that frequently occur within virtual environments and specifically video games; in which –often to reduce the memory overhead- both textural and geometric changes are slowly made, often without the player being attentive to those alterations. Specific examples of this would be the common removal of decal information such as bullet holes or footprints or the slow fading of enemies that have been dispatched by the player. Although virtual environments are commonplace and many of these attempt to engage the participants' senses by directing attention, there has been little research into the perception of changes in those environments.

### 2.7.1 REDIRECTED WALKING

A technique which is akin to change blindness in so much that the entire environment is imperceptibly adjusted to create an effect termed: 'redirected walking' (Razzaque, Kohn, & Whitton, 2001; Steinicke, Bruder, Ropinski, & Hinrichs, 2008). The user is able to walk continually in a finite space by the gradual adjustment of display angle at an imperceptible rate within a VR system, the user experience the visual environment as zig zag path while due to the rotation of the visual stimulus, they are in fact simply following the same slightly curved path repeatedly. *Figure 105.*

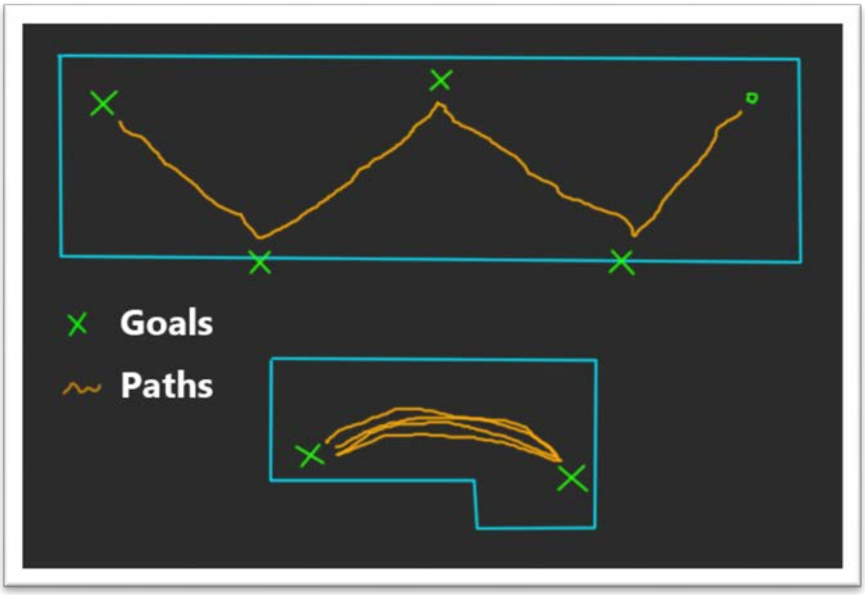


***Figure 105*. An overhead representation of the paths taken in [top] the virtual tracked space and [bottom] the laboratory real-world space (Razzaque et al,2008).**

Suma et al. (2010) demonstrated that virtual environments could be made to feel much larger than they actually were by triggering manipulations of the geometry within the scene, essentially having the participants enter, leave and re-enter the same room repeatedly while thinking they were entering new spaces. This involved the player entering a room containing a desk. When the player interacts with the computer on the desk, the doorway the player entered moves from its original position to the wall 90 degrees to its original location. When the player turns around to exit the room, the change in alignment is not registered, and these rotations could be continued cyclically indefinitely, the participant therefore experiencing a very long corridor containing many adjacent spaces where in reality, they are simply walking around in a continuous square pattern in the same finite space. This effect has been implemented by designers of the mixed reality experience The Void (Metz, 2015) which superimposes a virtual world on top of a prebuilt physical environment, demonstrating that in practice, the effect translates from experimental scenario to real world application. In this instance, the use of redirected walking is able to separate two players by having them enter different spaces while their perception is that of walking in a linear fashion accompanied by the other participant.

Beyond these examples, change blindness in virtual environments is a broadly overlooked area for study. This is despite its casual use in a vast range of titles to remove by slow fade, memory intensive elements such as bullet hole decals on walls, footprints in the snow or even in some cases the bodies of defeated enemies can fade from view and unless directly watched this wholesale removal of geometry remains undetected. An aspect of this removal of player created change in the environment is that, where the player may have been able to utilise those inclusions as an analogue of a breadcrumbs trail, and therefore retrace a prior path, such navigational cues are lost once the system removes them from the environment.

## 2.8 THE NAVIGATIONAL EFFECTS OF LIGHT AND COLOUR IN A VIRTUAL ENVIRONMENT

### 2.8.1 UNDERSTANDING LIGHT AND VISION

Following the development of real-time lighting solutions in virtual environments, primarily computer games, the implementation of these lighting systems have played an increasing role in both directing visual attention and the overall aesthetic of modern titles (Bernhard, Zhang, & Wimmer, 2011; El Nasr et al., 2009; Kahrs, 1996; Lowell, 1992). Lighting design in video games from an aesthetic perspective seeks to direct the eye of the viewer/player; light affords the scene with much that has been developed over centuries of traditional art development and speaks from a common visual language (Yot, 2011). Lighting can create depth in an image, it can intensify and complement an underlying composition, and it can be used to indicate time, place and season. Beyond this, light may be used to convey a sense of drama by emphasising the mood and atmosphere in a scene (Calahan, 1996; Yot, 2011).

It has been demonstrated in real-world scenarios that under distinct variations in lighting where one entrance is close to darkness and another is brightly lit that humans will choose to enter a location through the illuminated portal (Taylor & Socov, 1974). The preference for the illuminated doorway when there is dim illumination in the other doorway was demonstrated to be in 70% whereas if a doorway was lit at 100 lumens and the alternate was only lit at 1 lumen, the preference for the lit portal rose to 100%. This simple study while fundamental to understanding the human preference for illuminated paths has not been replicated, no other study has yet built directly on the outcomes described.

Lighting, and changes in contrast created by lighting (Vincent, Baddeley, Correani, Troscianko, & Leonards, 2009) draw visual attention. Modern games engines have developed robust real-time lighting systems, and over recent years, lighting based cues have become a regularly used method of player guidance (Lundeen, 2009). The study of the navigational effects of lighting in architectural spaces or open world environments is not something that can be easily replicated in the real world (Dalton, 2003). Therefore, this area of navigational stimulus is the focus of the majority of the studies that form this thesis.

While studies exist that look at the effects of lighting in video games and virtual worlds, the primary focus of much of this research has been concerned with the emotional impact of the lighting such as eliciting a fear response or as the basis for a discussion of colour perception (Billger, Heldal, Stahre, & Mb, 2004; El Nasr et al., 2006, 2009; Knez & Niedenthal, 2008; Toet, van Welie, & Houtkamp, 2009; Wolfson & Case, 2000). Knez and Niedenthal (2008) demonstrated that mazes were solved faster if the overarching colour of the lighting in the maze is of a specific hue. No evidence could be found of a study that sought to ascertain if mazes would be solved faster by changes in illumination guiding the player to the goal. The findings suggesting that the colour of a maze can make a difference to solve time are at odds with other aspects of colour perception studies that indicate that much of the reaction to specific colours is rooted in cultural biases investigated in the next section.

### 2.8.2 SOCIAL SCIENCES APPROACH TO COLOUR

A review of the psychological effects of colour perception and preference revealed a great deal of conflicting information that is largely drawn from personal opinion or cultural and or historical bias, and this cultural bias is discussed in some depth by Boulton (2014). One aspect of this cultural and historical bias is reflected in the fact that even traditional colours for girls and boys being pink and blue respectively were reversed in western culture as recently as 1920 (Prior to 1920 the traditional colour for boys was pink and a powder blue for girls) (Boulton, 2014). The mood altering effects of colour are also similarly problematic in literature, and these issues are reflected on and referenced in similar papers (Alton, 1995; Joosten, Lankveld, & Spronck, 2005; Knez, 2001; Knez & Kers, 2000; Knez & Niedenthal, 2008), but, conclusions conflict and cannot be deemed to be definitive. As it is evident from these conflicting viewpoints that much of this attitude toward colour is highly reflective of cultural consequences and anecdotal evidence found primarily in media and popular culture. Indeed, Roberson et al. (2005b), demonstrate that even the perception of whether a colour is for instance 'yellow' can be highly dependent on culture, in their study they discovered that much of the population of equatorial India did not differentiate yellow as a particular colour. While this may seem peculiar, at least yellow is not one of the primary colours that the human eye has evolved to perceive. It is also the case that in many non-industrialised societies where the language does not have a written form, those cultures do not differentiate between blue and green. They, in fact, have one term that covers all of the green-blue colour space (Kay, 2003). This understanding of the cultural biases of the perception and recollection of colour is sometimes overlooked. This may lead to declarations that warm tones are red and that cool tones are blue and that therefore there is a general preference for warm colours (Knez, 2001), despite there being many variations within those spectra and also that saturation and vibrancy of colour can be a major component of its psychological impact (Alton, 1995).

# 3 CHAPTER THREE:

# GUIDING THE EYE - LIGHTING AND COMPOSITION IN ART AND MEDIA

A major factor in the development of any kind of visual composition is an understanding of how the viewer will perceive a collection of objects. Indeed, it is an intrinsic component of human vision that broad forms do not have to be whole for them to be viewed as a gestalt or whole entity (Hartmann, 1935). *Figure 106*.

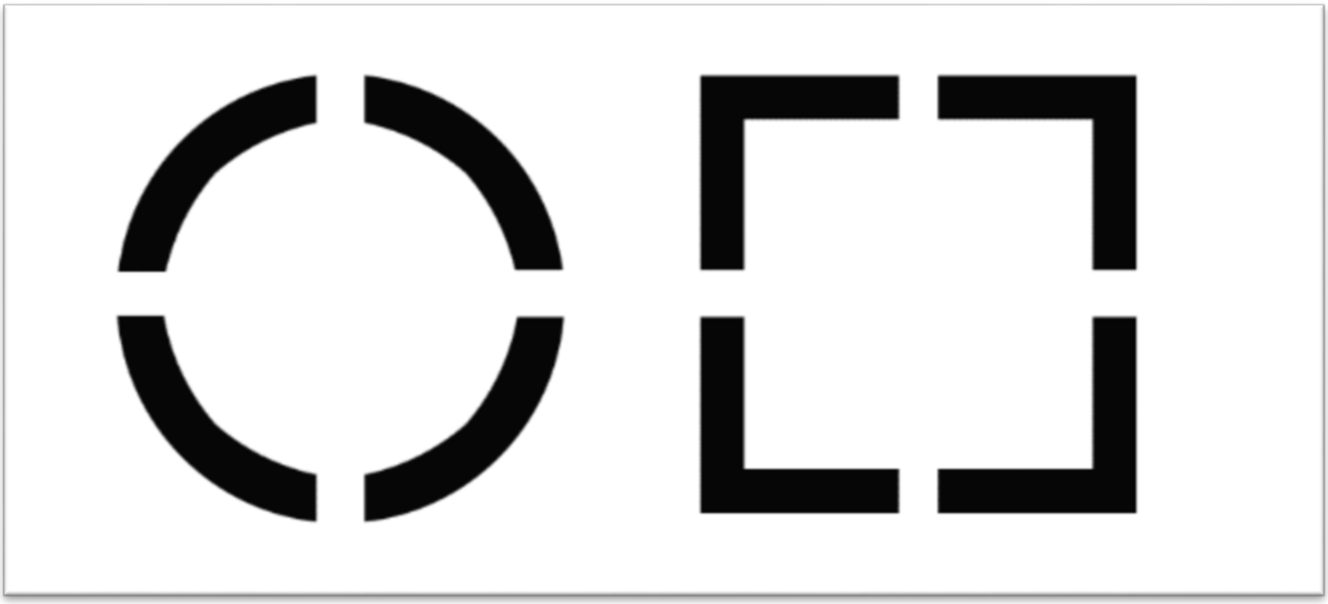

***Figure 106.*** **Individual forms create a gestalt shape, despite that shape not being complete.**

Pinker (1984) stated that pattern recognition was a fundamental of vision, however, perception and recognition were partitions upon a continuum, specifying precisely where perception ends and where cognition begins is complex and has best been categorised by the work of Marr and Nishihara (1978) which breaks the process down in the following manner:

(a) Defines a coordinate system that is centred on the as-yet unrecognised object,

(b) Characterises the arrangement of the object's parts with respect to that coordinate system

(c) Matches such characterizations against canonical characterizations of objects' shapes stored in a similar format in memory

These models are limited and only explain the processing of more complex objects such as tables or elephants. The entire subject of how visual perception and cognition work in conjunction with the visual system, remains an area for debate and conjecture, (Jeannerod & Jacob, 2004) as Jeannerod and Jacob attest:

> *On one hand, the claim that visual awareness of visual attributes (such as color, shape, size and orientation) asymmetrically depends on awareness of spatial relations among objects is consistent with the view that the representation of spatial relations among proto-objects has a quasi-conceptual character. On the other hand, this asymmetrical dependency fits with a conceptual analysis of what is the deep nature of visual perception. Visual awareness of the size, shape and orientation of one object consists in the perceptual comparison between its relative size, shape and orientation and those of neighbouring objects. In other words, visual awareness must satisfy the constraint of contrastive identification*

Ultimately, discussions around this level of perception stray into the territory of esoteric questions along the lines of do two people perceive the colour blue in the same manner.

## 3.1 PRINCIPLES OF COMPOSITION

Visual designers utilise the understanding that the human eye is drawn to focal points in an image or composition. These focal points can be simplified graphically as in the following illustrations, but it is the implementation in complex compositions that lends subtle focus to otherwise flat or uniform configurations (Davis, 2016). Games designers intuitively apply many of these salience principles to games environments, often structuring them to encourage exploration in particular directions (As discussed in Chapter One). The following examples demonstrate eight of the foundational principles utilised in visual design across traditional art and time-based media.

### 3.1.1 SALIENCE THROUGH CONTRAST

Visual attention is drawn to areas of difference (Davis, 2016); this is perhaps most simply exemplified by the simple change in contrast in the image below. *Figure 107.* The black square stands out from its surroundings and becomes more visually salient than the uniformity of the surrounding grey squares. This emphasis via the use of contrast is not limited to the actual brightness of a component; contrast can be achieved through the use of colour, size, shape and particularly motion. However, in an otherwise uniformly lit scene; contrast created by the illumination of a focal point can distinctly emphasise and separate an area or object from the remainder of the image. *Figure 107*.

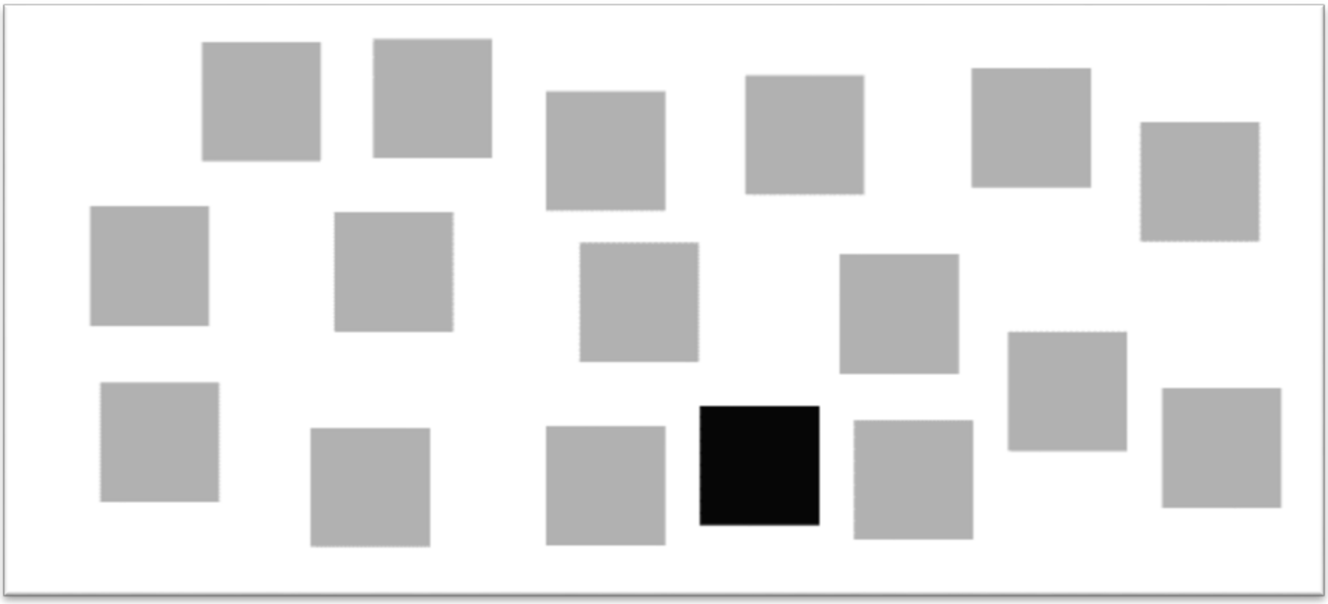

***Figure 107.*** **The dark square is salient due to it contrasting with the other lighter squares.**

### 3.1.2 SALIENCE THROUGH ISOLATION

Isolating an object can increase the objects visual salience as illustrated in *Figure 108.* In a composition composed entirely of identical circles, the rightmost circle commands attention, for no other reason than the fact that it is compositionally isolated. This from a designer's perspective means that in busy or cluttered scenes, simply allowing negative space to surround an object of importance can lead the viewer's gaze to it and simultaneously impart a level of visual importance.

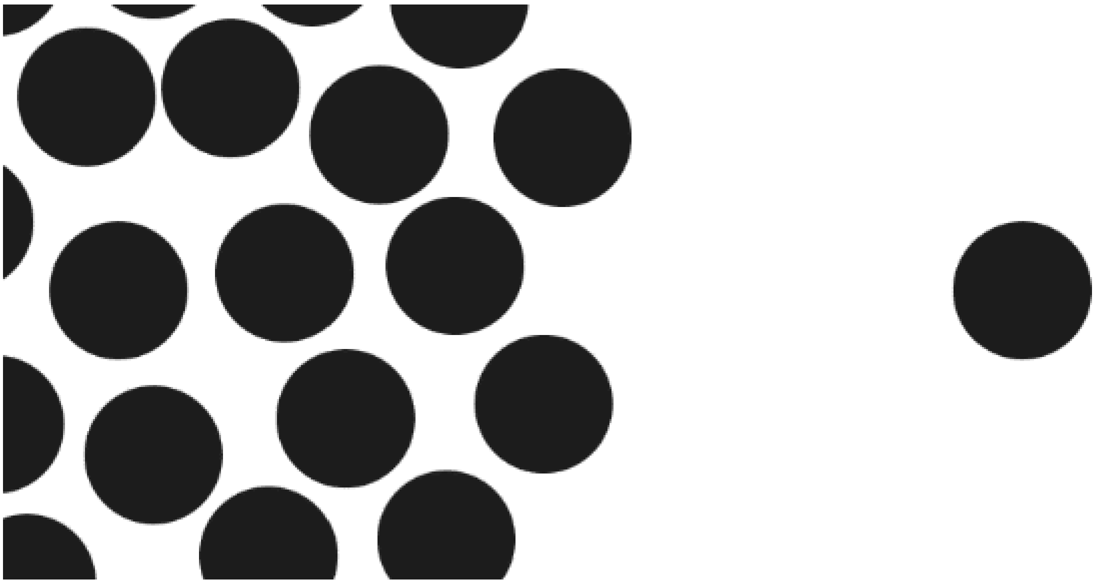

***Figure 108.*** **The circle to the right is salient due to its isolation.**

### 3.1.3 SALIENCE THROUGH SHAPE

Unusual shapes can also draw visual attention. If a scene is largely constructed with smooth flowing curves, the juxtaposition of a hard-edged object becomes visually salient, and the eye is naturally attracted to this difference. The image below demonstrates this principle in its simplest form, but in a well-constructed composition, this effect can be implemented in a more subtle manner. *Figure 109*.

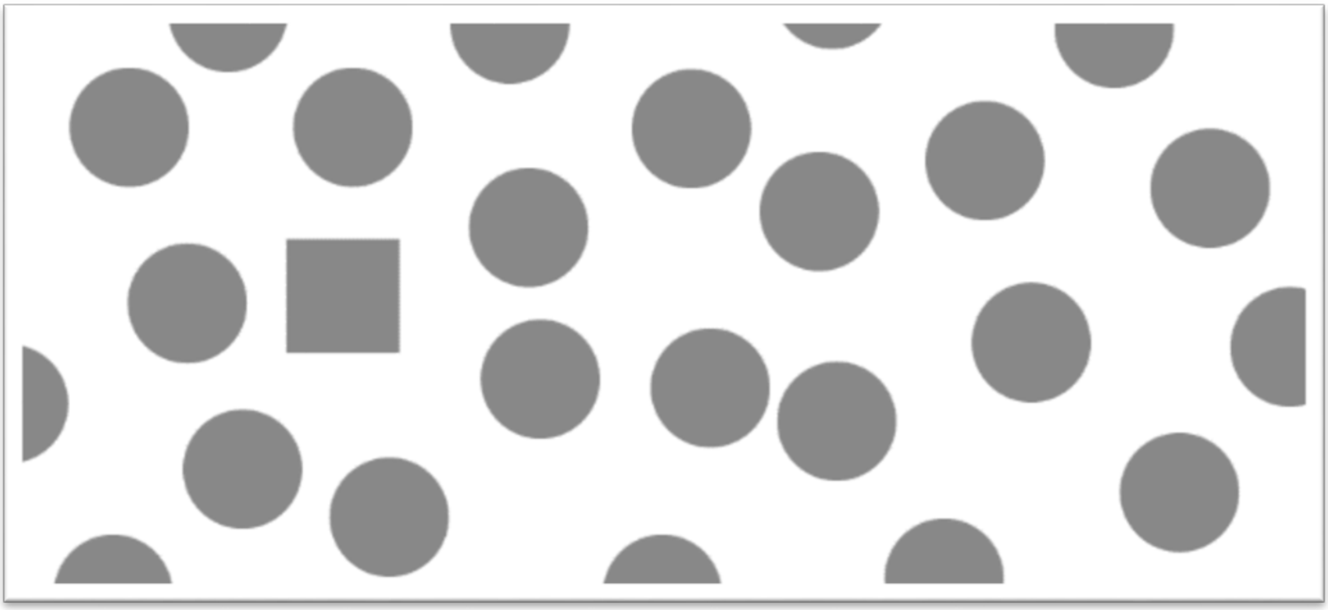

***Figure 109.*** **The square is salient due to it contrasting in shape to the surrounding circles.**

### 3.1.4 LEADING LINES

Geometrical edges and outline shapes can create lines that flow towards a focal point in an image; these leading lines can be arranged to converge or suggest convergence at a specific focal point, lending salience to the object at that location. The human visual system is adapted to edge detection, and it is a feature of the recognition of these edges that focuses visual attention along them. Picking out the salient characteristics of the line, being drawn inexorably to its end and consequently to any element that commands visual interest at that point. *Figure 110*.

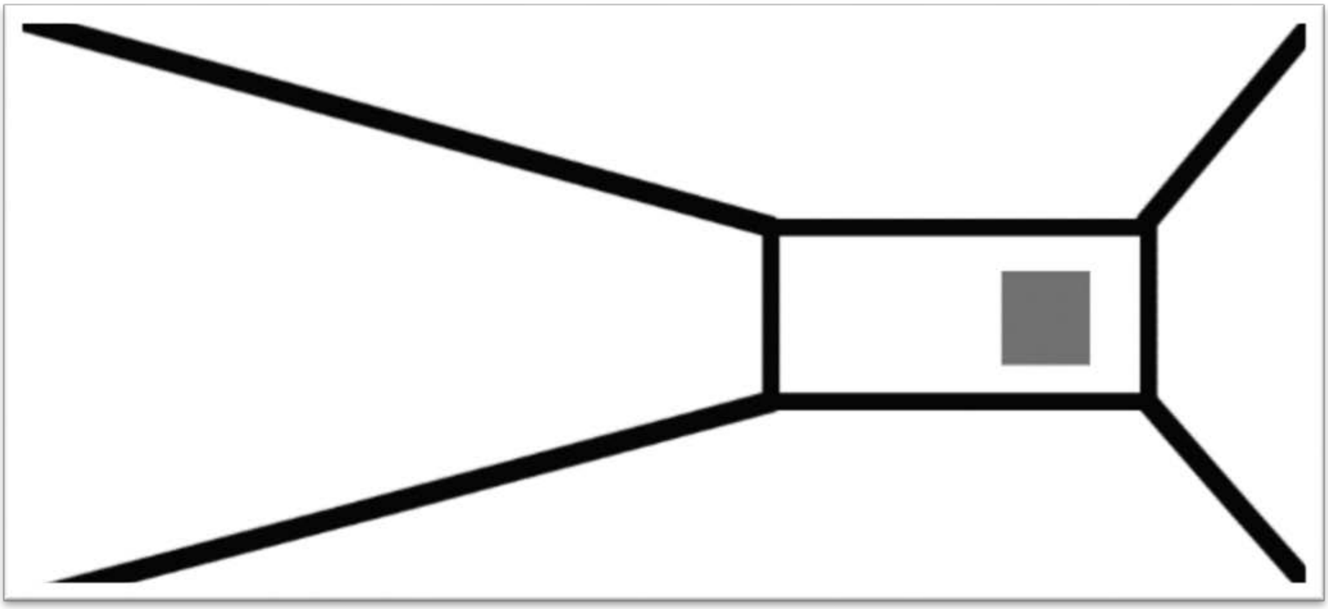

***Figure 110.*** **Lines flowing from the outer edges to the centre of an image add salience to the objects at the point of convergence.**

### 3.1.5 SALIENCE THROUGH RECOGNITION

The human vision system has a natural tendency to be drawn to representations of the familiar. This is particularly true in the case of the human form. Whether the representation is realistic or stylised, a human form will create a focal point in a scene. Such forms do not necessarily need to be animated - a statue, painting or poster of a human figure particularly a face will engender more visual salience than an abstract sculpture or graphic. Beyond standard object recognition, humans have a tendency to perceive faces in particular with very low-level stimuli, a couple of dots and a curved line is a seen as a graphical representation of a face. The need of the human vision system to discover patterns and particularly faces leads to a phenomenon termed pareidolia. This effect forces the perception of forms such as faces from ostensibly random patterns or noise. Sagan (1995) postulates that this phenomenon may be an evolutionarily important adaptation to allow humans to determine friend from foe in dark conditions and that the process of construction from limited input leads to misinterpretation. *Figure 111*.

***Figure 111.*** **The human vision system is primed to perceive faces, even in simple shapes; hence, the abstract shapes on the right are perceived not only as a face but also as a specific individual.**

### 3.1.6 SALIENCE THROUGH MOTION

The eye is naturally drawn to motion. Therefore, a focal point of an image can be highlighted by either being animated or by the utilisation of objects within a scene moving toward the focal point. Conversely, if all objects in a scene are on the move and one remains static, the eye is naturally drawn to this area of contrast (Howard & Holcombe, 2010).

It is also the case that human retina needs some level of motion for perception to continue. The Troxler Effect (1804) in which a static image begins to fade and disappear from peripheral vision if the point of foveal fixation is unchanging, demonstrates that the nature of the visual system is not only keyed to motion but that it actively requires it. *Figure 112*.

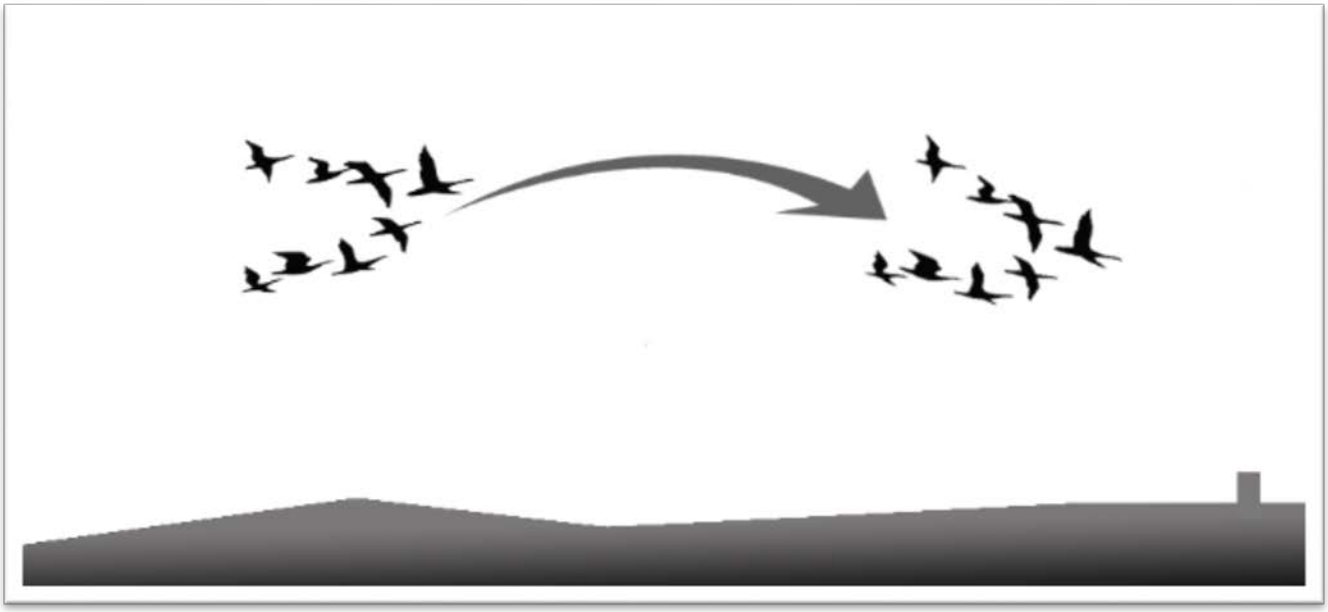

***Figure 112.*** **The motion of birds flying across a scene draws attention along a given path.**

### 3.1.7 DEPTH THROUGH CONTRAST

A commonly used method of suggesting depth in an image is to use luminance separation, this combined with saturation and the usage of cooler colours in the distance can draw the eye through an image. A composition with a warm foreground and cooler background will naturally purvey greater depth than a picture with tonally similar foregrounds and backgrounds. *Figure 113*.

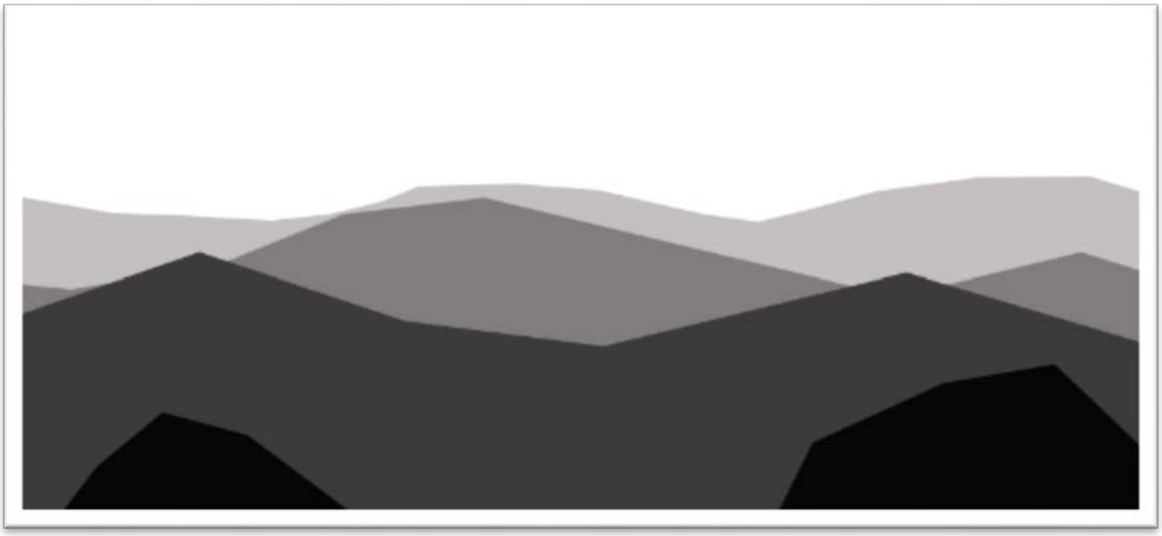

***Figure 113.* Luminance separation draws attention into the distance.**

In combination with guiding lines as below, the eye is drawn into the image; the use of paths need only be subtle for the eye to be drawn naturally along that path. *Figure 114*.

***Figure 114.* Luminance separation when combined with leading lines from a path for the gaze to be drawn along.**

### 3.1.8 SALIENCE THROUGH VALUE

The value or brightness of a particular area, particularly if it is in contrast to the surrounding scene can form a compelling focal point. However, it is not merely the case that people look at lights; it has been demonstrated that individuals are 5-10 times more likely to fixate at a point that is well illuminated and is in the foreground of a composition. There is additional evidence of a central bias to this gaze preference. The rule, therefore, being that areas of contrast do draw the eye, but not simply just the brightest element (Vincent et al., 2009). *Figure 115*.

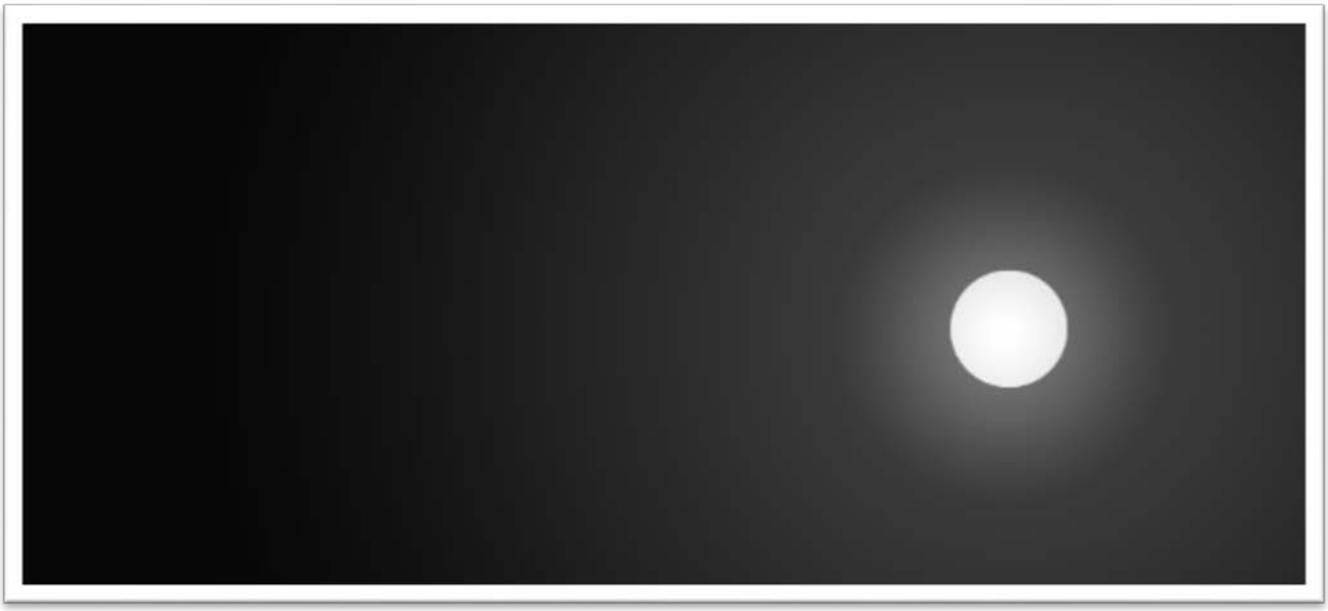

***Figure 115.*** **The human eye is drawn to strongly illuminated points in an image.**

# 4 CHAPTER FOUR: METHODOLOGY

## 4.1 OVERVIEW

The literature investigating the effectiveness of intrinsic navigational cues in all types of virtual environments, and especially video games is limited. As discussed in chapter one, a broad range of subtle cues are commonly used to draw players through game worlds. Despite the prevalence of these techniques, in particular movement, contrast and lighting, the implementation in game worlds of these techniques in games studios is based on a combination of design intuition and iteration based on playtesting. Often the playtesting is limited to one or two individuals per iteration (Schell, 2013). A major goal of this thesis was to create a series of guidelines and heuristics that provide a framework for the development of intrinsic cue based player guidance for game designers.

## 4.2 EPISTEMOLOGY

The epistemological methods and approaches to gathering and synthesising knowledge in this thesis stem from an interrelated series of empirical studies. Data collected from these studies has been analysed using a consistent statistical approach and inferences drawn are based upon a reasoned approach to the evidence. Conclusions about the influences particular cue types may have on player navigation are based on the statistical data gathered. Where the data suggests a clear influence of a cue type or a prioritisation of navigational cues, these data are reflected in a series of statements and guidelines that environment designers can refer to when creating intuitively navigable 3D spaces. Where appropriate, design implications and cue hierarchies are reflected as a collection of design guidelines.

## 4.3 APPROACH

Lighting, or moreover the changes in contrast created by lighting (Vincent et al., 2009) draw visual attention. Since the development of real-time lighting systems, lighting based cues have become a regularly used method of player guidance (Lundeen, 2009). What makes this area of navigational design particularly interesting is that it is not something that can be easily replicated in the real world in areas such as architectural navigation (Dalton, 2003). Therefore, the majority of the studies that form this thesis analyse aspects of light and contrast both on screen and in virtual reality using standard video game engine technologies. Other navigational cues were also considered competitive navigational influences, for instance, landmarks, gradients and architectural elements such as door and passage widths.

An interdisciplinary quantitative experimental approach to gathering data led to the development of unique virtual environments to test each aspect of the main hypotheses. The experimental hypotheses tested include:

- Players will navigate towards areas of contrast.
- Player navigation is positively influenced by presenting a contrasting path.
- Player navigation is negatively influenced by the lack of lighting.
- Players will solve mazes faster if subliminally guided by lighting.
- Players will solve mazes more slowly if there is aversive audio.
- Players will be drawn to motion.
- Players will prefer to move up when gradient variants are presented.
- Players may exhibit a preference for wide openings over narrow.
- Players will not notice broad textural changes in an entire environment if distracted.

Each separate study was designed to analyse particular aspects of navigational choices under varying stimuli, or detection of stimulus variance.

As detailed in the separate descriptions, they each served to gathered data on one aspect of the research in order to ascertain which stimuli take precedence and under what specific conditions.

All studies were conducted in controlled circumstances; levels of room lighting, background noise and participant guidance were consistent throughout.

Participants in all experiments read and signed a participant log indicating that they had read the volunteer information sheet and ethical guidelines and were happy to participate.

The log registered that participant with a unique number that would anonymise them in statistical analysis yet still allow their data to be removed if they later withdrew consent.

### 4.3.1 APPARATUS DESIGN CONTEXT

Four of the research methods and experimental frameworks utilised within the studies presented herein are derived from similar apparatus devised in the field of animal spatial cognition.

Humans although cognitively more advanced than the animals studied in spatial cognition experiments are still prone to make unconscious decisions about their navigation that have been shown to follow particular patterns of behaviour.

Animal spatial cognition models have been adopted for use in VE based human navigational psychology research (Astur, Ortiz, & Sutherland, 1998; Dalton & Bafna, 2003; Darken & Sibert, 1996; Vinson, 1999a) For instance performance differences in a virtual Morris water maze (Astur et al., 1998). As with the original rodent experiment, the goal was related to distal cues; their findings demonstrated that there are clear differences between male and females and that males are inherently more adept at navigation utilising distal cues. Of note is that the discomfort element of cold water used in the rat experiments was absent here. In these studies, aversive audio was introduced as the stimulus that drives the desire to solve the problem rapidly.

## 4.4 DESIGN

### 4.4.1 STUDY 1: VIRTUAL RADIAL ARM MAZE LIGHTING AND COLOUR VARIATION

Based upon a commonly used animal experimentation apparatus that presents the participant with a circular uniform space, with eight exits (Doeller et al., 2008; Maguire et al., 1999; Olton & Samuelson, 1976). The influence of illumination level and colour preference are analysed by varying the brightness and hues of lights within the corridors leading off from each exit. The apparatus precludes backtracking of the participant by closing a door once an exit path has been taken. In order to give a rationale for the task, coloured crystals are collected by the player in an antechamber at the end of each corridor.

The apparatus contains 24 separate room variants each with eight exits, corridors and associated antechambers containing pickup items in the form of hovering crystals. The collection of a crystal transports the player to the centre of the next radial arm maze space at a randomised angle.

Heat map and player navigation data was captured, the study analyses the selection of exits and their related lighting value and colour as well as the initial entry angle and the angle of rotation that the player takes before choosing an exit path.

Participants supplied data on sex, age, handedness, and gaming experience.

The apparatus was constructed in Unreal Development Kit (UDK) v.2012/07.

### 4.4.2 STUDY 2: PILOT STUDY – MAZE SOLVING UNDER DIFFERING ILLUMINATION CONDITIONS

Building on the understanding gained from the study into portal illuminance and hue variance, this study was designed to analyse whether an illuminated path would lead to more rapid solving of a virtual maze. Prior studies have sought to measure the effectiveness of navigational aids such as maps (Vembar et al., 2004) and the significance of landmarks in mazes (Jansen Osmann & Wiedenbauer, 2004). Both extraneous and integrated cues have been shown to reduce the time take to solve mazes. Further to these findings, Knez & Niedenthal (2008), claim to show a solve time effect given colour temperature variation in the lighting of the maze. As this colour temperature effect was studied via a colourisation method that produced a closely similar effect to the use of colourised lighting, a group of five mazes were constructed that were mathematically similar in their layouts. The variations were a neutral condition with uniform lighting. A variant with the path to the goal illuminated with the rest of the maze being lit at a darker value. The inverse of this condition had a dark path directly to the goal with the remainder of the environment being uniformly lit. The final two variants were uniformly lit in either blue or red.

Quantitative data in the form of solve time was the primary variable analysed.

Participants supplied data on sex, age, handedness, and gaming experience.

The apparatus was constructed in Unreal Development Kit (UDK) v.2012/07.

### 4.4.3 STUDY 3: CENTRAL GOAL MAZE SOLVING WITH VARIANT NAVIGATIONAL CUES

Several issues were apparent from the pilot maze solving study, due to the layout of the maze, solve times were extremely varied, the variance led to standard deviations that could not be compensated for by any standard statistical test. A further issue was related to the layout of the mazes insomuch that they had a linear path to the goal point, this therefore allowed for participants to use what is referred to as the wall follower or left-hand rule to solve the mazes, further skewing the resultant data. This study improved the structure of the apparatus, adding concentric islands meant that the mazes could not be solved by the left-hand rule (Perrin, 1914; Watson, 1914). The change that led to data that could be consistently analysed was that the mazes were also reduced in overall solve time complexity, the shortest path from entrance to the goal in the pilot study had been 104 grid square units, by comparison, all of the mazes in the central goal study had optimal paths only 37 units long.

The final design of the apparatus consisted of 30 mathematically similar variations incorporating the differing lighting conditions of the pilot study but also introducing both complementary and competitive navigational cues in the form of graffiti based landmarks and audio cues at either the goal or the perimeter of the maze.

Quantitative data in the form of solve time was the primary variable analysed.

Participants supplied data on sex, age, handedness, and gaming experience.

The apparatus was constructed in Unreal Development Kit (UDK) v.12791.

### 4.4.4 STUDY 4: VIRTUAL WATER MAZES WITH SUB-THRESHOLD PERCEPTION LIGHTING

The illumination of the lit path to the goal of the maze solving study raised the question as to whether the participants were perceptually aware of the lit path cue, and at what thresholds a cue of this nature became an obvious aid to navigation. In order to study this issue via an experimental framework, a variation on a Morris water tank (Astur et al., 1998; Morris, 1981, 1984) was devised where the goal point for the environment was a spot illuminated brighter than the surrounding environment. The apparatus consists of a simple domed space with alternating landmark cues that switch on and off between levels; the goal was always located at the same point in space, with relation to the landmarks. However, the player was inserted into the environment in a random location and with a random orientation in order to preclude first perspective alignment effects (Tlauka et al., 2011) and therefore direct navigation to a previously discovered goal. The light source that indicated the goal increased in value exponentially as the series progressed. At first, it was not visible at all, and by the final levels, it was a very clear bright spot on the ground.

Quantitative data in the form of solve time in addition to heat map data of player movement and navigation strategy were captured and analysed.

Participants supplied data on sex, age, handedness, and gaming experience.

The apparatus was constructed in Unreal Engine 4.

#### 4.4.5 STUDY 5: PORTAL VARIANCE AS AN INFLUENCE ON PLAYER NAVIGATION

The radial arm maze [*Figure 117*] study only sought to examine the influence of portal brightness, hue and contrast on player navigational choices. As doorways offer many other variables beyond simple lighting, this study aims to ascertain the influence provided by other commonly used environmental variables. The apparatus created consisted of 12 zones, in sequence, in this case as it became clear that the overwhelming majority of volunteers for these tests were players of video games, the base gameplay built into UDK was employed, and each room had an enemy combatant to defeat before the player could move on to the next zone. Engaging in combat also ensured that player motion across the arena space would be randomised before they approached the portals at the exit to the arena. The doorways varied in a combination of width, either wide or narrow. Exits could be at the same level as the environment or either up or down a staircase. The exits all had torch sconces running down the outermost wall, in some cases, these glowed, and in others, an animated flame and smoke effect was added thus providing a motion cue. The final variation was the overall light value within an exit corridor as per the initial portal study.

Quantitative data in the form of heat maps of player movement and navigation strategy were captured and analysed.

Participants supplied data on sex, age, handedness, and gaming experience.

The apparatus was constructed in Unreal Development Kit (UDK) v.12791.

### 4.4.6 STUDY 6: LIGHTING EFFECTS ON NAVIGATION IN AN ARCHITECTURAL SPACE

This study examines the influence of lighting as a navigational cue in an urban virtual environment. There is a wealth of architectural literature concerned with the manner in which individuals navigate through urban spaces (Dalton & Bafna, 2003; Golledge, 1995; Montello, 1997; Sadalla et al., 1980). These studies can in some regards inform game space development; certainly, the key aspects of personal navigation can act as useful precepts:

- Preference for maintaining a linear path
- Preference for maintaining linear path despite gradient
- Preference for path with the farthest line of sight
- Preference to avoid backtracking
- Path with more turns perceived to be longer than an equal length path with fewer turns
- Longest leg first preferred to shortest leg initially
- Preference for curved paths over sharp angled turns
- Identification of landmarks correlates with the correct choice of path
- Angle of exit routes from a junction relative to the entry

The above are useful heuristics that designers can implement in order to influence player motion. However, in worlds where the lighting of an environment lighting impinges on decision-making, do designers have the relevant knowledge to judge which pathway options remain preferable even when one option may be brightly lit and the other in shadow?

This study was constructed to offer all of the various optionality of route types and to combine these variables with either dark paths or lit paths in a night-time scene.

The environment created was a small town with branching streets; signage indicated that participants should not take backtracking routes. Three lighting variations on these environments were created, one with uniform lighting, the remaining two scenes alternately lit each path option. For instance, one junction offered the participant the choice between a wide, downwards inclined lit path or a narrow flat darker path.

Two variants of this apparatus were created; the initial apparatus was produced in UDK v.12791. After the original study had concluded, development kits for what have subsequently become consumer Virtual Reality headsets became available. A VR variant of the environment was recreated inside of Unreal Engine 4. The data between these two separate branches of the study was captured in different ways due to software limitations at the time. UDK allowed for the direct capture and recording of player motion and this data could be either analysed individually or aggregated in the form of heatmaps. This was not possible with the build of Unreal Engine 4 available at the time, and therefore, screen capture software was employed, and the video recordings individually analysed to describe player navigational choices.

Participants supplied data on sex, age, handedness, and gaming experience.

The screen-based version of the apparatus was constructed in Unreal Development Kit (UDK) v.12791.

The Virtual Reality conversion was created in Unreal Engine 4.

### 4.4.7 STUDY 7: LIGHTING EFFECTS ON WAYFINDING IN A LARGE OPEN WORLD ENVIRONMENT

Studies 1-6 constrained the player in either small spaces or offered them simple or even binary navigational choices, these environments allowed for clear navigational choice data to be captured, whether this was a portal choice or a solve time, all of the data was based on very limited navigational choices being presented to the participants. Open world games present a different kind of navigational challenge to a player; many rely on HUD based elements such as quest maps to offer player guidance. This study aimed to analyse the effectiveness of intrinsic navigational cues in the form of static maps, pathways, landmarks and weenies amongst other related environmental cues. It then analysed the differences that the introduction of dynamic lighting based navigational cues had on player navigation.

The environment created was a small island that has seven unique architectural structures set amongst differing interlinked natural zones such as a deciduous wooded area and a beach. The environment was designed to include many of the features that are key to findings in wayfinding studies set in the real world such as landmarks, defined paths and signage. This study with its variant states and introduction of dynamic lighting was the first such wayfinding study, and therefore introduced an approach to navigational analysis that was of a comparative nature. Heatmaps of participant movement from the main data set and due to the participants being able to roam freely about the area, an inferential method of assessment was utilised when examining the resultant data.

Quantitative data in the form of heat maps of player movement and navigation strategy were captured and analysed. The participants supplied data on sex, age, handedness, and gaming experience.

The apparatus was constructed in Unreal Development Kit (UDK) v.12791.

### 4.4.8 STUDY 8: CHANGE BLINDNESS IN A GAME BASED DISTRACTION TASK

The prior studies had demonstrated that there was a threshold at which the variance in the value of a light source began to affect player navigational choices. The question therefore arose; can variance in contrast and value change over time without being perceived and if so at what duration of change in these values would this be perceived by the observer?

A study was devised where aspects of gradual change blindness (Simons & Rensink, 2005) such as colour or brightness changes could be applied to a virtual world context.

The idea though simple had never been conducted under controlled conditions previously and whilst the process to change one texture for another can be achieved in The Unreal Development Kit, in practice, a virtual environment was required, that would appear to be testing something entirely different and therefore not telegraph the intent of the experiment to the participants. An escape the room game was constructed that encouraged the participant to move around the environment and to attend to individual objects sequentially. Whilst distracted by the escape task, the majority of materials in the room transformed in a variety of ways, including value, hue and pattern. Three variants of the apparatus were created with durations of 90 seconds, 45 seconds and 22.5 seconds.

A post participation questionnaire recorded the participant's recall of colours and textures of objects and larger elements in the scene.

The apparatus was constructed in Unreal Development Kit (UDK) v.12791.

# 5 CHAPTER FIVE:

# PILOT STUDY 1: VIRTUAL RADIAL ARM MAZE COLOUR VARIATION

## 5.1 INTRODUCTION

It has been demonstrated in real-world scenarios that under distinct variations in lighting where one entrance is close to darkness and another is brightly lit humans will choose to enter a location through the illuminated portal (Taylor & Socov, 1974). The preference for the illuminated doorway when there is dim illumination in the alternate doorway was demonstrated to be in the region of 70% whereas if a doorway was lit at 100 lumens and the alternate was only lit at 1 lumen, the preference for the lit portal rose to 100%. This simple study while fundamental to understanding the human preference for illuminated paths has not been replicated and despite being referenced more than 50 times, no other study has built directly on the outcomes described. This aspect of navigational choice was considered fundamental to understanding how lighting and other similar intrinsic cues affect decision-making. Taylor and Socov (1974) used a physical apparatus with only two entrance points, as part of their study, they clearly discuss a potential right-hand preference amongst participants. To alleviate this issue, a circular environment was devised that allowed portals to be chosen by rotation in either direction. The apparatus created was similar in basic structure to a commonly used radial arm maze apparatus designed for the study of animal navigational psychology (Doeller et al., 2008; Maguire et al., 1999; Olton & Samuelson, 1976).

Beyond simply varying the lighting of portals, a further notion of colour preference influencing the participant's decisions was considered. The suggestion has been made (Knez & Niedenthal, 2008) that a preference for warmer (reddish) hues over cooler (blueish) hues may influence navigational decisions. It, therefore, was considered necessary to analyse whether this was potentially the case for portal choices.

## 5.2 HYPOTHESIS

In the absence of other salient cues, it was hypothesised that variation in brightness (value) or variation in colour (hue) might affect route selection. While there was a suggestion in literature

(Knez & Niedenthal, 2008) that a preference for warmer hues may influence navigational decisions, there was little indication in other literature that specific hues engender specific responses. The consensus appearing to be that colour preferences themselves are often culturally variable and are a form of associative learning (Roberson, Davidoff, Davies, & Shapiro, 2005a; Roberson et al., 2005b; Wallach, 1963). It was theorised that other factors such as variance and contrast might also be influential cues (Elazary & Itti, 2008; Franconeri, Hollingworth, & Simons, 2005).

## 5.3 METHOD

### 5.3.1 **PARTICIPANTS**

79 participants, 71 male, 8 female, aged between 18 and 49 (mean 22.58) took part in the brightness (value) variant. 75 participants, 69 male and 6 female took part in the brightness (value) plus colour (hue) variant. All participants reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

## 5.4 MATERIALS AND APPARATUS

Based upon the standard radial maze ‘multiple choice situation’ developed originally for the study of spatial learning and spatial memory in rats (Crannell, 1942; Olton & Samuelson, 1976) [*Figure 116*], a virtual environment was developed in The Unreal Development Kit (UDK) v.12791.

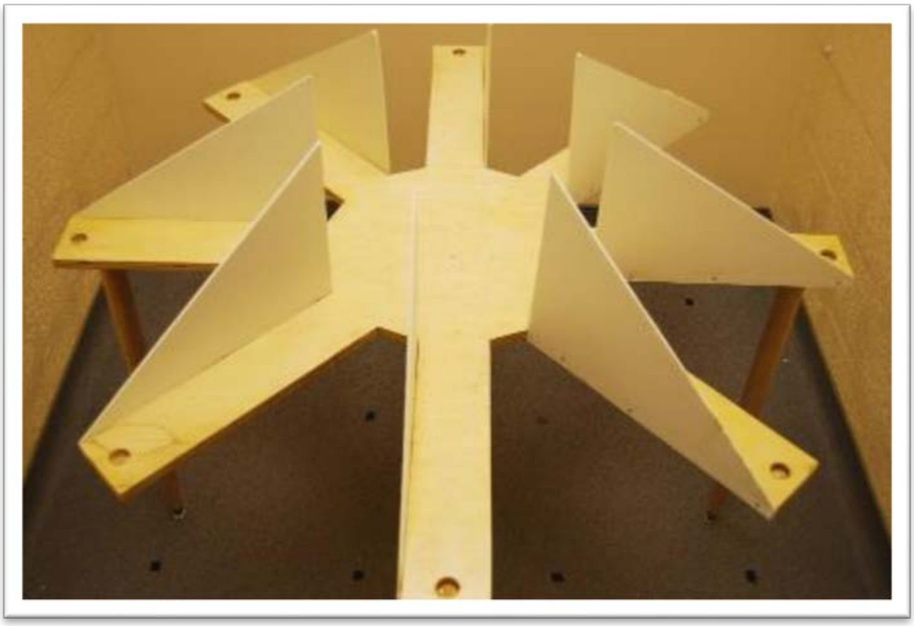

*Figure 116.* **A typical eight-arm radial maze.**

The participant was positioned in the centre of a circular domed space containing eight geometrically identical exits. *Figure 117*. When the participant passed through an exit, a barrier dropped down to preclude backtracking. Each curved corridor had obscured sightlines after which a glowing crystal was presented to be collected; this pseudo-reward was included to provide a goal for the participants. Once the crystal was collected, the player was teleported into the centre of the next chamber and oriented at a random rotational angle. The exits and accompanying pathways were illuminated in a variable manner.

Two variants of the environment were created each containing 25 domed chambers each with eight exits, in variant A., the only variable introduced was the brightness (value) of the doorways, this was achieved by the change in lighting value for a series of light sources in each of the corridors. In variant B. the light sources are colourised either in a warm or cool shade. *Figure 118*.


*Figure 117.* **The radial maze cave system developed in Unreal Development Kit.**

*Figure 118.* **The radial maze seen from within. Doorways are illuminated in either warm or cool colours.**

### 5.4.1 VARIANT A.

The table below details the lighting values assigned to each of the light sources associated with each specific doorway in the environment. No other variation was made to the lighting or any other element of the environment. The individual lights were all set to a consistent colour of R255 G 249 B 228 (hex value - #FFF9E4)

| Level No | exit 1 | exit 2 | exit 3 | exit 4 | exit 5 | exit 6 | exit 7 | exit 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 1 | 0.5 | 1 | 2 | 1 | 0.5 | 1 | 2 |
| 8 | 1 | 0.5 | 2 | 0.5 | 1 | 0.5 | 2 | 0.5 |
| 9 | 0.5 | 2 | 1 | 2 | 0.5 | 2 | 1 | 2 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 0.25 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 13 | 0.25 | 1 | 0.25 | 1 | 0.25 | 1 | 0.25 | 1 |
| 14 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 0.1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 17 | 0.1 | 1 | 0.1 | 1 | 0.1 | 1 | 0.1 | 1 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19 | 0.1 | 1 | 0.25 | 1 | 0.1 | 1 | 0.25 | 1 |
| 20 | 0.25 | 1 | 0.25 | 0.1 | 0.25 | 1 | 0.25 | 0.1 |
| 21 | 1 | 0.1 | 0.25 | 0.1 | 1 | 0.1 | 0.25 | 0.1 |
| 22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 | 0.25 | 1 | 2 | 0.1 | 0.25 | 1 | 2 | 0.1 |
| 24 | 1.5 | 0.1 | 0.1 | 0.1 | 1.5 | 0.1 | 0.1 | 0.1 |
| 25 | 0.01 | 0.5 | 1 | 1.25 | 0.25 | 0.75 | 1.5 | 1.75 |

***Table 2.*** **A shaded table of the brightness values assigned to each doorway in the study.**

### 5.4.2 VARIANT B

The table below shows both the individual values assigned to the lights illuminating each of the corridors leading from the doorways and the colour value allocated to each of those doorways, the warm shade being R255 G147 B41 (Hex value - # FF9329) and the cool shade being R41 G149 B255 (Hex value - # 2995FF)

| Level No | exit 1 | exit 2 | exit 3 | exit 4 | exit 5 | exit 6 | exit 7 | exit 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 |
| 4 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 5 | 2 | 1.5 | 2 | 1.5 | 2 | 1.5 | 2 | 1.5 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 1 | 0.5 | 1 | 1.5 | 1 | 0.5 | 1 | 1.5 |
| 8 | 1 | 0.5 | 2 | 0.5 | 1 | 0.5 | 2 | 0.5 |
| 9 | 0.5 | 2 | 1 | 2 | 0.5 | 2 | 1 | 2 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 0.25 | 1 | 1 | 0.25 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 13 | 0.25 | 1 | 1 | 0.25 | 0.25 | 1 | 1 | 0.25 |
| 14 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 0.1 | 1 | 1 | 0.1 | 1 | 1 | 1 | 1 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 17 | 0.1 | 1 | 1 | 0.1 | 0.1 | 1 | 1 | 0.1 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19 | 0.25 | 1 | 1 | 1 | 1 | 0.25 | 0.1 | 0.1 |
| 20 | 0.25 | 0.25 | 0.25 | 0.25 | 1 | 0.1 | 0.1 | 0.1 |
| 21 | 0.1 | 0.1 | 0.1 | 1 | 0.25 | 0.25 | 1 | 0.1 |
| 22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 | 1 | 2 | 2 | 0.25 | 0.25 | 0.1 | 0.1 | 1 |
| 24 | 0.1 | 0.1 | 2 | 0.1 | 0.1 | 2 | 0.1 | 0.1 |
| 25 | 0.01 | 0.5 | 1 | 1.25 | 0.25 | 0.75 | 1.5 | 1.75 |

***Table 3.*** **A table of the brightness and colour values assigned to each doorway in the study.**

### 5.4.3 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4th generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch wide-screen monitor – all monitors having the same calibration settings. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Colour-blind volunteers were excluded from the survey. All read and signed the accompanying ethics form.

## 5.5 RESULTS AND DISCUSSION

### 5.5.1 LIGHT BRIGHTNESS VARIATION

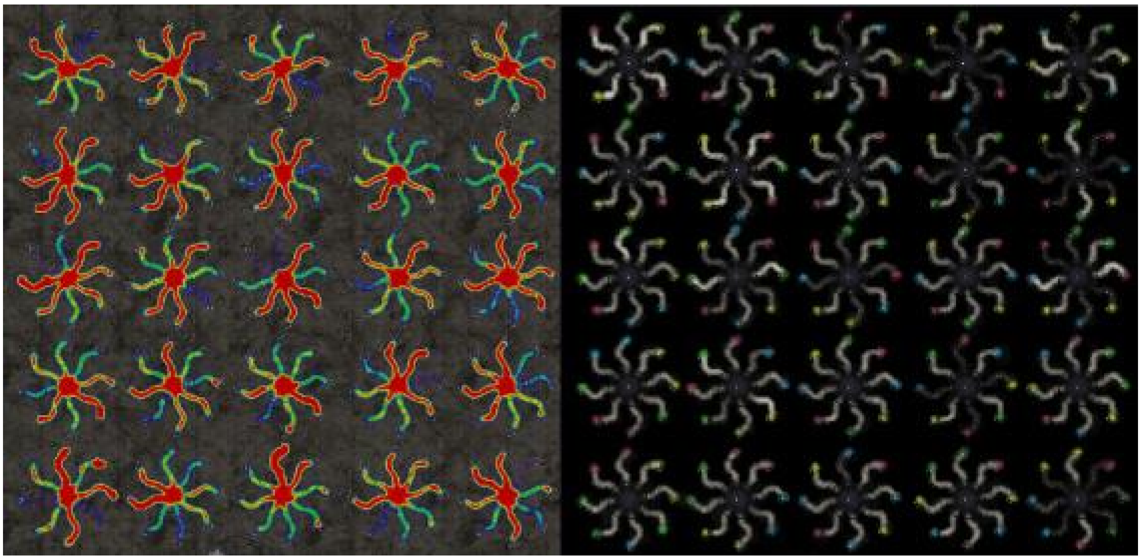

*Figure 119.* Heat map representation of player movement data [left] with corresponding brightness choices [right]

### 5.5.2 COLOUR VARIATION

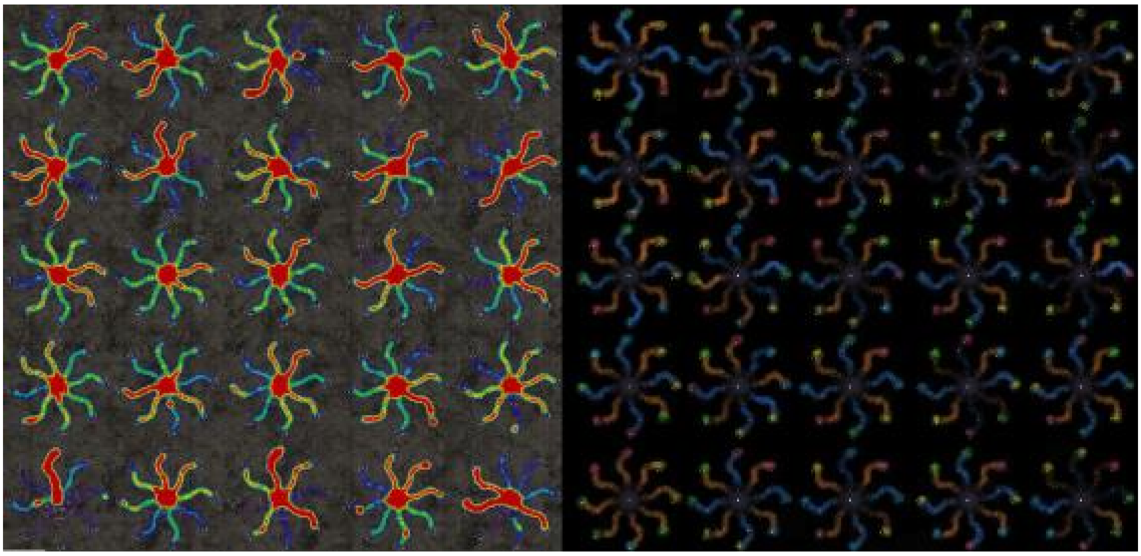

*Figure 120.* Heat map representation of player movement data (left) with corresponding colour and brightness choices (right)

### 5.5.3 ORIGIN VS EXIT VECTOR

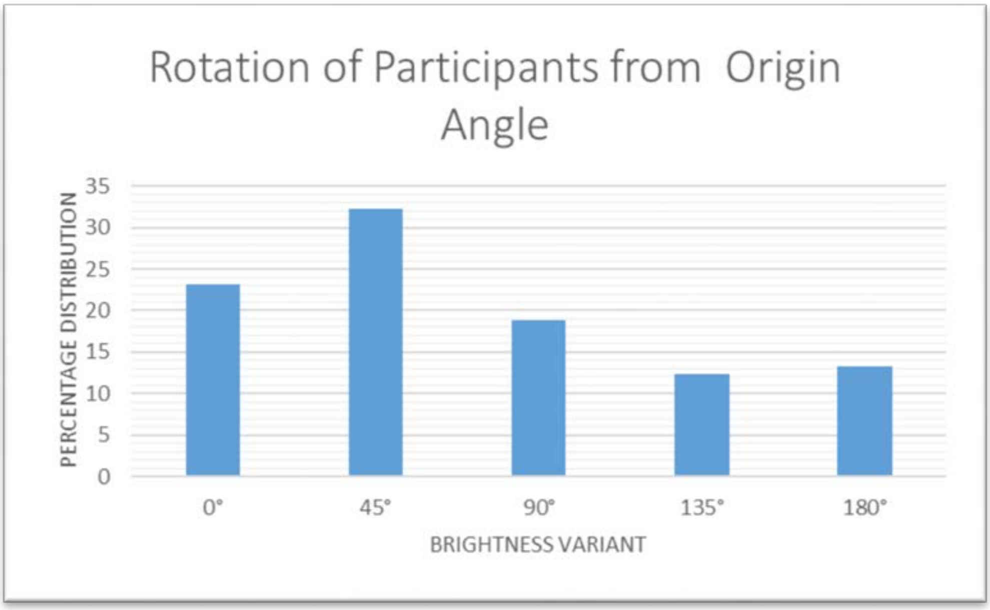


***Figure 121.*** **A representation of exit angle rotation form entry angle in the brightness only variant.**

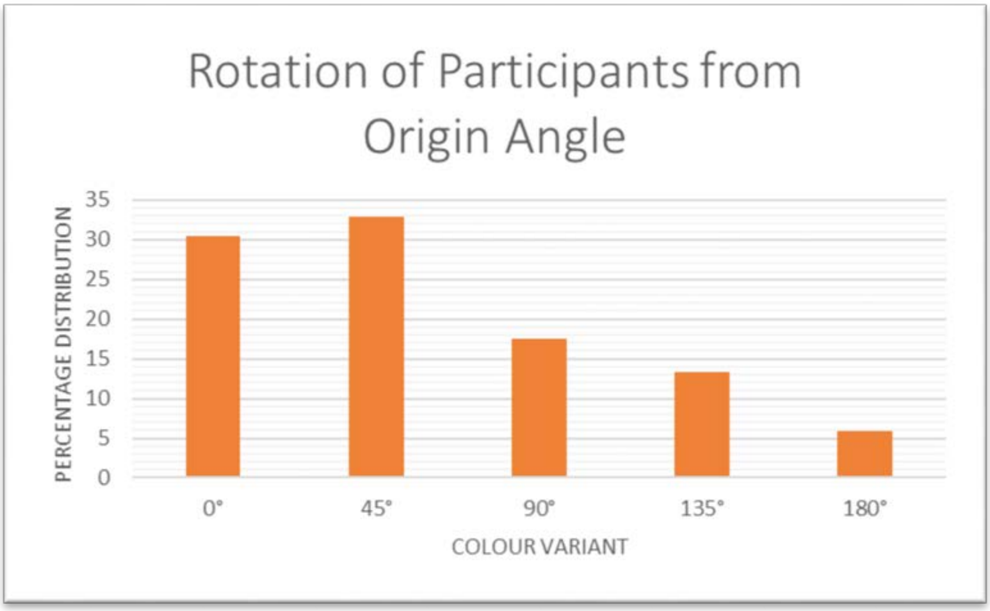


***Figure* 122. A representation of exit angle rotation from entry angle in the colour and brightness variant.**

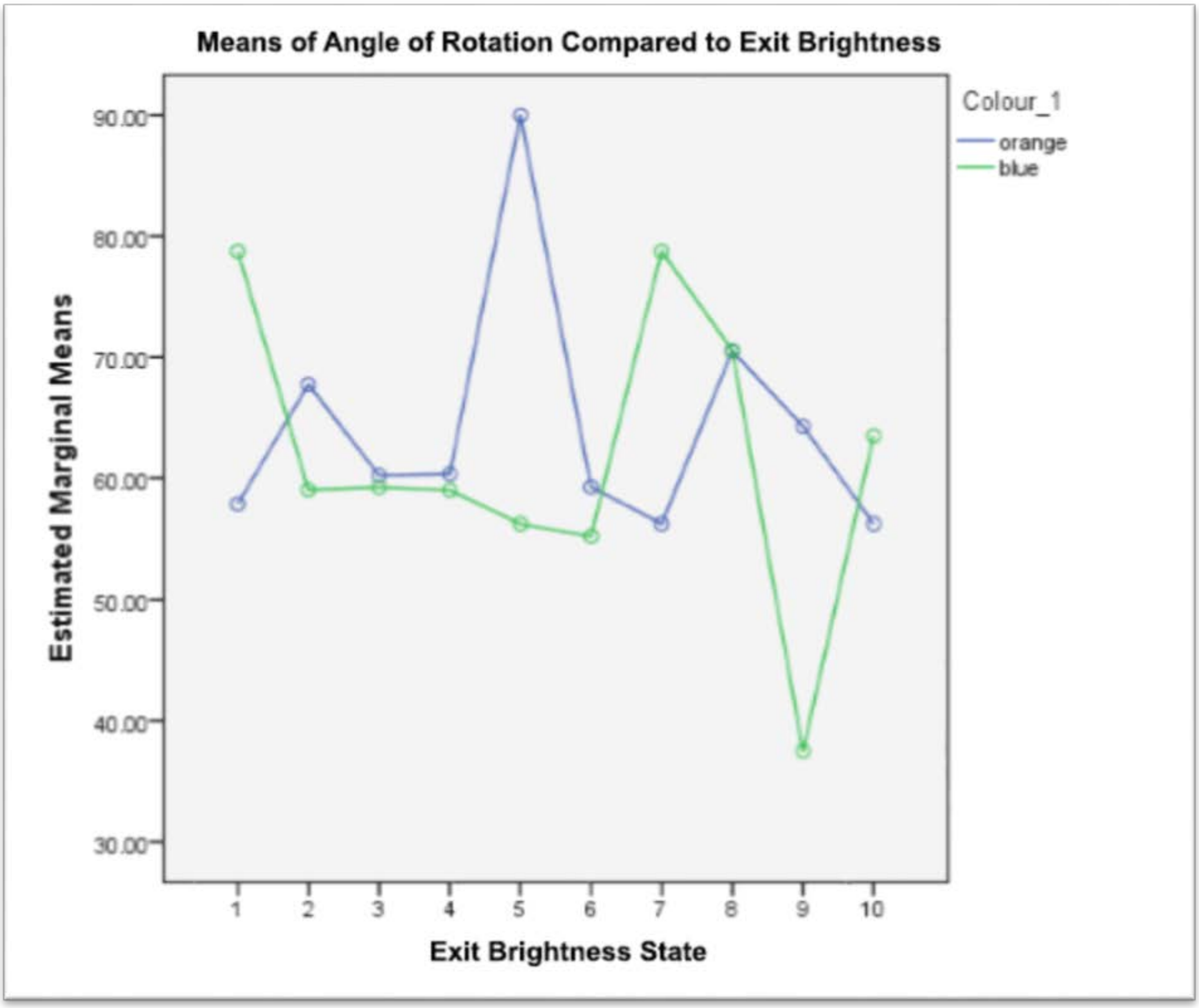


*Figure 123.* **The selection of exit paths with relation to the brightness of each exit.**

A univariate ANOVA showed found no effect of lighting (F (9, 1875) =0.756, p=0.657). While some preference for contrasting exits was observed in analysis of the heatmaps, no difference between groups was detected when comparison was made of the overall brightness of illumination and with exit preference. The same was also true of the warm/cool variant of the study in which a univariate ANOVA showed found no effect of lighting with colour variation (F (9, 1875) =0.525, p=0.857).

### 5.5.4 DISCUSSION

This study was developed to answer the question do players make path choices based upon simple differences in either illumination or colour. Within current generation video games, it is common for the designers to attempt to use the lighting within the game as a form of guidance, effectively suggesting and enhancing path choice by the variance in illumination or colour saturation within the lighting design. It is theorised that these simplistic interpretations of player guidance do not work without context and do not hold any special significance in and of themselves. Indeed, as discussed within the discussion of colour in the literature review, although it has been suggested in numerous articles that particular colours may evoke certain emotional reactions in humans; this concept is overly simplistic and fails to contextualise those interactions with colour. The perception of colour has been demonstrated to not only be wholly subjective, (Wallach, 1963) it is also interdependent on surrounding stimuli (Lotto & Purves, 1999).

The data for the relationship between original orientation and final path choice suggests that in accordance with architectural navigational precepts (Dalton, 2003) there is in both the real and virtual worlds, a tendency to follow a given path or under certain circumstances to deviate from a linear path only by a shallow angle.

# 6 CHAPTER SIX:

# PILOT STUDY 2: MAZE SOLVING UNDER DIFFERING ILLUMINATION CONDITIONS

## 6.1 INTRODUCTION

Mazes are a broadly used apparatus in many cognitive psychology experiments. Both in animal studies (ME Wilson & Valentine, 1931), and human navigational psychology (Gillner & Mallot, 1998; Janzen, Schade, Katz, & Herrmann, 2001; Moffat et al., 2001). The effectiveness of navigational aids such as maps (Vembar et al., 2004) and the significance of landmarks in mazes (Jansen Osmann & Wiedenbauer, 2004), have demonstrated that both extraneous and integrated cues reduce the solve time of mazes. Knez & Niedenthal (2008), claim to show a solve time effect given colour temperature variation in the lighting of the maze. However, no prior study has aimed to discover whether subtle lighting differences of paths in a maze can act as sub-perceptual guidance and therefore decrease the solve times of the maze. Moreover, no research has been conducted into whether subtly illuminating the most direct path to the goal leads to a faster solve time.

## 6.2 HYPOTHESIS

Lighting in virtual environments introduces contrast between spaces, as areas of contrasting brightness are commonly introduced as the optimal path for the player to follow in video games (M. Brown, 2015; S. Rogers, 2010), it was therefore suggested that in simple maze conditions:

1. There would be a difference in maze solving times under differing illumination conditions
2. Colour variations in lighting would not be a significant factor in solve times.

## 6.3 METHOD

The environment developed for this study was a rectangular maze with the goal at the opposite end to the entrance. Mazes were created that had matching distances to goals, matching alternating options and the same number of dead ends. These consisted of:

- A uniformly illuminated maze with neutral coloured light
- A maze with neutral lit path to the goal
- A maze with the path to the goal being darker than the other neutrally lit paths
- A maze which was illuminated with red light
- A maze that was illuminated with blue light

### 6.3.1 PARTICIPANTS

71 participants; 64 male, 7 female, aged between 18 and 54 (mean 22.15) all reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

Participants were provided with a sheet with the simple instruction to find the statue at the end of each maze and to note down their solve times.

### 6.3.2 MATERIALS AND APPARATUS

In order to test the hypotheses, five mathematically similar mazes were created in Unreal Development Kit (UDK) v.12791. All mazes were constructed on 16x16 grid, they all had the same number of blocks from start point to goal.

The main design criteria for the development of these mazes were that they were mathematically similar, insomuch that the distance from the entry point to the goal was identical, and that the number of turns, dead ends and remaining spaces were identical.

The environments were neutral and had no landmarks or additional visual data. They consisted of simple repeated walls, floor and ceiling. *Figure 125*. These environments were constructed from sample materials that are included in the Unreal Development Kit.

A trigger volume at the beginning of each maze started a timer and simultaneously closed the door to the entrance corridor, ensuring that any dead time at the start was not recorded as solve time.

The goal for each maze was a large imposing statue; [*Figure 124*] a second trigger volume at the statue location halts player movement and displays the time taken to complete the maze.

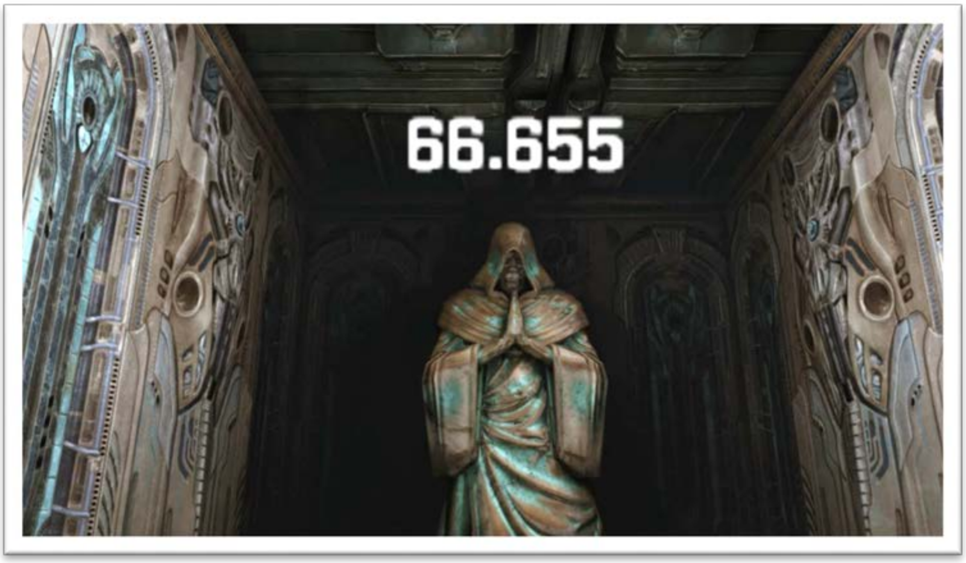


***Figure 124*. The goal point of each maze is a large hooded statue. A trigger volume stops player movement and displays the elapsed time on screen.**

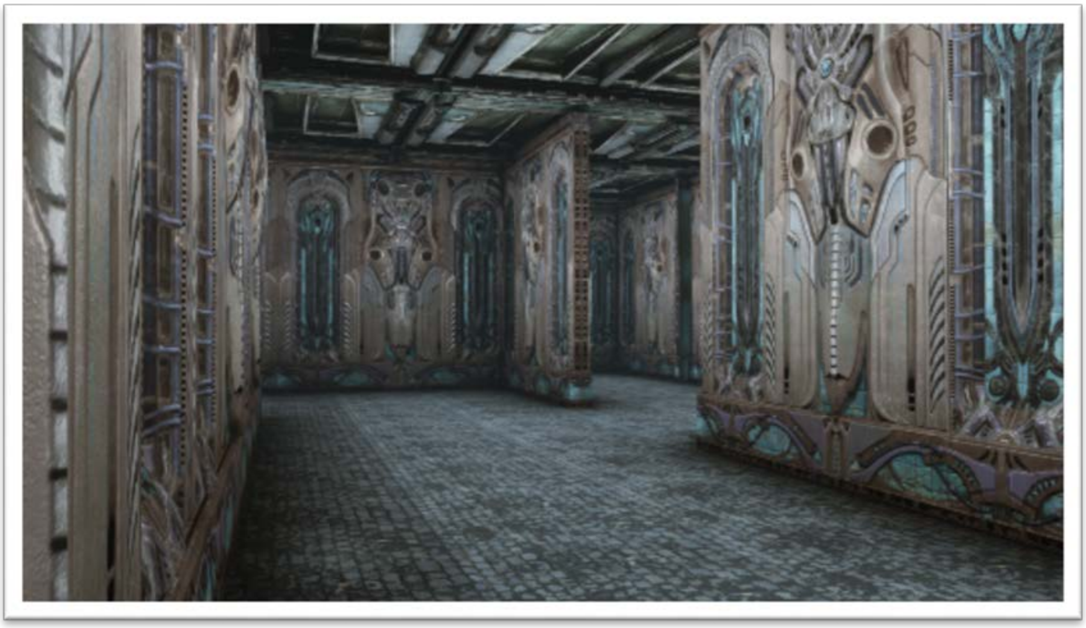

*Figure 125.* **The maze environments were created using models and textures packaged with Unreal Development Kit.**

To ensure that the environments impacted the solve time data as little as possible, mazes were duplicated, and mirror flipped [*Figure 126*] and assigned to an opposite use: The lit path flipped became the dark path to goal and similarly, warm (red) when flipped became cool (blue).

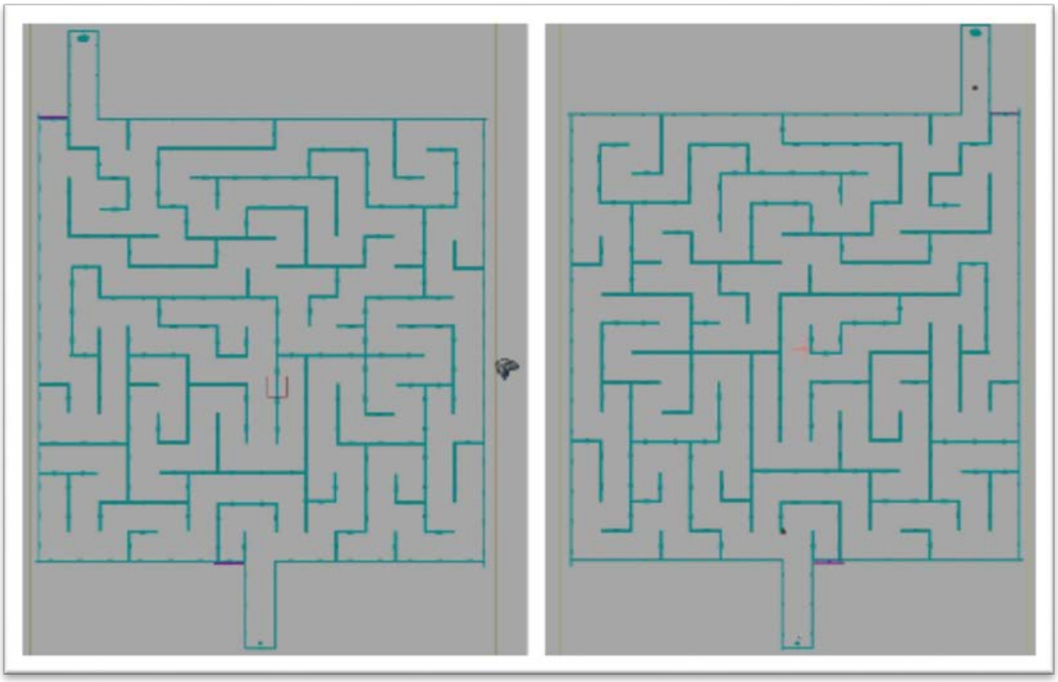

*Figure 126*. **Examples of maze layouts used in this study.**

An effort was made to duplicate the colour conditions of Knez & Niedenthal (2008) original environments. However, the colour temperature values described in the study did not correspond to the colours represented in the images printed in the paper. Therefore strongly saturated shades of red and blue were used as these best met the descriptions given in the original paper and were selected via colour sampling of embeded images. *Figure 127*.

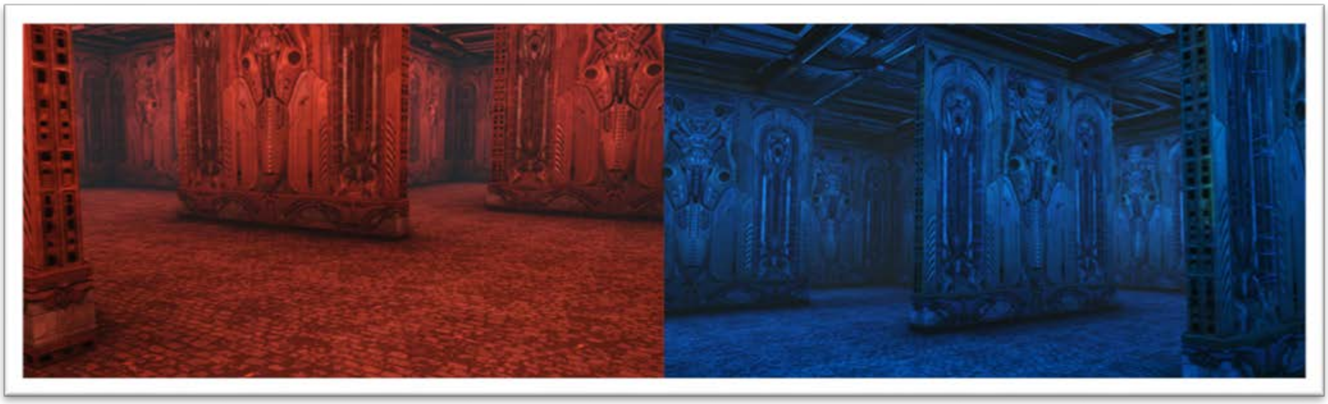

***Figure 127.*** **Examples of the colour adjusted lighting used in the study.**


***Figure 128.*** **The colour values used for each lighting colour. Neutral [left], cool [centre], warm [right]**

The neutral, cool and warm mazes were lit with individual lights all of which were set to a standard brightness of 1.00 the neutral lighting condition had colour hex values of #FFFFFF the cool variant had a colour hex value of #007CFF, and the warm variant had a colour hex value of FF543A. *Figure 128*.

The lit path [*Figure 130*, *Figure 131*] and darker path variants had their brighter lights set to the same value as the lights in the neutral condition; the darker lights were all set to a brightness value of 0.3. No other changes were made to the lights. *Figure 129*.

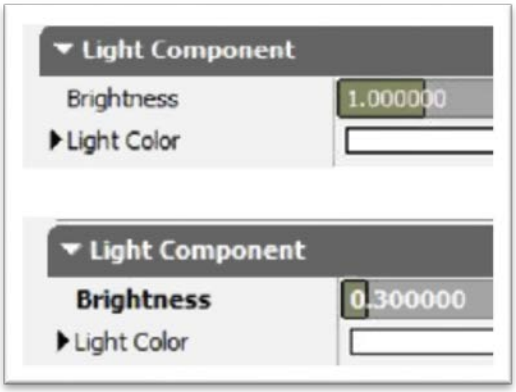


***Figure 129.*** **The brightness values assigned to the lit [top] or dark [bottom] states.**

*Figure 130.* A dark area of the lit path to goal maze.

*Figure 131.* The lit path to the goal. The dead end in the centre of the image is illuminated at 30% of the brightness of the lit path.

## 6.4 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4th generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch wide-screen monitor. The environment was kept as similar as possible between sessions with sound levels kept to a minimum, lights dimmed, and blinds closed.

Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Colour-blind volunteers were excluded from the survey. All read and signed the accompanying ethics form.

Each participant was supplied with a randomly assigned set of five mazes, one of each variant to solve. The flipped and duplicated mazes were allocated an A or B coding, and a random sequence generator was then employed to give a unique order sequence for each participant (e.g. 3A,2B,1A,5B,4A)

A briefing sheet was given to each participant asking them to locate the statue at the end of each maze and to record the on-screen solve time for each test.

## 6.5 RESULTS AND DISCUSSION

Not all of the participants completed all of the mazes allocated to them; three participants withdrew from testing due to motion sickness which was attributed to the alpha sorting of some surfaces. The results from these participants completed mazes have been included in the data set as the data was analysed based upon averages of completed mazes across all participants. Five participants had indicated that they had solved all of the mazes by simply using the wall follower or left-hand rule and these times had been removed from the data set. Of the remaining data, three of the solve times were dramatically larger than the mean. Therefore Hoaglin and Iglewicz's outlier labelling rule (1987) was applied to identify distinct outliers in the data set. Over the five mazes, 22 (6.75%) extreme outliers were detected and removed from the data set.

### 6.5.1 DESCRIPTIVES

A repeated measures ANOVA showed that $F(4, 244) = 0.800$, $p=0.526$ demonstrating no significance between groups. The table below illustrates the reason for the discrepancy between the apparent faster solve times for the maze with the lit path to the goal and the other variants. This being very large standard deviations in solve times.

**Descriptive Statistics**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Neutral | 204.72 | 172.225 | 62 |
| Cool | 191.87 | 238.428 | 62 |
| Warm | 196.06 | 188.447 | 62 |
| Lit_Path | 176.16 | 159.030 | 62 |
| Unlit_Path | 229.21 | 280.454 | 62 |

***Table 4.* Mean solve times for each of the variant mazes with standard deviations.**

## 6.6 DISCUSSION

The data demonstrated a flaw in the original methodology and design, that being that certain individuals appeared to solve all, or in some cases later mazes in a uniformly fast time. Post questioning of participants and careful analysis of the data collected allowed for the removal of potentially skewing data where the mazes had clearly been solved by utilisation of the 'left-hand rule'. Five participants were removed due to uniformly using this method. However, it is possible that some participant data has still been affected by using this approach and therefore the following experiment (Chapter Seven) uses a design of maze that overcomes this potential design flaw.

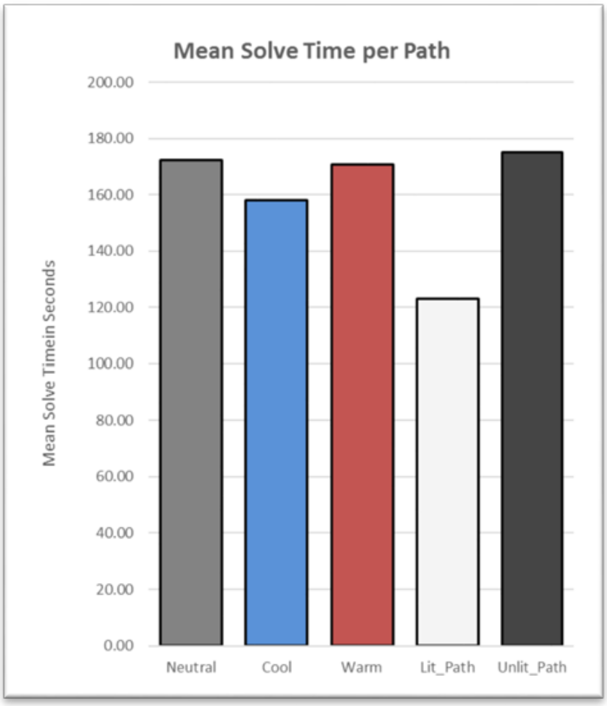


***Figure 132.*** **Mean solve times for each light and colour variant.**

Although the results showed as predicted that the lit path to goal was solved fastest this was only apparent from simple means of the data, [*Figure 132*] a repeated measures analysis of the same data returned results that showed no statistical significance across all variants. Due to the complexity of the mazes, the standard deviations were so large that statistical significance was not possible to verify. The clear reason for the very broad distribution of solve times is concerned with the design of the maze environment. The shortest route to the goal was 104 units long, this in practice made the maze too complex and it was evident that further studies using maze apparatus should be simplified with far shorter paths to the goal.

While simple means of the solve times may suggest that illuminating the path to the goal reduces the solve time for mazes, this was not possible to verify due to the large standard deviations from those means. A further compounding factor, in this test, was that the illuminated path was noticeable and did not meet the requirement of being a sub-perceptual cue. Despite the lit path working as a guide to participant navigation, the same was not true of a dark path leading to the goal.

# 7 CHAPTER SEVEN:

# CENTRAL GOAL MAZE SOLVING WITH VARIANT NAVIGATIONAL CUES

## 7.1 INTRODUCTION

The initial maze study (Chapter Seven) while yielding interesting results had inherent design flaws which required the removal of participant data set due to five participants having utilised the wall follower or 'left-hand rule'.

Other maze types have been used in psychological experiments, particularly in rat studies, an implementation of a variant of the (Watson, 1914) Circular Maze is illustrated below. *Figure 133*. However, a circular maze with continuous walls as shown below remains solvable by a wall following rule. A further apparatus, again used in rat studies is the enclosed alley maze (Uster, Bättig, & Nägeli, 1976). *Figure 134*. This maze type did not have continuous walls, and the goal was located at the centre of the maze. A maze with discreet islands has the advantage that it cannot be solved by utilising the wall follower rule this is advantageous when being solved by humans as prior knowledge of this rule can lead to skewed results. It was not evident from the literature review that mazes of this specific type had been used in previous studies of this kind.

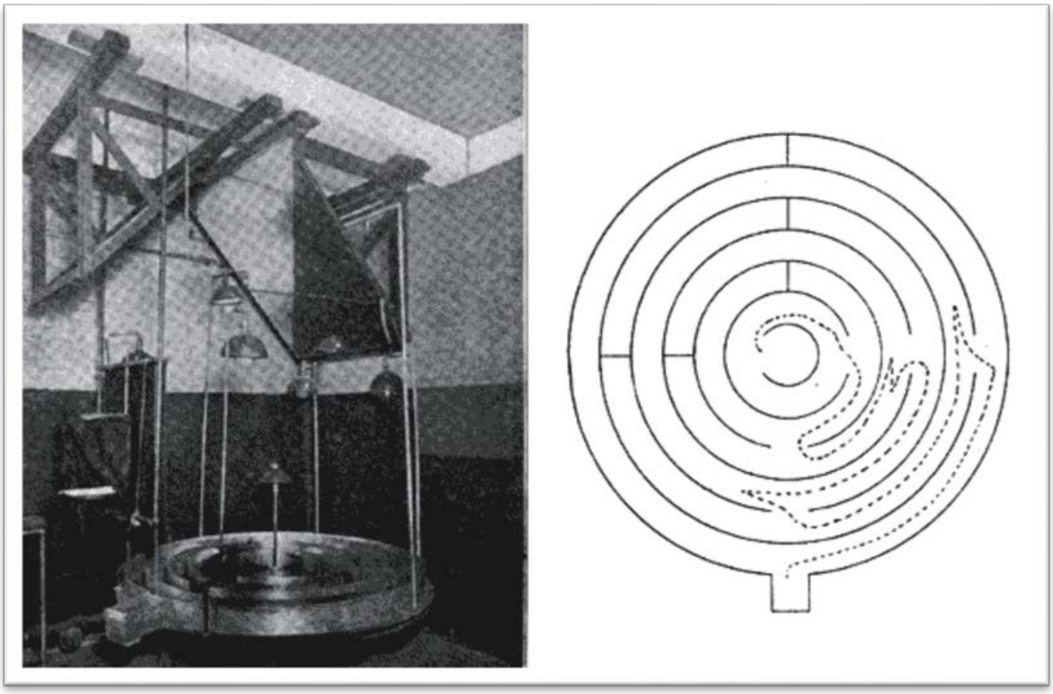

*Figure 133.* **Circular maze apparatus. Brockbank 1918**

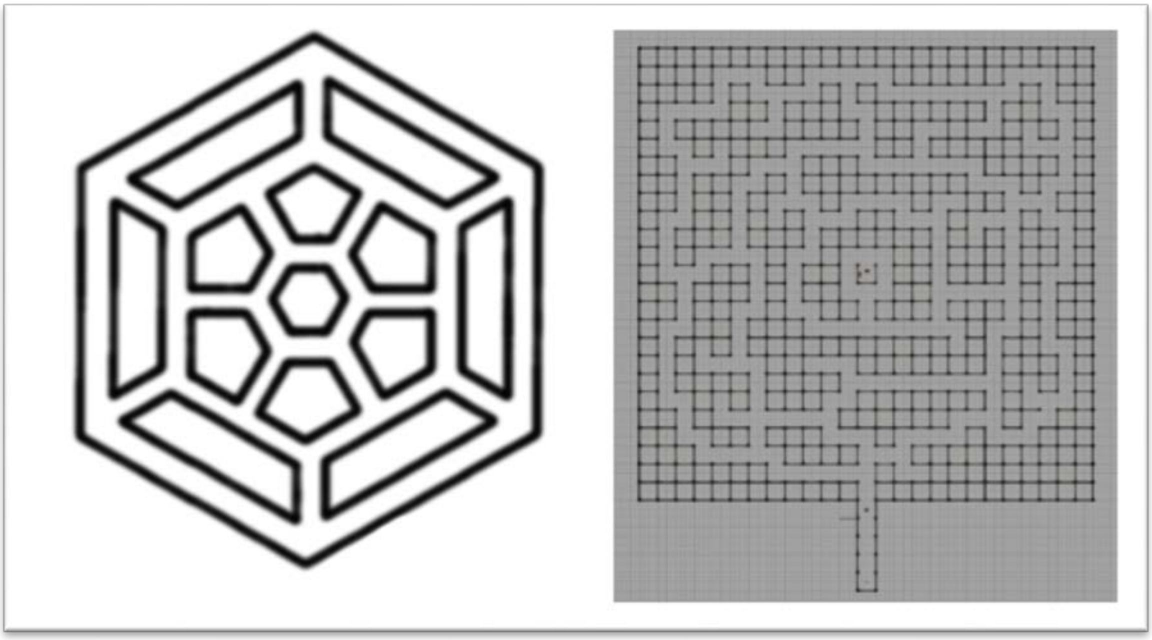

*Figure 134.* **An example of an enclosed alleyway maze** (Uster et al., 1976)**[left] and concentric island maze apparatus developed for this study [right].**

The method employed to modify the overall colourisation of the environment was not via the use of coloured light sources. Instead, lights were used in the standard manner, and their colour setting remained neutral. The overall colourisation of the scene was then added as a colour filter post-processing effect across the entire scene. Whilst this is not specifically a method of illuminating the scene via discreet colour emitting sources, it recreates and reflects the use of the term 'lighting' as employed by Knez & Niedenthal (2008).

## 7.2 HYPOTHESIS

Lighting in virtual environments introduces contrast between spaces, as areas of contrasting brightness are commonly introduced as the optimal path for the player to follow in video games, it follows that in simple maze conditions that:

1. There would be a difference in maze solving times under differing lighting conditions
2. Colour variations in lighting would not be a significant factor in solve times.
3. A positional audio cue will have an influence on solve time
4. Points of interest will have an impact on solve time
5. Combining contrast, positional audio and points of interest will allow for cue competition, and therefore influence solve time.

## 7.3 METHOD

### 7.3.1 PARTICIPANTS

134 participants, 115 male, 19 female, aged between 17 and 54 (mean 22.01) all reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

## 7.4 MATERIALS AND APPARATUS

In order to test the hypotheses, 30 mathematically similar central goal mazes were constructed in Unreal Development Kit (UDK) v.2012/07 [See table 5. For a description of the variables under study in each variant].

The initial experiment had utilised ornately textured walls built into The Unreal Development Kit, to reduce visual complexity in this study, bespoke neutral grey concrete walls and ceilings were developed giving the feel of an underground bunker or similar uniform space.

Once the player sets off from the start point, a trigger volume at the beginning of each maze started a timer and simultaneously closed the door to the entrance corridor, ensuring that any dead time at the outset was not recorded as solve time.

The goal for each maze was a large imposing statue, which once approached stopped the level and displayed the time taken to complete the maze. *Figure 135*.


***Figure 135.*** **Completion time of the maze displayed on screen once the statue at the centre had been located.**

Each maze was a 23x23 grid consisting of three concentric open islands with the goal point being located at the heart of the environment. Each maze also had a shortest path of 37 units from the start point to the goal point (The pilot study had a shortest path to the goal of 104 units). 14 small right angle dead ends were included in each layout. *Figure 136*.

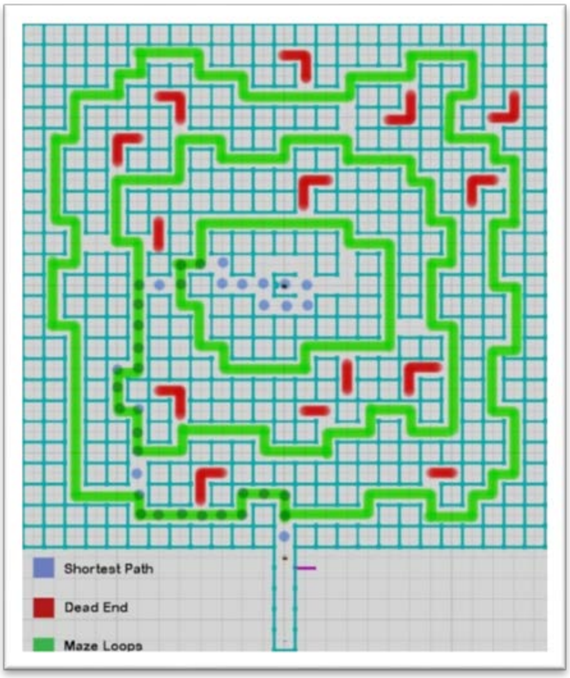


***Figure 136.*** **An example of the design of the mazes in this study.**

#### 7.4.1.1 LIT PATH AND DARK PATH VARIANTS

Initial uniform lighting was created for all of the thirty base mazes these mazes were then separated into five categories.

1. Group one retained its standard uniform lighting.
2. Group two was colour corrected via post processing of the display to a red hue. *Figure 137*
3. Group three was colour corrected via post processing of the display to a blue hue. *Figure 138*
4. Group four was altered by illuminating the path to the goal with lights set to the default value of 1.0 and decreasing the illumination of all other lights to 0.2 of the original brightness. *Figure 139*
5. Group five was altered by having the path to the goal illuminated more darkly than the surrounding lighting, again by reducing the brightness of the lights to the goal to a value of 0.2 with all remaining lights being set to a brightness value of 1.0.


***Figure 137.*** **The method used to set the post-processing colour for the red variant.**


***Figure 138.*** **The method used to set the post-processing colour for the blue variant.**

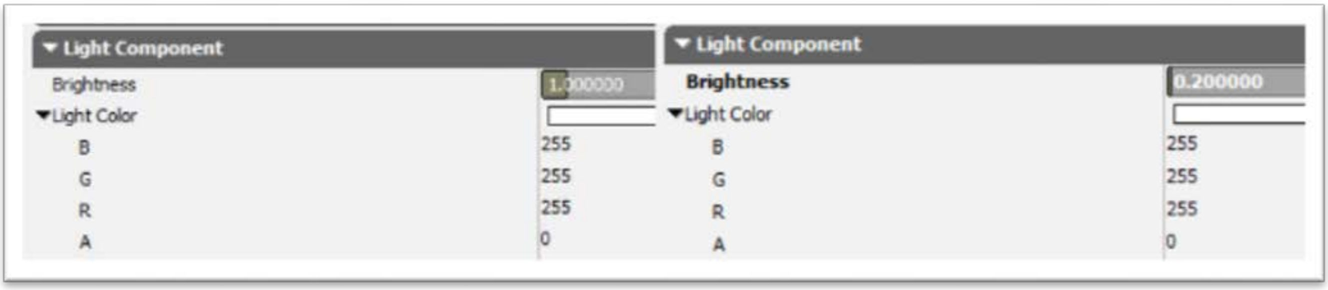


***Figure 139.*** **The variation of the Light Component value to reduce brightness in variants four and five.**

In initial testing, these values for the lighting variants produced a variation in lighting between light and dark corridors that while visible were not immediately obvious to those asked. Despite the variable for the light within the engine being set to 0.2 and 1.0, this does not translate to one light being only one-fifth as bright as the other or vice versa. In order to quantify the differences between illumination states in the rendered scene, an averaging of scene pixels was implemented. In the image below, [*Figure 140* the left half of the scene was illuminated with lights that have a light component value of 0.2 and the right half was illuminated with lights have a light component value of 1. *Figure 141*. The image was then split into two equal sections, and the mean brightness of the pixels in these halves was derived by using the average function in Adobe Photoshop.

The grey squares in the illustration below [*Figure 140*] are samples of the averaging process. Using a representative brightness scale from 0-100 - where zero represents black and 100 represents white; the averaged scene image brightness was 22. On this scale, both the darker and brighter sides averaging precisely 6 points away at 16 and 22 respectively. As this was a 100-point scale, this means that rather than there being a difference in brightness of 80% as the lighting numbers may suggest, the approximate average difference in on screen brightness was only 12% or 6% from the mean in either direction.

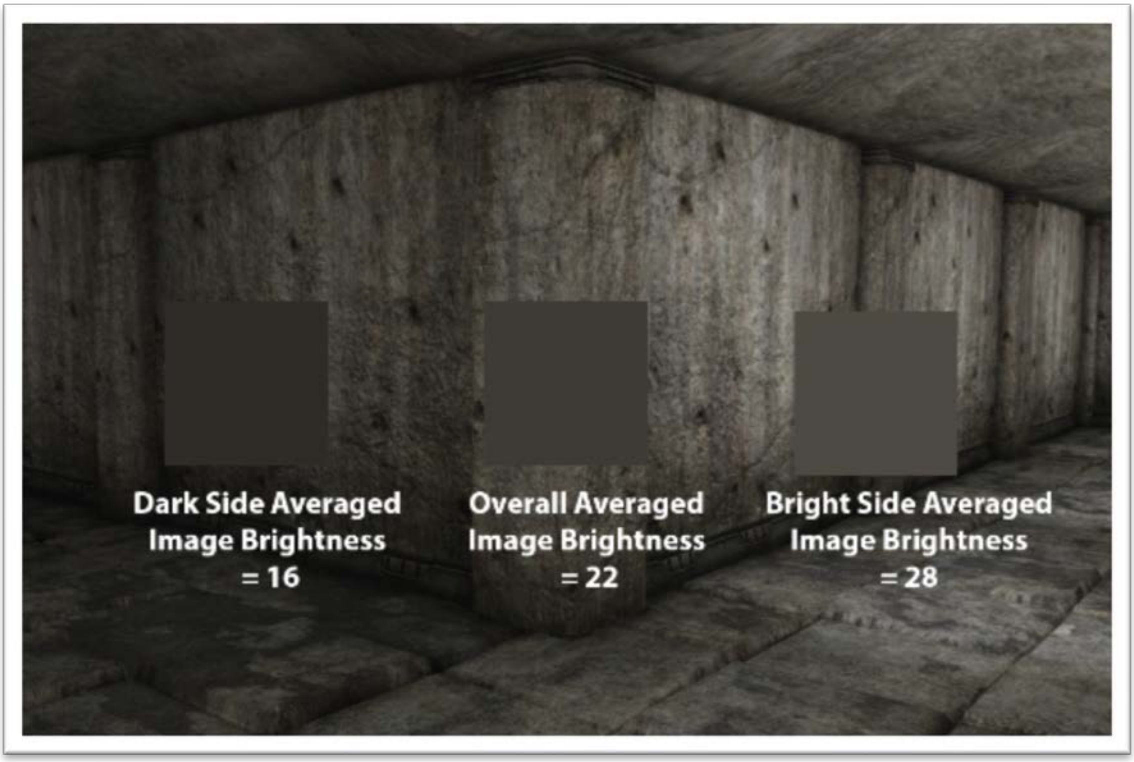


*Figure 140.* **The grey squares represent the averaged values of their respective sides with the centre square being the overall scene average.**

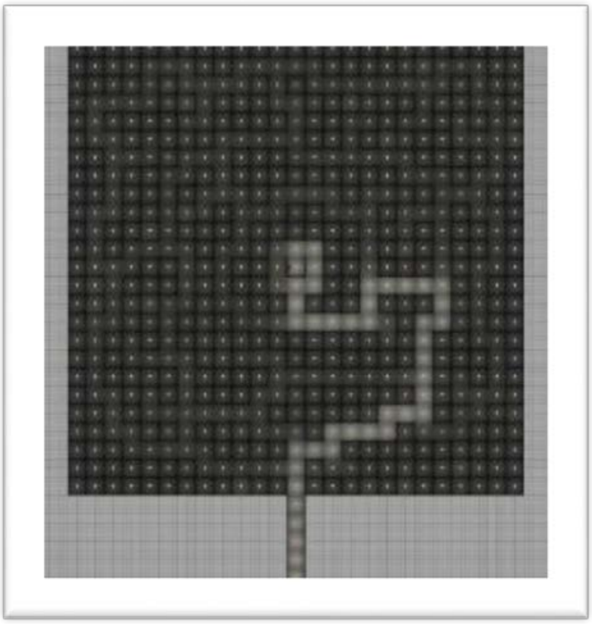

*Figure 141.* **An example of a maze in which the lit path was illuminated by light with a component value of 1.0 and the remaining squares are illuminated with component values of 0.2**

Following the structure described in the table below [*Table 5],* these lit variants were then separated into six groups containing each of the variations in lighting. *Figure 142*. A discordant and aversive piece of audio that combined echoes of off key string instruments with a low groaning and growling sound was placed in variants 2 and 5 at the goal of the maze. In variants, 3 and 6 four copies of this sound were placed at the centre point of each of the surrounding walls. The audio cues each had an exponential falloff applied to them. Therefore, the audio cue at the centre of the maze was silent at the outer corners of the maze and very quiet at the centres of the outer walls, whereas the audio cues at the outer walls of the maze would be loudest at those points and fall off to silence at the centre of the maze. These aversive audio cues offered either a potential cue reinforcement with the lit path to goal state where located at the goal or a potential cue conflict with the lit path to goal state where placed at the furthest points from the goal.

A further contextualised visual landmark cue was introduced for variants 4, 5 and 6 in the form of unique graffiti art. The table below details the individual variables that have been altered in a 6x3x2 matrix to produce thirty unique variants. *Table 5*.

| Lighting | Audio | Graffiti |
|---|---|---|
| Neutral | None | NO |
| Red | None | NO |
| Blue | None | NO |
| Lit Path | None | NO |
| Dark Path | None | NO |
| Neutral | Aversive Audio at Goal | NO |
| Red | Aversive Audio at Goal | NO |
| Blue | Aversive Audio at Goal | NO |
| Lit Path | Aversive Audio at Goal | NO |
| Dark Path | Aversive Audio at Goal | NO |
| Neutral | Aversive audio silent at goal | NO |
| Red | Aversive audio silent at goal | NO |
| Blue | Aversive audio silent at goal | NO |
| Lit Path | Aversive audio silent at goal | NO |
| Dark Path | Aversive audio silent at goal | NO |
| Neutral | None | Yes |
| Red | None | Yes |
| Blue | None | Yes |
| Lit Path | None | Yes |
| Dark Path | None | Yes |
| Neutral | Aversive Audio at Goal | Yes |
| Red | Aversive Audio at Goal | Yes |
| Blue | Aversive Audio at Goal | Yes |
| Lit Path | Aversive Audio at Goal | Yes |
| Dark Path | Aversive Audio at Goal | Yes |
| Neutral | Aversive audio silent at goal | Yes |
| Red | Aversive audio silent at goal | Yes |
| Blue | Aversive audio silent at goal | Yes |
| Lit Path | Aversive audio silent at goal | Yes |
| Dark Path | Aversive audio silent at goal | Yes |

***Table 5.*** **The cue assignments of the thirty mazes.**

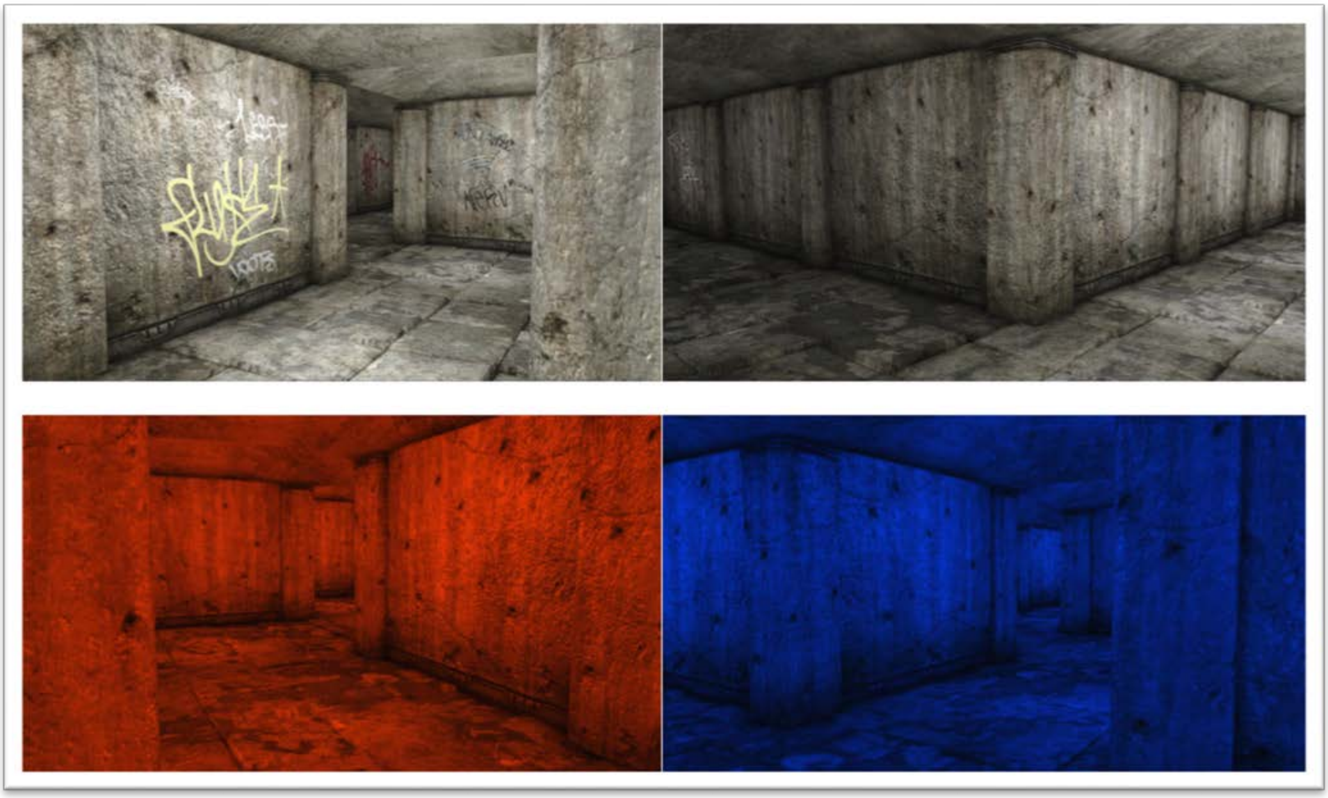

*Figure 142.* **Examples of variant mazes from top left; uniform lighting with graffiti, lit path to goal with graffiti, red post processing, and blue post processing.**

### 7.4.2 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4th generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch-wide-screen monitor. Each participant was supplied with a set of Sennheiser HD201 headphones and the sound level on each PC was set to 70%. Participants were asked to wear the headphones throughout, despite ten of the variant mazes having no audio component. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Colour-blind volunteers were excluded from the survey. All read and signed the accompanying ethics form.

Each participant was supplied with a randomly assigned set of six mazes, one of each variant to solve. Because there are only five lighting variants across the six competing cue variants, the neutral condition allocated twice to each participant to allow for clearer data on each of the cue variant conditions.

## 7.5 RESULTS

Not all of the participants completed all of the mazes assigned to them, the 134 participants 16 female and 118 male completed 553 mazes. Nineteen of the solve times were dramatically larger than the mean and were removed from the dataset. Hoaglin and Iglewicz's outlier labelling rule (1987) was applied to identify distinct outliers in the data set over the thirty mazes, nineteen (3.4%) extreme outliers were detected and removed. *Figure 143*.

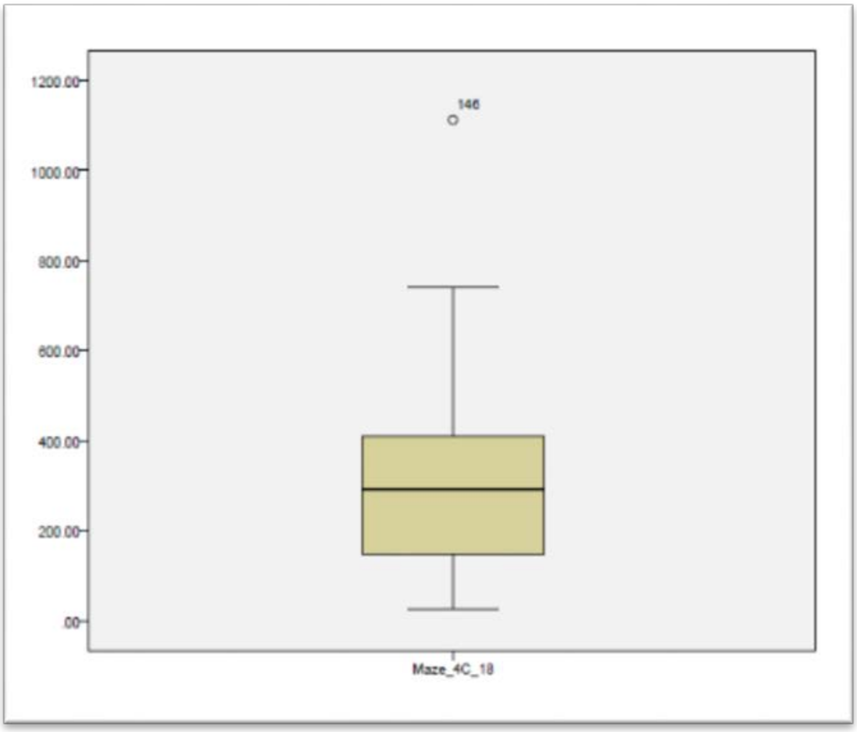


***Figure 143.* An example of one of the extreme outliers removed from the statistical analysis using Hoaglin and Iglewicz's outlier labelling rule** (1987)**.**

### 7.5.1 DESCRIPTIVES

#### 7.5.1.1 LIGHTING

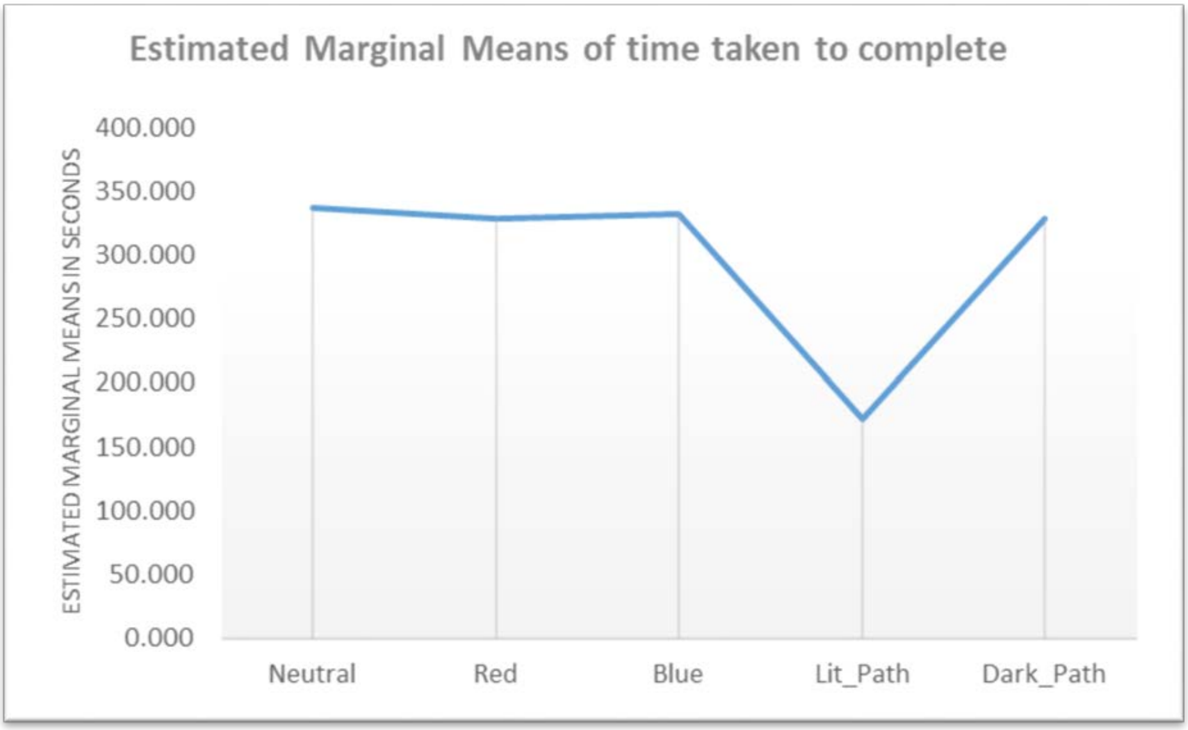


***Figure 144.* The effects of lighting variance.**

A univariate ANOVA showed that there was a significant main effect of lighting (F (4,503) =5.837, p=0.000). A Post Hoc Bonferroni test showed that there was a significant main effect between the lit path and all of the other pathways, (p=0.01), with participants taking significantly less time to complete the mazes. There were no other significant differences between the other pathways. Against a neutral condition, the red, blue and dark path variants showed no significant difference in solve time of any kind (p=1.00), whereas the lit path was solved significantly faster (p=0.005). Against a red condition, the neutral, blue and dark path variants showed no significant difference in solve time of any kind (p=1.00), whereas the lit path was solved significantly faster (p=0.00). Against a blue condition, the neutral, red and dark path variants showed no significant difference in solve time of any kind (p=1.00), whereas the lit path was solved significantly faster (p=0.001). Against a dark condition, the neutral red, and blue path variants showed no significant difference in solve time of any kind (p=1.00), whereas the lit path was solved significantly faster (p=0.013). These results clearly demonstrate that even when lighting along a path was only vaguely perceptible, it had a significant influence on navigational choice. *Figure 144*.

#### *7.5.1.2 AUDIO*

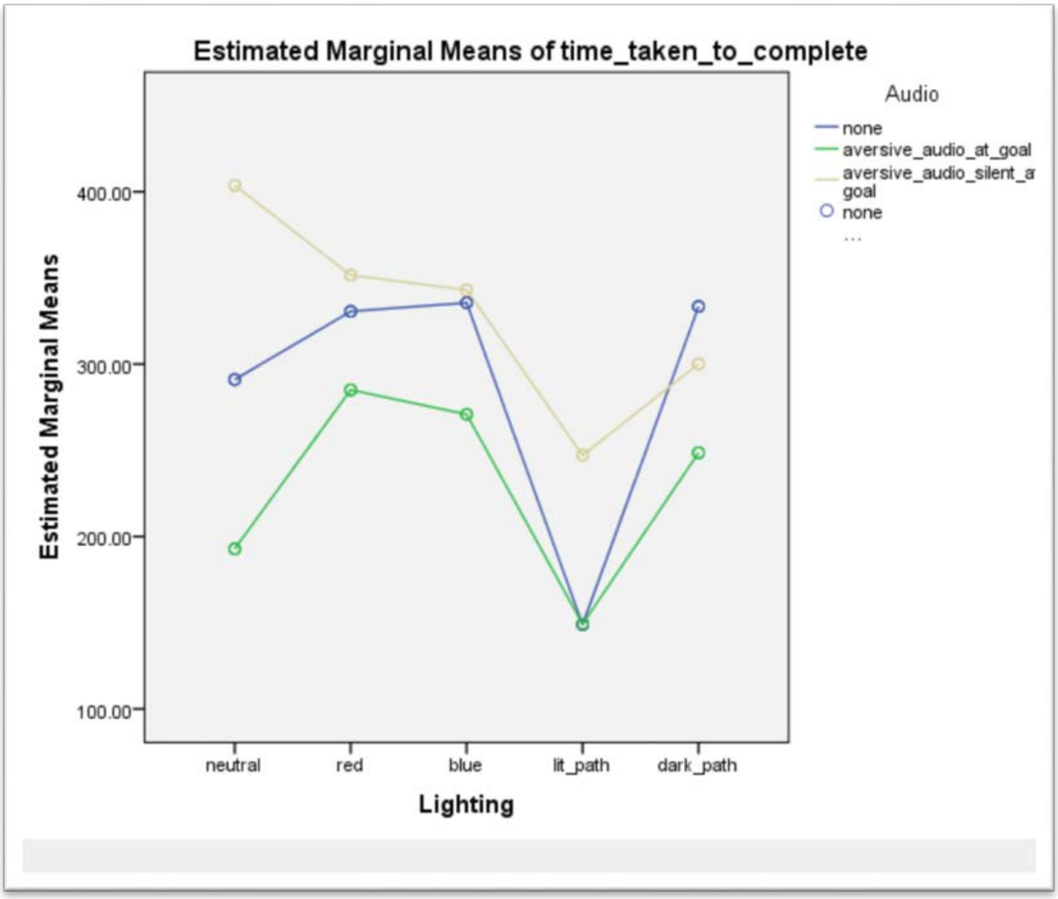


***Figure 145.*** **The effects of audio and lighting variance.**

The results demonstrated a clear main effect of an audio cue reducing the solve time when the audio cue was an isolated variable. Where there was audio at the goal, despite this being a sound that was chosen to be aversive, there was a significant effect in overall solve times, (F (2,503) = 7.699, p=0.001). However, while both lighting and audio cue produced significant effects in isolation, there was not a combined reinforcement effect (F (8,503) =1.127 p=0.343). *Figure 145*.

#### 7.5.1.3 GRAFFITI

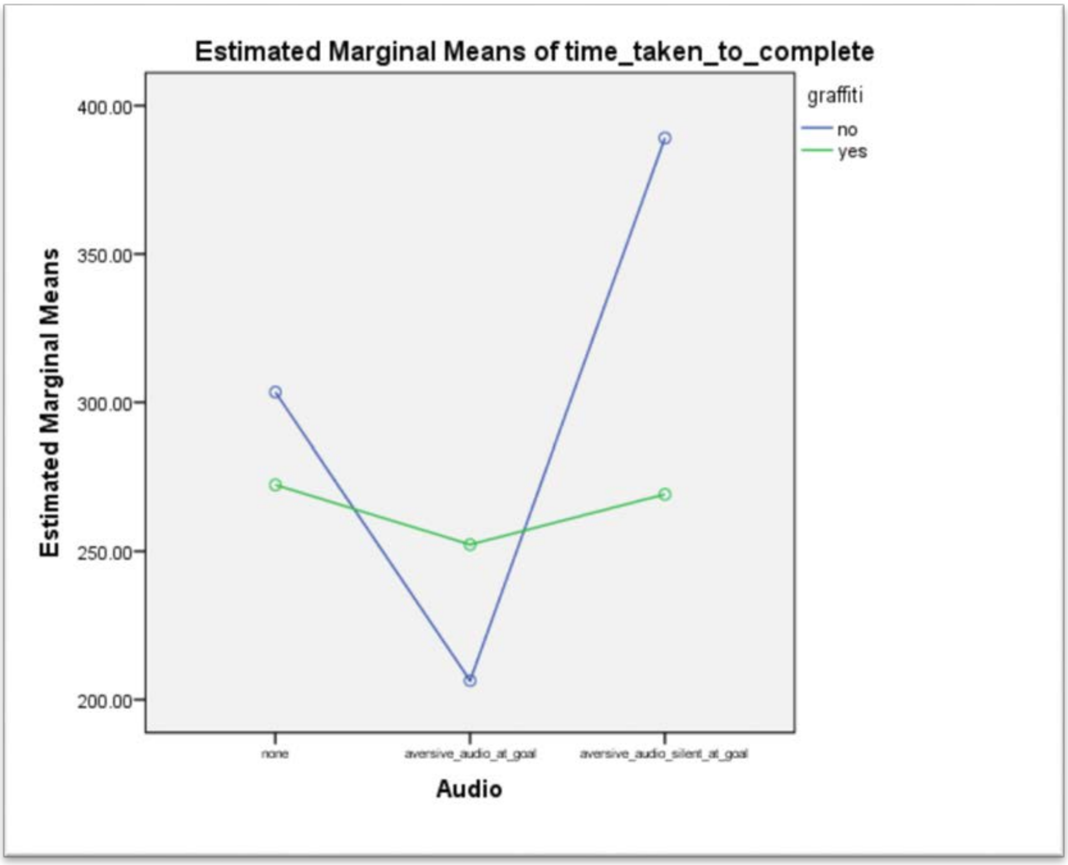


***Figure 146.* The effects of graffiti and audio variance.**

Despite graffiti potentially offering specific landmark guidance, no main effect for graffiti was detected, (F (1,503) =2.843 p=0.92). No reinforcement effect was detected between lighting and graffiti (F (8,503) =.865 p=0.485). Nor was a reinforcement effect detected between lighting, audio and graffiti (F (8,503) =.800 p=0.602). *Figure 147*.

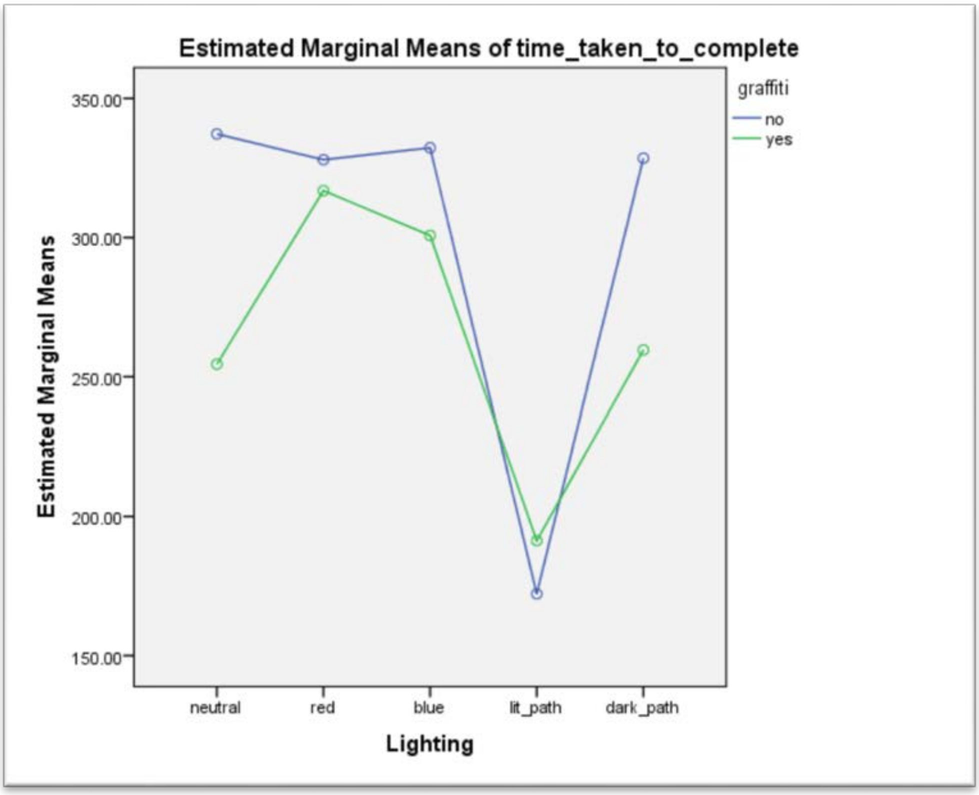


*Figure 147.* **The effects of graffiti and lighting variance.**

However, despite there being no reinforcement effects in the previous cases, a reinforcement effect was detected in the case of audio and graffiti (F (2,503) = 5.270 p=0.05). Therefore, the visual cue of even a subtle lit path offered far more significant navigational assistance than landmark cues. *Figure 146*.

Due to the very large percentage of males (118) to females (16) 86.4% male, it was not plausible to separate the data to analyse sex differences in any significant manner. The same was also true of other participant data that was captured, of the five categories of gamer type, over 70% identified as frequent gamers and only 2% as non-gamers.

## 7.6 DISCUSSION

The use of subtle directional cues has been demonstrated in this study to have a distinct impact on the solve time of mazes. Primary among these factors is subtle guidance lighting, even with the on-screen difference being set to a low variance of 16% between light and dark states (8% from the mean). A main effect for solving mazes using a subtle lighting cue was demonstrated. It should be noted that all of the mazes have identical paths to the goal, the fastest solve time achieved in development was 19.08 seconds. Therefore, the average solve time for lit paths was still 9.3 times longer than optimal. This figure clearly demonstrates that despite the guidance being intrinsic to the maze environment; it was not a dominant and obvious feature. Informal debriefing of participants indicated that very few had consciously noted the brighter path and the data

A main effect was also demonstrated for a centrally located positional audio cue with fall off to the extremities of the environment acting as a navigational cue. This was despite an aversive sound being used in this test. This factor when reversed with the positional audio being located at the central points of all four perimeter walls falling off to silence at the central goal point caused confusion in the players. Solve times compared to the neutral condition decreased by 33.8% where a central audio cue was implemented and increased by 25.2% when located at the perimeter. The difference between these two variations was 95.2%. This difference was produced in instances where this cue was the only variant. The study clearly demonstrated that despite the positioning of the audio that the participants were attempting to navigate towards it.

Participants mentioned in the informal debriefing after completing the session that they had found the external audio cue mazes extremely frustrating. It should be noted that as all participants solved mazes in a randomly assigned order, roughly 50% of them would have solved a maze where the audio cue was centrally located and led them directly to the goal, and therefore when this was reversed, it would confuse and frustrate them more when solving the inverted variant. The inverse of this is probably true for the other half of participants who after finding the audio led only to frustration may have been tempted not to follow it in the version where it would have led them to the goal.

The final variant introduced in the mazes was the inclusion of multiple pieces of unique graffiti distributed at all the main junctions in each maze. It is interesting that despite these being obvious landmarks that could have been used by participants to avoid backtracking or similarly losing their way, the graffiti only showed a main effect in solve times when working in conjunction with the audio cue.

Whether taken in isolation or combined with other data group data, no significant difference could be inferred between solve times for the neutral red or blue colour variations across all tests.

### 7.6.1 SUMMARY OF KEY FINDINGS

It is clear from this group of experiments that there was evidence that demonstrates:

1. Players solve mazes faster when presented with a subtly brighter path to the goal.
2. Players solve mazes faster when there was a positional audio cue at the goal.
3. Players will utilise landmarks to help solve mazes, while these cues work in conjunction with other subtle directional cues this was not consistent, and this study could only find a direct effect when combined with audio guidance.
4. Colourisation of an environment had no significant impact on navigation.
5. The presentation of multiple competing and conflicting navigational cues increase cognitive load, cause confusion and result in significantly longer maze solving times.

These findings are contextualised to the solving of mazes but are significant and add to the body of understanding as to how intrinsic overlaid perceptual cues influence player motion in video games. They clearly demonstrate that the audio and lighting cues in virtual environments and video games can afford subtle almost sub-perceptual ways to influence player navigation, and that these elements can be at a sub perceptual level and yet have a measurable effect. Importantly, subtle cues can either reinforce or conflict, as evidenced by the participant's attraction to even a positional sound cue that was deemed to be aversive in nature.

# 8 CHAPTER EIGHT: VIRTUAL WATER MAZES WITH SUB-THRESHOLD PERCEPTION LIGHT GOALS

## 8.1 INTRODUCTION

The central goal maze solving study demonstrated that there was a significant reduction in maze solve time when there was a subtle illumination of the path to the target point. These results raised the question as to whether the participants were perceptually aware of the lit path cue, and if they were, at what thresholds a cue of this nature became an obvious aid to navigation.

It is common in modern video games for a lighting hotspot to indicate a point of interest [*Figure 148*, *Figure 149*]; these cues are contextual and while considered by game designers to be effective have not previously been demonstrated to work in isolation (Lundeen, 2009; Mitchell, 2008).

*Figure 148.* **An example of hot spot lighting in Left 4 Dead (Valve Corporation, 2008)**


*Figure 149.* **An example of contrasting guidance lighting in Left 4 Dead (Valve Corporation, 2008)**

### 8.1.1 MORRIS WATER TANKS

A commonly utilised piece of apparatus in many animal spatial navigation and cognition research frameworks is the water maze. Water mazes are generally referred to as Morris water tanks. This apparatus involves rats being immersed into cold, opaque water and studying their strategies for seeking out a hidden platform (Morris, 1984). The temperature of the liquid acts as an aversive stimulus that causes the rats to seek a platform that removes them from the water. One of the key components of this apparatus is its uniform circular form that offers impoverished visual information and necessitates improvisation in navigational strategy. *Figure 150*.

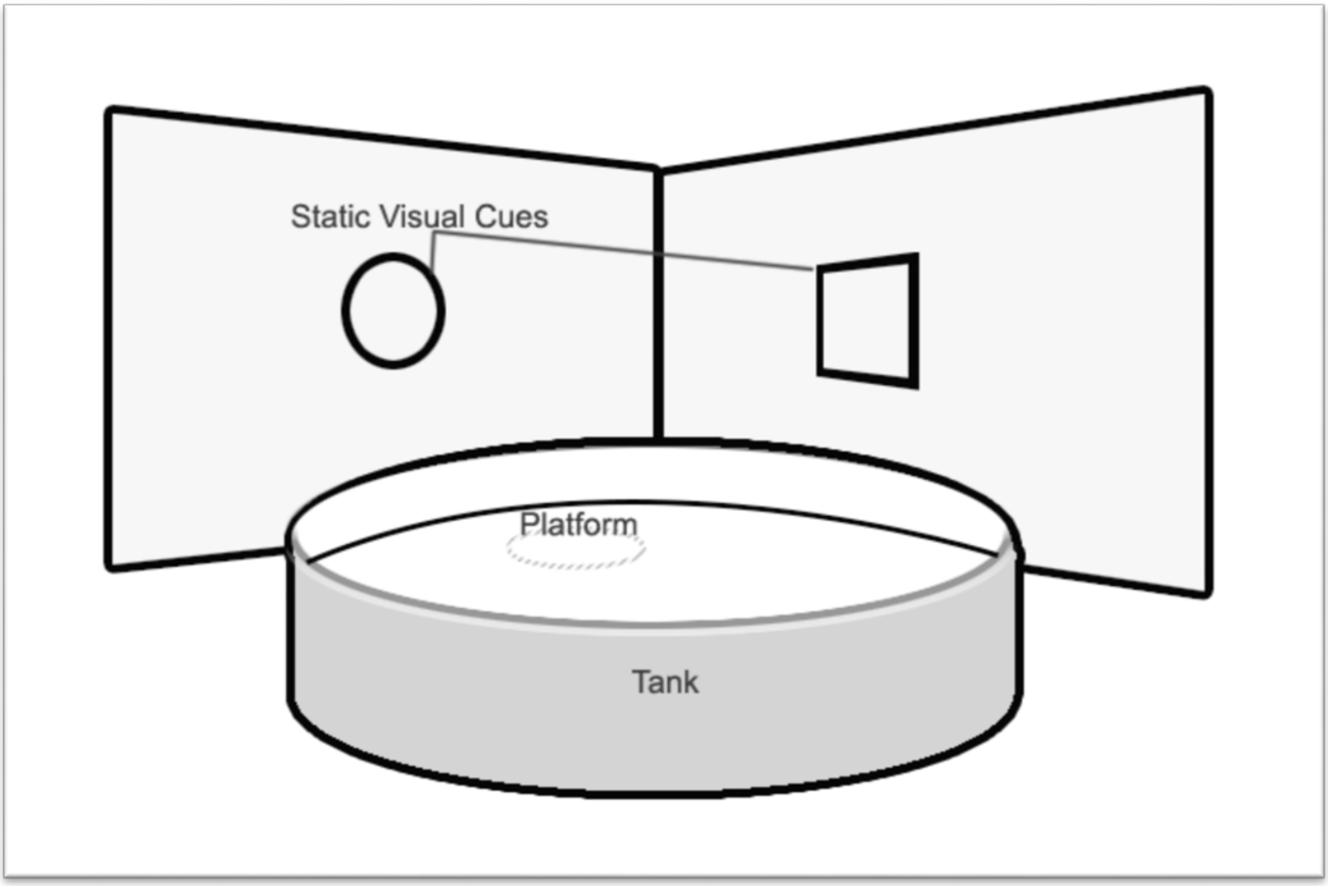


*Figure 150.* **Typical Morris water tank apparatus.**

The apparatus of a water maze style has been utilised in a virtual manner by researchers into human cognitive psychology (Astur et al., 1998; Sandstrom et al., 1998). Although sub-threshold stimuli have been shown to produce measurable effects (Kouider & Dehaene, 2007) it was unclear if this would be true in the case of a simple navigational task.

## 8.2 HYPOTHESIS

Lighting design in video games frequently utilises a hot spot method of drawing the player's attention to the point of interest. It is, however, unclear if this technique is relevant in isolation and at what thresholds a brighter point in a virtual space becomes a salient point of navigational interest. The key aims of this study were to ascertain whether:

- Without guidance, players are drawn to brighter spots in an otherwise uniformly lit environment
- If participants are drawn to brighter areas, whether they associate that point as a goal.
- If brighter spots do attract player navigation, at what threshold does this become apparent?

## 8.3 METHOD

### 8.3.1 PARTICIPANTS

27 participants; all male, aged between 18 and 24 (mean 19.96) 25 of the participants were right-handed, and two left-handed. All reported having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants were recruited primarily from students and staff in the School of Computing and Engineering; they were not paid for their participation.

### 8.3.2 MATERIALS AND APPARATUS

Prior virtual water-maze style experiments have sought to analyse goal seeking given architectural spatial cues (Astur et al., 1998). *Figure 151.* In order to test the hypotheses outlined above, a variation was developed where the hidden platform/trigger point was congruent with spatially aligned symbols, and illumination was initially set to sub-perceptible levels. The illumination of the goal over subsequent tasks increased in brightness every alternate level and the visibility of the consistently aligned symbols on the perimeter walls alternated between levels.

As it was not feasible to immerse participants in ice-cold water whilst they sought the goal, an unpleasant sound was played through headphones until the virtual platform was located. Research indicates that humans find the crying of a baby (Murray, 1985) the most aversive of sounds and therefore, this was chosen as the aversive audio component for the study.

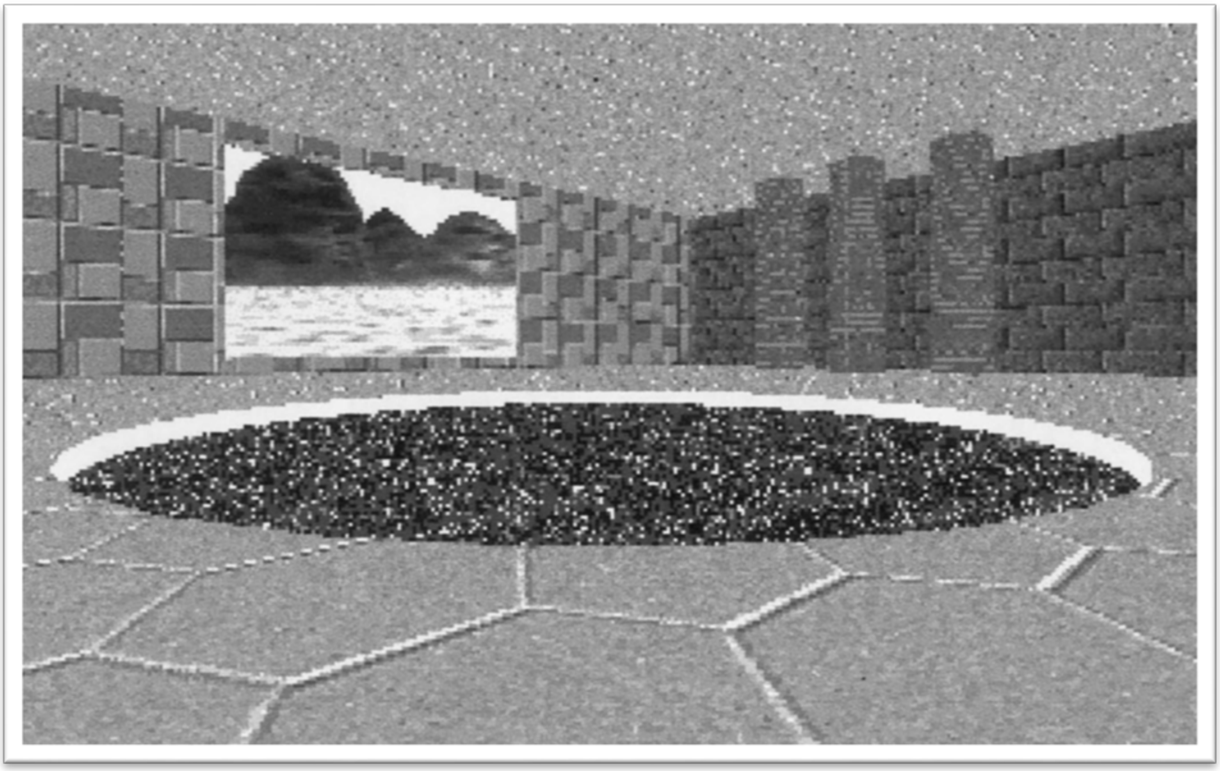

***Figure 151.* An example of a virtual water maze providing architectural reference cues** (Astur et al., 1998).

### 8.3.3 DESIGN

Based upon a Morris water tank apparatus (Morris, 1984), an environment was developed in Unreal Engine 4. This consisted of a uniformly repeating checker pattern grey floor plane surrounded by a smooth cylindrical enclosing wall. This environment was lit as uniformly as the engine would allow. Landmarks in the form of projected decals were placed equidistantly around the circumference of the surrounding walls. The landmarks being simple black symbols of a circle, square, triangle and star. *Figure 153*. These symbols were always positioned in the same orientation and alignment to the hidden trigger point, but they only appeared in alternate levels of the environment. The only other variant in the space was the inclusion of a point light source. This light was initially set to a brightness value of 2, and the falloff of the light was adjusted so that this could not be distinguished against the checker pattern floor. As described in the table below, this light source would increase in brightness by a factor of three on alternate rounds. Therefore, over the five alternate rounds, the brightness would rise from 2 to 6 to 18 to 54 to 162. In practice, this meant that an imperceptible difference became a subtle brighter spot with an illumination of 6 which eventually became a very pronounced hot spot at a level of 162. This is illustrated below. *Figure 152*. The illustration also clearly shows that the goal square was set to a brighter level than the surrounding comparable squares, but that it was not visibly obvious. Throughout the participants search for the goal point, an aversive audio recording of a distressed baby was played on a continuous loop. Once the goal point had been located, a triumphant musical recording was played to the player via headphones that had all been calibrated to the same volume setting.

| Round | Brightness | Landmarks |
|---|---|---|
| 1 | 2 | Yes |
| 2 | 2 | No |
| 3 | 6 | Yes |
| 4 | 6 | No |
| 5 | 18 | Yes |
| 6 | 18 | No |
| 7 | 54 | Yes |
| 8 | 54 | No |
| 9 | 162 | Yes |
| 10 | 162 | No |

***Table 6.*** **A description of the variables in each round of the study.**

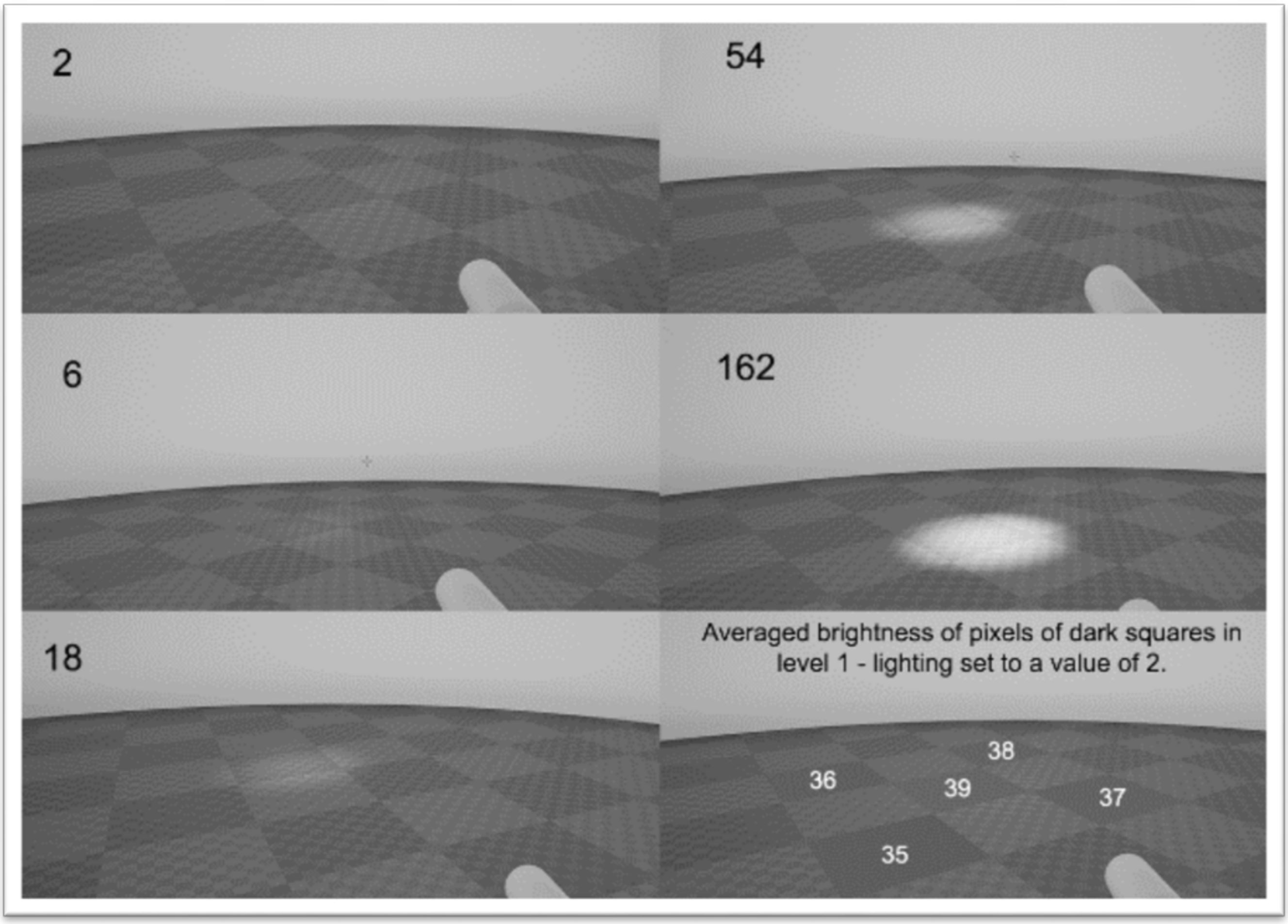


*Figure 152.* An illustration of the increase in brightness of the illuminated goal point and of the differences in brightness of the surrounding squares - Mean brightness 36.5.

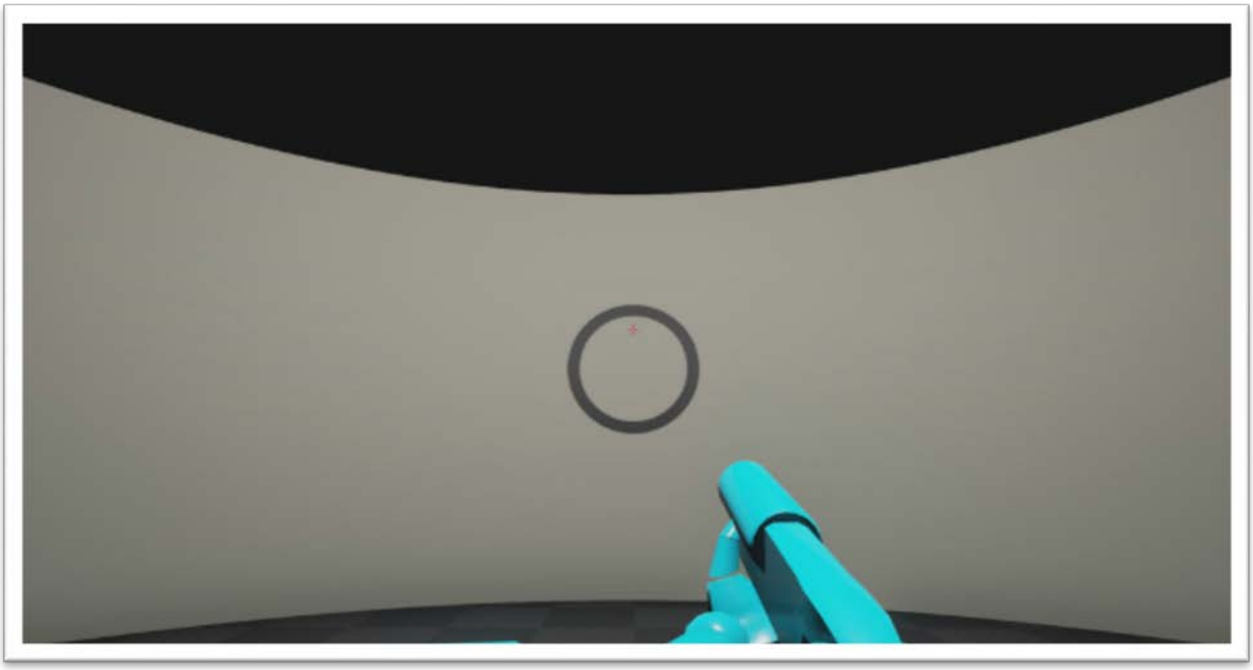

*Figure 153.* An illustration of the alternating landmark decals, in this case, the circle decal.

## 8.4 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4$^{th}$ generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch-wide-screen monitor. Each participant was supplied with a set of Sennheiser HD201 headphones and the sound level on each PC was set to 70%. Participants were asked to wear the headphones throughout the test. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Colour-blind volunteers were excluded from the survey. All read and signed the accompanying ethics form.

The participants were not told of the nature of the test, nor that the brighter spot was the active target point.

## 8.5 RESULTS AND DISCUSSION

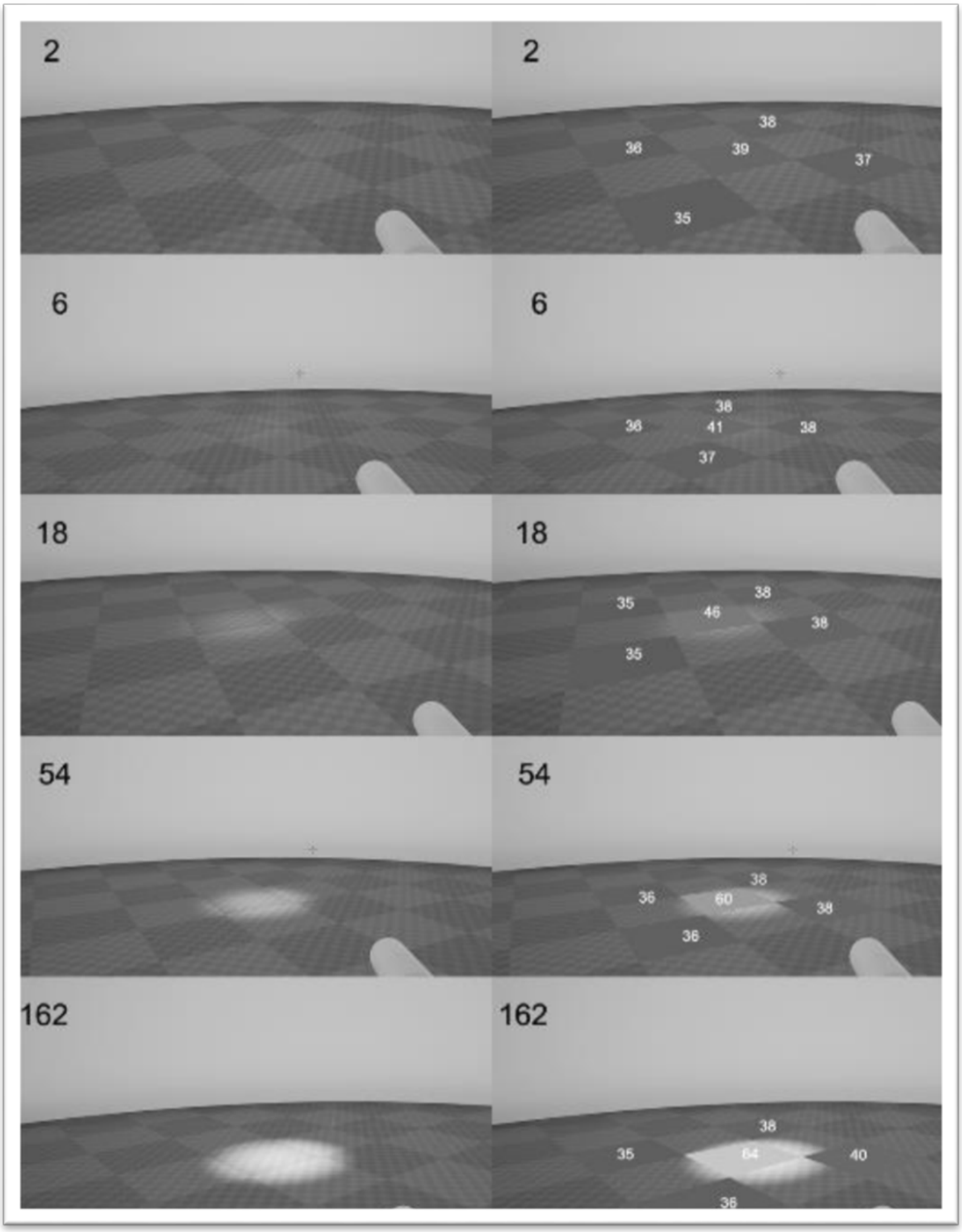


***Figure 154.*** **An illustration of the averaged brightness of all adjacent dark squares to the illuminated dark square.**

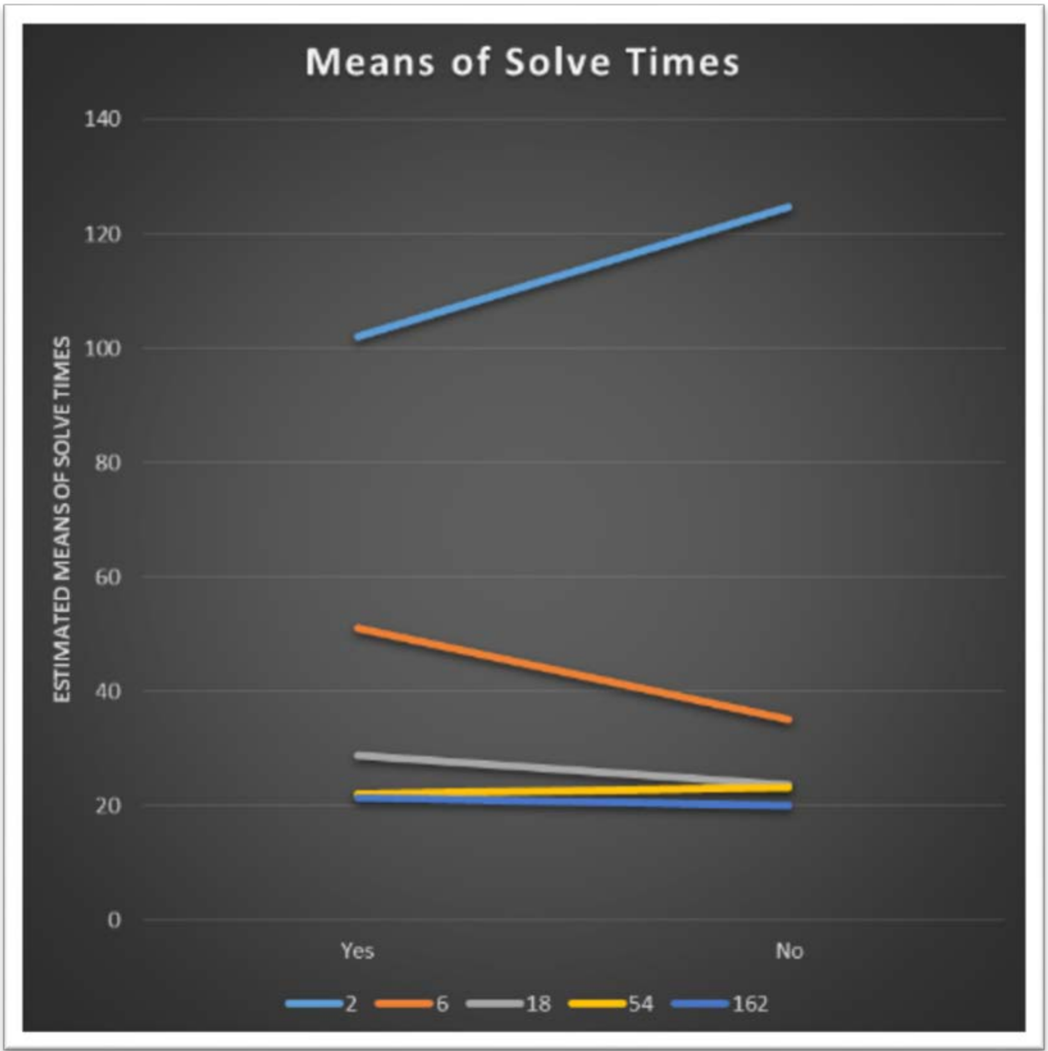


*Figure 155.* **Mean solve times in seconds for all lighting and landmark variants.**

A univariate ANOVA showed that there was a significant main effect of lighting (F (4,260) =14.351, p=0.000). A Post Hoc Bonferroni test showed that there was no significant difference between the brightness values of 6 (+10% overall brightness) (p=1.00), 18 (+26% overall brightness) (p=1.00), 54 (+62% overall brightness) (p=1.00) & 162 (+72% overall brightness) (p=1.00) when each was compared to the initial brightness value of 2 (+7% overall brightness).

In the case of the alternating projected symbols, a univariate ANOVA showed that there was no significant effect of landmarks (F (1,260) =000, p=0.99). Due to the set-up of the apparatus, the landmark cues were not the goal. Therefore, the visibility of the light point became the more salient point of interest. The graph above [*Figure 155*] demonstrates that there was a small variation in solve time between rounds 1 and 2 but that once the lighting had become a perceptible cue in rounds 3 and 4, the surrounding landmark points possibly acted as more of a distraction than assistance. By levels, 5 through 10 the visibility and salience of the lit goal point led to the landmark cues having no detectable effect. *Figure 154*.

## 8.5.1 DISCUSSION

The aims of this study were to investigate the saliency of illuminated points in virtual environments and to determine at what level of brightness those points became preferred navigational stimuli.

### 8.5.1.1 KEY FINDINGS

This study has clearly demonstrated for the first time in a study of this type that where participants had no prior instruction to head to the lit spot, an area of visual contrast acted as a salient cue and rapidly became associated with a goal. This behaviour was quickly reinforced, once the participant had made the association.

In this study, a difference in on screen brightness of +7% was not visible to participants and therefore was not utilised as a navigational cue. An increase in the differences of the brightness of a square to adjacent square of only three percent to +10% was sufficient for participants to attend to that highlighted spot and navigate towards it. As there was a small increase in solve time for the level with a +10% brightness and projected decal cues, it is conceivable that there was a small cue competition effect of those symbols being visible. The results of this study demonstrate an outcome that only the prior maze study has previously shown, that there is a threshold at which lighting variance becomes a salient stimulus and that the threshold for this is roughly 10% variance.

At an increase in relative brightness of only, +26% compared to adjacent squares the illuminated spot became a significant and dominant navigational cue and the cue competition of the surrounding projected symbols was no longer a factor. Beyond an increase in relative brightness of 26%, the effect began to level out as participants navigated directly to that spot once they had located it. The findings presented here offer for the first time, a clear indication to lighting designers for interactive environments the thresholds by which they can begin to manipulate player attention and route selection.

| Brightness | A1 | A2 | A3 | A4 | Mean | Lit Square | Diff % |
|---|---|---|---|---|---|---|---|
| 2 | 36 | 38 | 37 | 35 | 36.50 | 39 | 7% |
| 6 | 36 | 38 | 38 | 37 | 37.25 | 41 | 10% |
| 18 | 35 | 38 | 38 | 35 | 36.50 | 46 | 26% |
| 54 | 36 | 38 | 38 | 36 | 37.00 | 60 | 62% |
| 162 | 35 | 38 | 40 | 36 | 37.25 | 64 | 72% |

***Table 7.*** **The percentage differences between the means of adjacent unlit squares and the central lit square.**

It was clear from the results that once a cue becomes even subtly distinguishable that a saliency threshold was reached after these conditions are met; the bright spot was rapidly navigated to by participants.

The overall brightness or contrast of an illuminated point of interest does not require a distinct difference from the surroundings. The human visual system is drawn to areas of contrast and this saliency via contrast provides enough of a cue to aid navigation (Davis, 2016).

In a scenario where navigation can be successfully performed by following a localised and reactive lighting cue, the distal cues of symbols on the surrounding walls had no significant effect on navigation.

# 9 CHAPTER NINE:

# PORTAL VARIANCE AS AN INFLUENCE ON PLAYER NAVIGATION

## 9.1 INTRODUCTION

The first study (Chapter 6) demonstrated that simple illuminance is not a significant variable in decision-making and that contrast or variance are cues that are more salient. In a games context, path options are seldom as simple as two identical portals or doorways having brightness variance in lighting. While the technique of framing is commonly used to draw the eye through a portal to a brighter lit area, differences in portal design may elicit differing navigational paths. For instance, it has been demonstrated that changes in elevation can affect navigational choices, given the option of either a level or rising path, individuals will tend to take the raised path or climb virtual stairs (Dalton, Hölscher, & Turner, 2005; Ho¨lscher & Bro¨samle, 2007). As motion is known to be visually salient, it is often used to draw player attention to a goal. These factors can coexist together in an environment, and their effectiveness as a navigational cue and the hierarchy of these cue types is unknown. This study aims to determine which cues are the most salient. Also considered are the dimensions of portals, for simplicity, in this study; the variable is simply the width of the doorway.

## 9.2 HYPOTHESIS

It was predicted that visual differences between portals would affect participant navigational choices in a video game virtual environment, the following variations were considered:

1. Motion within a portal may have an effect on navigational choices
2. Variations in dimensions of portals may affect navigational choices
3. Changes in elevation before portals may affect navigational choices
4. Variations in brightness within a portal may affect navigational choices

## 9.3 METHOD

The main variables measured in these experiments were the effects of the following conditions.

- Flickering or static lights – (Visual motion) *Figure 156*.
- Changes in elevation via stairs *Figure 156*.
- Door widths *Figure 157*.
- Variation in portal brightness (Contrast) *Figure 158*.

### 9.3.1 PARTICIPANTS

38 participants; 34 male, 4 female, aged between 18 and 45 (mean 21.66) all reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

### 9.3.2 MATERIALS AND APPARATUS

| Room | Exit Left | Exit Elev | Exit Width | Light Type | Bright Dim | Exit Right | Exit Elev | Exit Width | Light Type | Bright Dim |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Exit Left | Flat | Wide | Torch Static | Bright | Exit Right | Flat | Narrow | Torch Static | Bright |
| 2 | Exit Left | Up | Narrow | Torch Flickering | Dim | Exit Right | Up | Wide | Torch Flickering | Dim |
| 3 | Exit Left | Down | Wide | Torch Flickering | Bright | Exit Right | Down | Wide | Torch Static | Bright |
| 4 | Exit Left | Flat | Narrow | Torch Static | Dim | Exit Right | Flat | Narrow | Torch Flickering | Dim |
| 5 | Exit Left | Up | Wide | Torch Static | Bright | Exit Right | Up | Wide | Torch Static | Bright |
| 6 | Exit Left | Flat | Narrow | Torch Flickering | Dim | Exit Right | Up | Narrow | Torch Flickering | Dim |
| 7 | Exit Left | Up | Wide | Torch Static | Bright | Exit Right | Down | Wide | Torch Static | Bright |
| 8 | Exit Left | Down | Wide | Torch Flickering | Dim | Exit Right | Down | Wide | Torch Flickering | Dim |
| 9 | Exit Left | Down | Narrow | Torch Static | Bright | Exit Right | Flat | Narrow | Torch Static | Bright |
| 10 | Exit Left | Flat | Narrow | Torch Flickering | Dim | Exit Right | Flat | Narrow | Torch Flickering | Dim |
| 11 | Exit Left | Flat | Wide | Torch Flickering | Dim | Exit Right | Flat | Wide | Torch Flickering | Bright |
| 12 | Exit Left | Up | Narrow | Torch Static | Bright | Exit Right | Up | Narrow | Torch Static | Dim |

***Table 8.*** **A table of the variance at each portal within the apparatus.**

In order to test the hypotheses, a bespoke virtual environment with video game elements was created using Unreal Development Kit (UDK) v.2012/07 the environment consisted of 13 separate spaces with 2 exits positioned at the opposite corner to the entrance of each room. The exits to these spaces are described in detail in the chart below. The exit doors in the environment were in some instances either up or down a series of steps, [*Figure 156*] inside each of these corridors around the 90-degree turn would be a further set of steps that returned the participant to the original ground level. All exit doors contained trigger volumes that closed the doors once the player was inside and a further set of trigger volumes and associated doors at the exit to the corridor. These automatic doorways prevented backtracking in the study. Each of the new spaces entered would contain an AI (Artificial Intelligence) 'guard'. The inclusion of these combatants acted as a distraction from this being simply a door choice experience and added a random element of movement to the path of each participant. The session was ended when the participant entered a glowing sphere at the end of the environment.

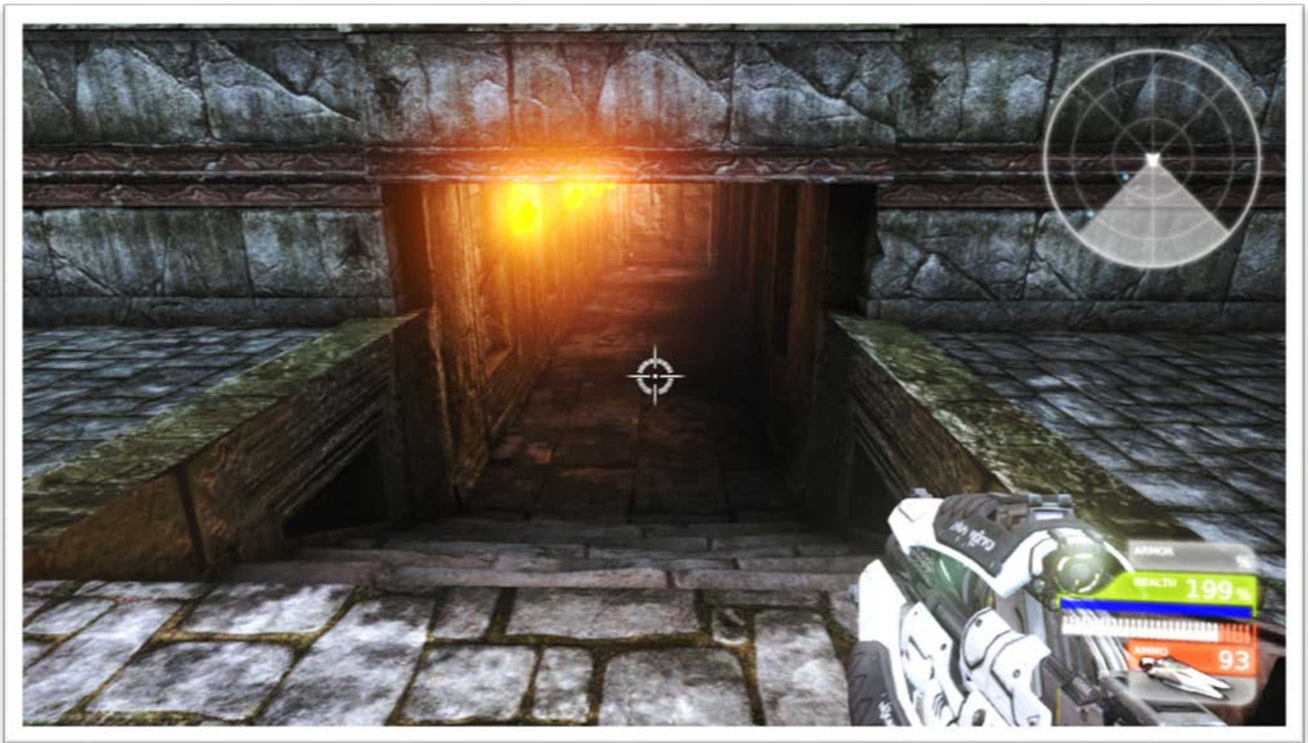


***Figure 156.*** **A wide portal at a lower elevation with a motion cue in the form of flaming torches.**

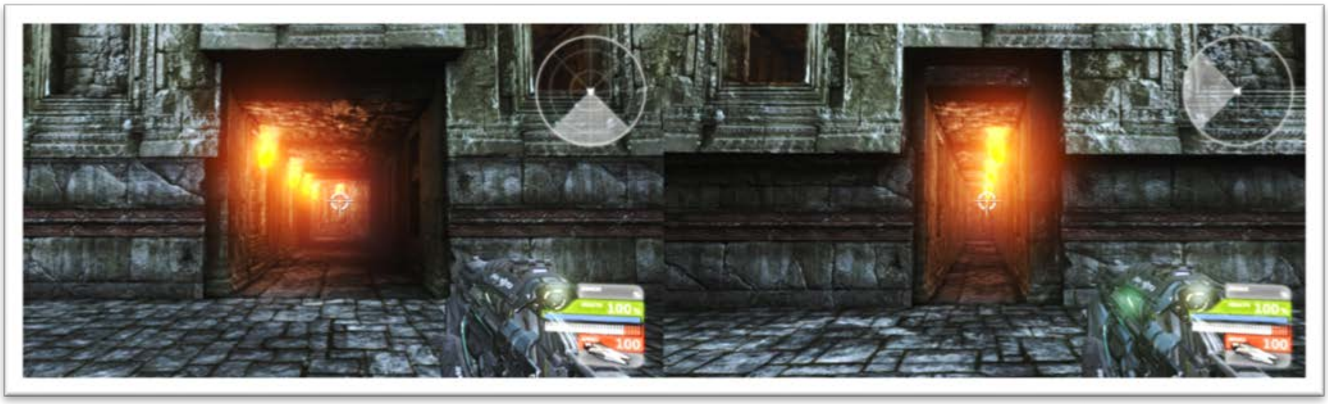


***Figure 157.*** **Portal options at the exit of room one. A wide passageway [left] or a narrow passageway [right].**

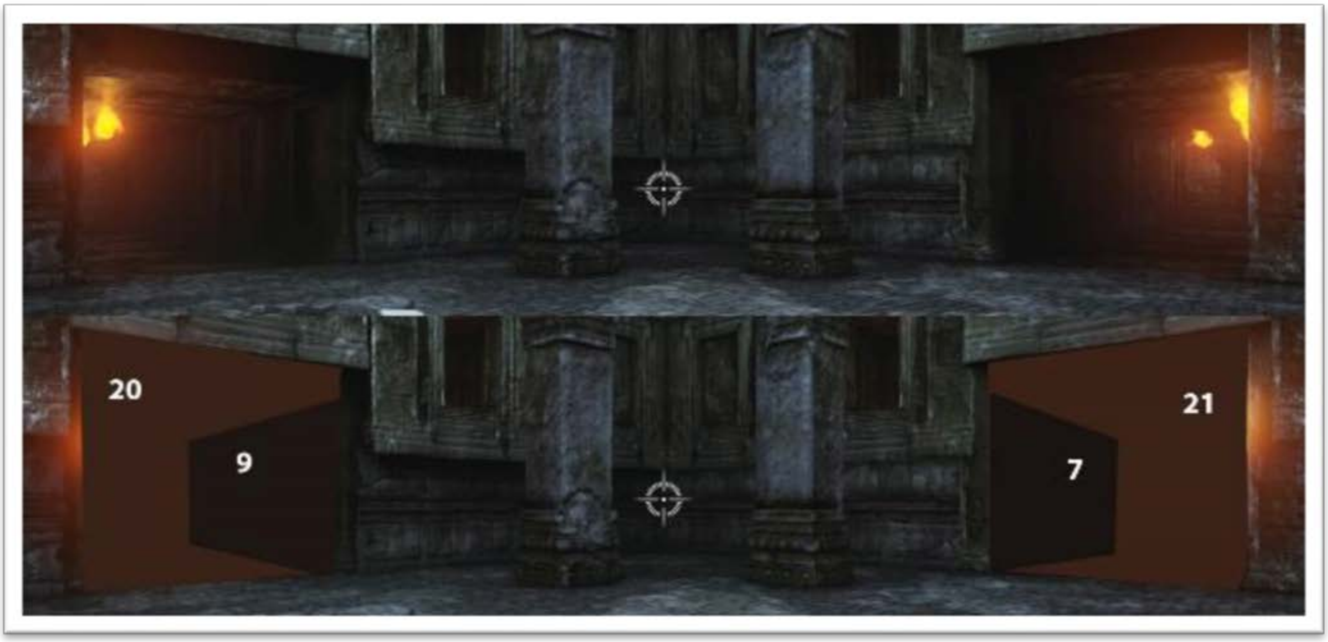


***Figure 158*****. A demonstration of the subtle differences in illumination between the two lighting variants.**

## 9.4 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4$^{th}$ generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch wide-screen monitor. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

All participants completed a survey form detailing their sex, age, handedness, the average number of hours spent playing video games per week, what level of experience they had of playing video games and how they rated their own sense of direction.

The participants were asked to defeat the enemies in each room and then to find and enter the teleport zone. No further instructions were supplied pertaining to either the playing of the game or the nature of the test.

## 9.5 RESULTS

Heatmapping of the player's movements goes some way to showing the preferences in rooms 3 and 4. *Figure 159*. It also demonstrates that participants tended to cluster to the centre of each space and to approach the exits in a broadly linear fashion. This tendency to take the shortest route and to maintain linearity being predicted by much of the route selection literature (Dalton, 2003; Golledge, 1995).

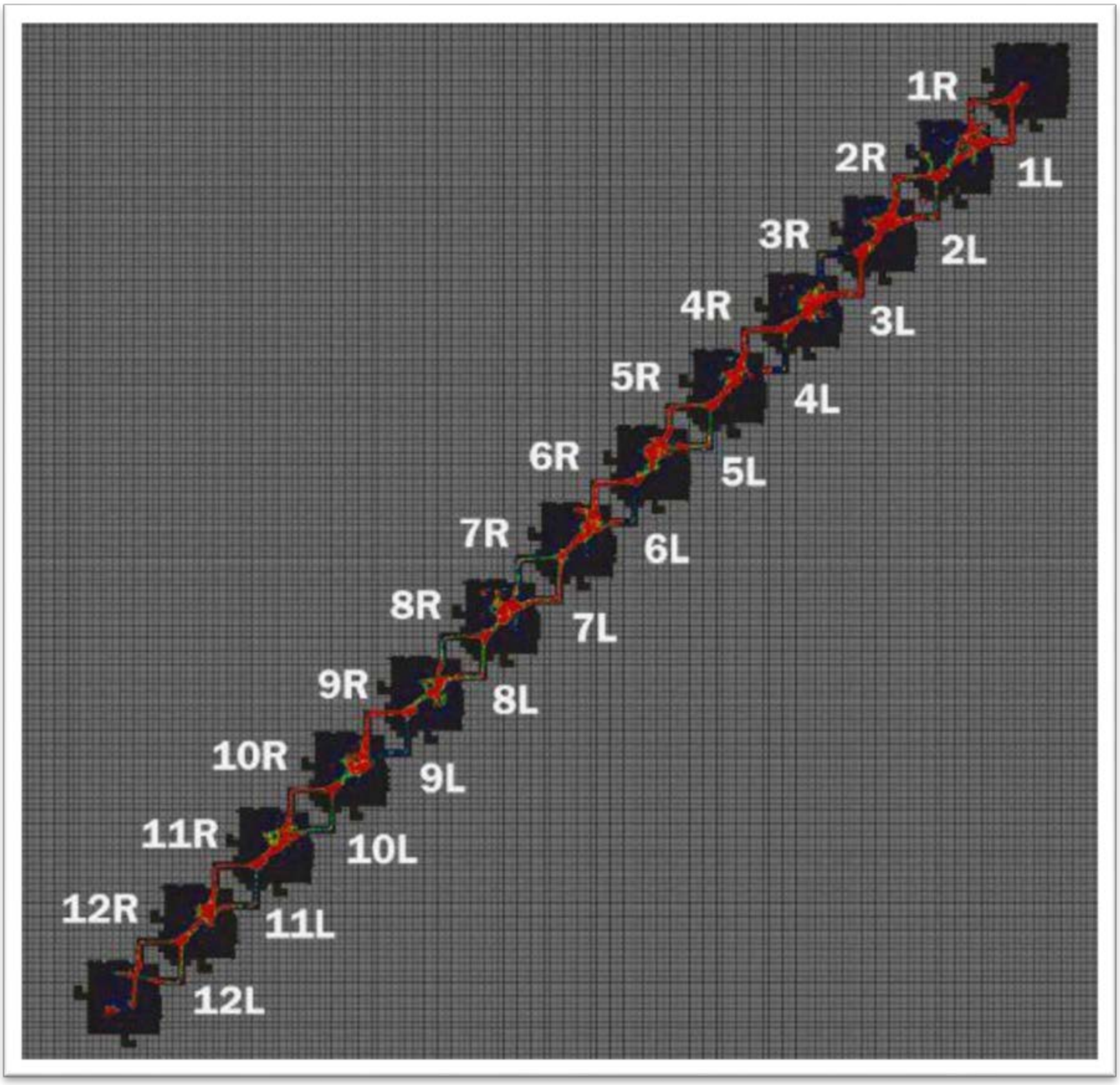


***Figure 159.*** **A combined heatmap of all participant movement data.**

## 9.5.1 DESCRIPTIVES

The table below [*Table 9*] details the variables that are altered between exits in the corresponding rooms.

| Room | Exit Left | Exit Elev | Exit Width | Light Type | Bright Dim | Exit Right | Exit Elev | Exit Width | Light Type | Bright Dim |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Exit Left | Flat | Wide | Torch Static | Bright | Exit Right | Flat | Narrow | Torch Static | Bright |
| 2 | Exit Left | Up | Narrow | Torch Flickering | Dim | Exit Right | Up | Wide | Torch Flickering | Dim |
| 3 | Exit Left | Down | Wide | Torch Flickering | Bright | Exit Right | Down | Wide | Torch Static | Bright |
| 4 | Exit Left | Flat | Narrow | Torch Static | Dim | Exit Right | Flat | Narrow | Torch Flickering | Dim |
| 5 | Exit Left | Up | Wide | Torch Static | Bright | Exit Right | Up | Wide | Torch Static | Bright |
| 6 | Exit Left | Flat | Narrow | Torch Flickering | Dim | Exit Right | Up | Narrow | Torch Flickering | Dim |
| 7 | Exit Left | Up | Wide | Torch Static | Bright | Exit Right | Down | Wide | Torch Static | Bright |
| 8 | Exit Left | Down | Wide | Torch Flickering | Dim | Exit Right | Down | Wide | Torch Flickering | Dim |
| 9 | Exit Left | Down | Narrow | Torch Static | Bright | Exit Right | Flat | Narrow | Torch Static | Bright |
| 10 | Exit Left | Flat | Narrow | Torch Flickering | Dim | Exit Right | Flat | Narrow | Torch Flickering | Dim |
| 11 | Exit Left | Flat | Wide | Torch Flickering | Dim | Exit Right | Flat | Wide | Torch Flickering | Bright |
| 12 | Exit Left | Up | Narrow | Torch Static | Bright | Exit Right | Up | Narrow | Torch Static | Dim |

***Table 9.* A table of the variance at each portal within the apparatus.**

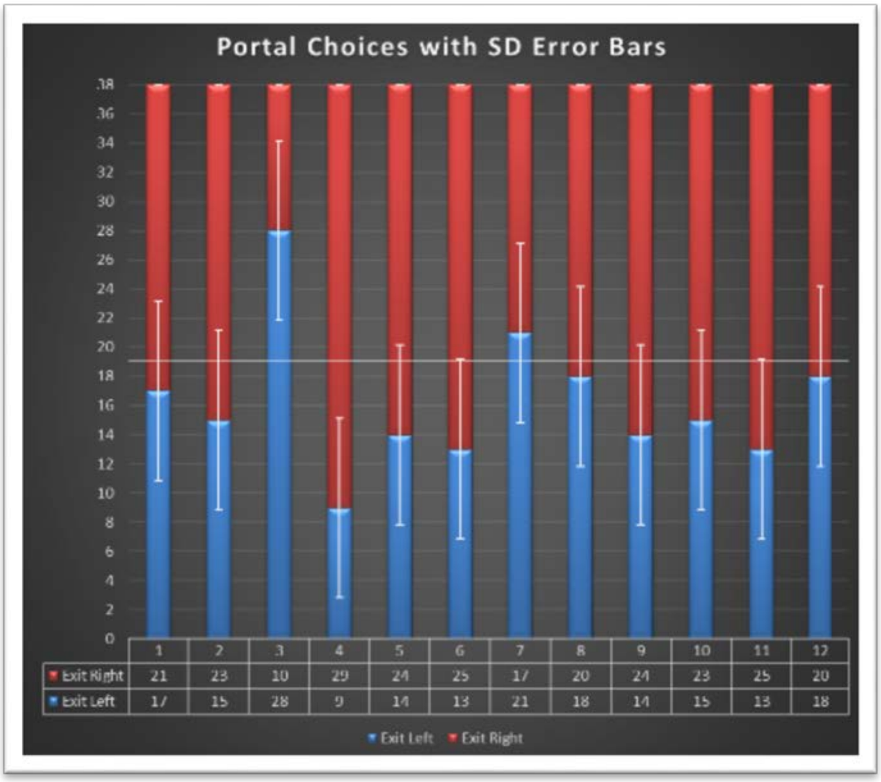


***Figure 160.* A bar graph of the left / right preferences at each junction in the study.**

### 9.5.2 THE INFLUENCE OF PORTAL WIDTHS

A chi-square test of independence was performed to examine the relation between the left-hand wide portal and the narrow right-hand portal at the exits of room one. The relation between these variables was not significant, $X^2(1, N = 38) = .42$, $p < 0.516$. The results demonstrated no specific difference between groups with regards to the differences in portal dimensions. *Figure 160*.

In the case of room two, where the portal dimensions were reversed, a chi-square test of independence was performed to examine the relation between the narrow left-hand portal and the right-hand wide portal. The relation between these variables was also not significant, $X^2(1, N = 38) = 1.68$, $p < 0.194$. Again, the results demonstrated difference between groups with regards to the differences in portal dimensions.

### 9.5.3 THE INFLUENCE OF MOTION

A chi-square test of independence was performed to examine the relation between the left-hand portal with an animated flickering flame and the right-hand portal with a static glowing torch at the exits of room three. The relation between these variables was significant, $X^2(1, N = 38) = 8.53$, $p < 0.004$. The results demonstrated a specific correlation effect of a preference for a path with a motion cue.

In the case of room four, a chi-square test of independence was performed to examine the relation between the left-hand portal with a static glowing torch and the right-hand portal with an animated flickering flame. The relation between these variables was significant, $X^2(1, N = 38) = 10.53$, $p < 0.002$. Again, the results demonstrated a difference between groups with regards to a preference for a path with a motion cue.

### 9.5.4 THE INFLUENCE OF BRIGHTNESS

A chi-square test of independence was performed to examine the relation between the left hand dimly lit portal and the right hand brighter lit portal at the exits of room eleven. The relation between these variables was not significant, $X^2(1, N = 38) = 3.79$, $p < 0.052$. The results demonstrated no difference between groups with regards to the differences in brightness at the values set in this study.

In the case of room twelve, where the differences in brightness between portals were reversed, a chi-square test of independence was performed to examine the relation between the left hand brighter lit portal, and the right hand dimly lit portal. The relation between these variables was also not significant, $X^2(1, N = 38) = .11$, $p < 0.746$. Again, the results demonstrated no difference between groups with regards to the differences in brightness at the values set in this study.

### 9.5.5 THE INFLUENCE OF STAIRS

A chi-square test of independence was performed to examine the relation between the left-hand portal with a portal with no change in exit elevation and the right-hand portal with rising stairs at the exits of room six. The relation between these variables was not significant, $X^2(1, N = 38) = 3.79$, $p < 0.052$ The results demonstrated no difference between groups with regards to the differences in exit elevations.

In the case of room seven, where the portal dimensions were reversed, a chi-square test of independence was performed to examine the relation between the left-hand portal with rising stairs and the right-hand portal with falling stairs. The relation between these variables was also not significant, $X^2(1, N = 38) = .42$, $p < 0.516$. Again, the results demonstrated no difference between groups with regards to the differences in exit elevations.

In the case of room nine, where the portal dimensions were reversed, a chi-square test of independence was performed to examine the relation between the left-hand portal with falling stairs and the right hand no change in exit elevation. The relation between these variables was also not significant, $X^2(1, N = 38) = 2.63$, $p < 0.105$. Again, the results demonstrated no difference between groups with regards to the differences in exit elevations.

Rooms five, eight and ten were controls of the elevation change:

A chi-square test of independence was performed to examine the relation between the left-hand portal with a portal with rising stairs and the right-hand portal with rising stairs at the exits of room five. The relation between these variables was not significant, $X^2(1, N = 38) = 2.62$, $p < 0.105$. The results demonstrated no difference between groups with regards to the differences in exit elevations.

In the case of room eight, where the portal dimensions were reversed, a chi-square test of independence was performed to examine the relation between the left-hand portal with falling stairs and the right-hand portal with falling stairs. The relation between these variables was also not significant, $X^2(1, N = 38) = .11$, $p < 0.746$. Again, the results demonstrated no difference between groups with regards to the differences in exit elevations.

In the case of room ten, where the portal dimensions were reversed, a chi-square test of independence was performed to examine the relation between the left-hand portal with no change in exit elevation and the right-hand portal with no change in exit elevation. The relation between these variables was also not significant, $X^2(1, N = 38) = 1.68$, $p < 0.194$. Again, the results demonstrated no difference between groups with regards to the differences in exit elevations.

### 9.5.6 LEFT RIGHT BIAS

A visual analysis of the graphs created from the participant data suggested that there was a right-hand bias in the path choices made across each of the spaces (Robinson, 1933; Scharine & McBeath, 2002). This being despite four of the rooms either being reversals of difference parameters or being in a control state with no structural differences. Therefore, all participant data for all rooms was analysed to test for left-right bias.

A chi-square test of independence was performed to examine the relation between all of the left-hand portals and all of the right-hand portals. The relation between these variables was significant, $X^2(1, N = 456) = 9.55$, $p < 0.002$. The results demonstrated a difference between groups with regards to a preference for right hand over left-hand paths.

Due to the discovery of this effect, a further analysis was carried out on the combined outcomes of the left/right flipped portal differences in order to compensate for this left-right bias. A chi-square test of independence was performed to examine the relation between all portals with an animated flickering flame and all portals with a static glowing torch. The relation between these variables was significant, $X^2(1, N = 76) = 19.000$, $p = 0.000$. The results demonstrated a difference between groups with regards to a preference for a path with a motion cue that was at a greater level of significance than the results of a single room.

In the case of portal brightness difference, a chi-square test of independence was performed to examine the relation between all portals with brighter exits and all portals with dimmer exits. The relation between these variables was significant, $X^2(1, N = 76) = 1.316$, $p = 0.251$. The results demonstrated no difference between groups with regards to the differences in brightness at the values set in this study.

## 9.6 DISCUSSION

The right-hand bias in this study is in concordance with prior literature, while this is a genuine bias, it is predominantly evident in western culture and especially of right-handed participants (Robinson, 1933; Scharine & McBeath, 2002)

The human visual system is adept at detecting motion, and game designers have utilised this attraction to motion extensively as a guidance cue. This study demonstrates that players not only attend to motion cues but that the draw the motion of the player towards them in a significant manner. The minor differences in overall portal brightness were deliberately set at a minimally detectable threshold, in order to determine if a subliminal variance in lighting was a factor in navigation. This study has clearly demonstrated that lighting guidance needs to be clear and visible to the player and in this instance made no significant difference at all to player route choices. In the case of this particular study, no specific navigational influence was demonstrated in elevation changes. However, the result of room six with the options of taking the right hand rising stairs or a left-hand option maintaining the same level was very close to significance $p = 0.052$. It is possible that a replication of this study may provide evidence which is in line with the architectural evidence on the preference for a rising path or stairs (Dongkuk Chang & Penn, n.d.; Dalton et al., 2005; Golledge, 1995; Penn, 2003)

In relation to the findings in chapters seven and eight, this study again, reinforces the finding that there is a distinct threshold at which lighting brightness begins to influence player navigational choices. In the prior studies the thresholds had been set at a level of 10% or greater variance in lighting brightness and had statistically significant effects, this study with thresholds of only 2%, well below the 10% value demonstrated that there is no statistically significant effect below that pre-determined threshold.

# 10 CHAPTER TEN:

# ARCHITECTURAL NAVIGATION OF A VIRTUAL TOWN WITH LIGHTING VARIANTS

## 10.1 INTRODUCTION

Navigation is one of the primary functions of vision in the vast majority of animals (Golledge, 1995). The systems that humans as with many animal species utilise include; cue or landmark recognition, turn angle estimation, route linkage sequencing alongside various route plotting strategies including; dead reckoning, environmental simplification and shortcutting. In practice, these route plotting strategies are adaptive systems that interact with and adapt to the surroundings and impact the speed, method and direction of motion (Dalton, 2003). Routes may be perceived as longer or shorter dependant on whether they point towards or away from a primary reference point (Montello, 1991, 1997; Sadalla et al., 1980).

Space syntax (Hillier & Hanson, 1984) sets out to define a set of discrete rules or principles of navigational behaviours (Dalton, 2003; Golledge, 1995; Peponis et al., 1990). The most dominant of these is a preference to maintain linearity when presented with divergent path choices. Similarly, people will instinctively prefer to take the longest leg of a known journey first choosing a different path from A to B than from B to A (Dalton & Bafna, 2003). One of the primary findings of Dalton's research is that key navigational decisions are maintained between the real and virtual worlds (Dalton, 2003). It has repeatedly been demonstrated that humans demonstrate a preference for following paths that offer the longest line of sight, strategic visual elements such as landmarks and that people actively avoid backtracking or revisiting a previously explored area. This latter finding was shown to be particularly true for people navigating a novel environment (Dalton, 2003; Golledge, 1995; O'Neill, 1991).

The effects of illumination on navigational choices remains an under-researched area, the effect of variation of the illumination of a path has not been studied in correlation to the preferences detailed above. This study introduced this lighting variance in order to determine whether the illumination of a scene can override the following previously discovered principles of navigation.

- Preference for maintaining a linear path
- Preference for maintaining linear path despite gradient
- Preference for path with the farthest line of sight
- Preference to avoid backtracking
- Path with more turns perceived to be longer than an equal length path with fewer turns
- Longest leg first preferred to shortest leg initially
- Preference for curved paths over turns
- Identification of landmarks correlates with the correct choice of path
- Angle of exit routes from a junction relative to the entry

## 10.2 HYPOTHESIS

Given that numerous previous studies have demonstrated particular navigational behaviours in virtual architectural spaces, it was hypothesised that:

1. Variation of illumination between path options would influence navigational choices.
2. Cue competition effects would be demonstrated between lighting cues and architectural cues.
3. The performance of the same task in an immersive virtual reality context may engender different responses.

## 10.3 METHOD

### 10.3.1 PARTICIPANTS

74 participants, 68 male, 6 female, aged between 17 and 54 (mean 22.15) all reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

The participants formed three groups

1. Group one consisted of 26 22 male, 4 female, aged between 17 and 54 (mean 22.22) these participants explored an environment that had uniform lighting throughout.
2. Group two consisted of 26 24 male, 2 female, aged between 18 and 41 (mean 22.11) these participants explored an environment that had half of the path options lit normally and half with the lighting set to 13% of the original.
3. Group three consisted of 22 22 male, 0 female, aged between 18 and 27 (mean 22.23) these participants explored an environment that had half of the path options lit normally and half with the lighting set to 13% of the original these paths being the opposite paths to group two.

Participants were supplied with an instruction sheet that simply asked them to locate the final obelisk and instructed them not to take any paths labelled with a no entry sign.

### 10.3.2 PARTICIPANTS VIRTUAL REALITY VERSION

58 participants, 54 male, 4 female, aged between 18 and 40 (mean 20.98) all reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants completed a pre-test questionnaire to determine their age, gender, handedness, game playing experience and self-perceived sense of direction. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

The participants formed three groups

1. Group one consisted of 20; 18 male, 2 female, aged between 18 and 24 (mean 20.57) these participants explored an environment that had uniform lighting throughout.
2. Group two consisted of 18; 16 male, 2 female, aged between 18 and 25 (mean 20.77) these participants explored an environment that had half of the path options lit normally and half with the lighting set to 13% of the original.
3. Group three consisted of 19; 19 male, 0 female, aged between 19 and 40 (mean 21.57) these participants explored an environment that had half of the path options lit normally and half with the lighting set to 13% of the original these paths being the opposite paths to group two.

Participants were supplied with an instruction sheet that simply asked them to locate the final obelisk and instructed them not to take any paths labelled with a no entry sign.

### 10.3.3 MATERIALS AND APPARATUS

To test the hypotheses, a virtual environment was built in Unreal Development Kit (UDK) v.2012/07. This environment contained junctions that offer two alternate routes that individually test navigational design principles such as the preference to maintain linearity with three versions being either fully lit, half of the options in a darker state and inverse of this light/dark condition. The entire apparatus was duplicated in Unreal Engine 4 to allow the study to be conducted in VR using an Oculus Rift DK2 headset. This version of the apparatus halved the brightness difference between the two variants in the standard apparatus.

The design of the apparatus involved in this study allowed for the analysis of the navigational principles discussed in the introduction. *Figure 161*. This architectural optionality combined with variants of the apparatus that introduce well-illuminated and dark pathways. Using a combination of the screen capture data and heat map data, navigational decisions were analysed from six groups of participants.

- Group one were presented with a uniformly lit environment, where the choices made stem from the architectural cues within the VE
- Group two explored the same virtual space, but with half of the path options in deep shadow.
- Group three explored the same virtual space with the lighting of the paths inverted.

These three groupings were the same for the VR version of the study. Given the familiarity of the town environment, it was theorised that dark spaces would be avoided and that participants would choose to override other navigational choices normally made in a uniformly lit space.

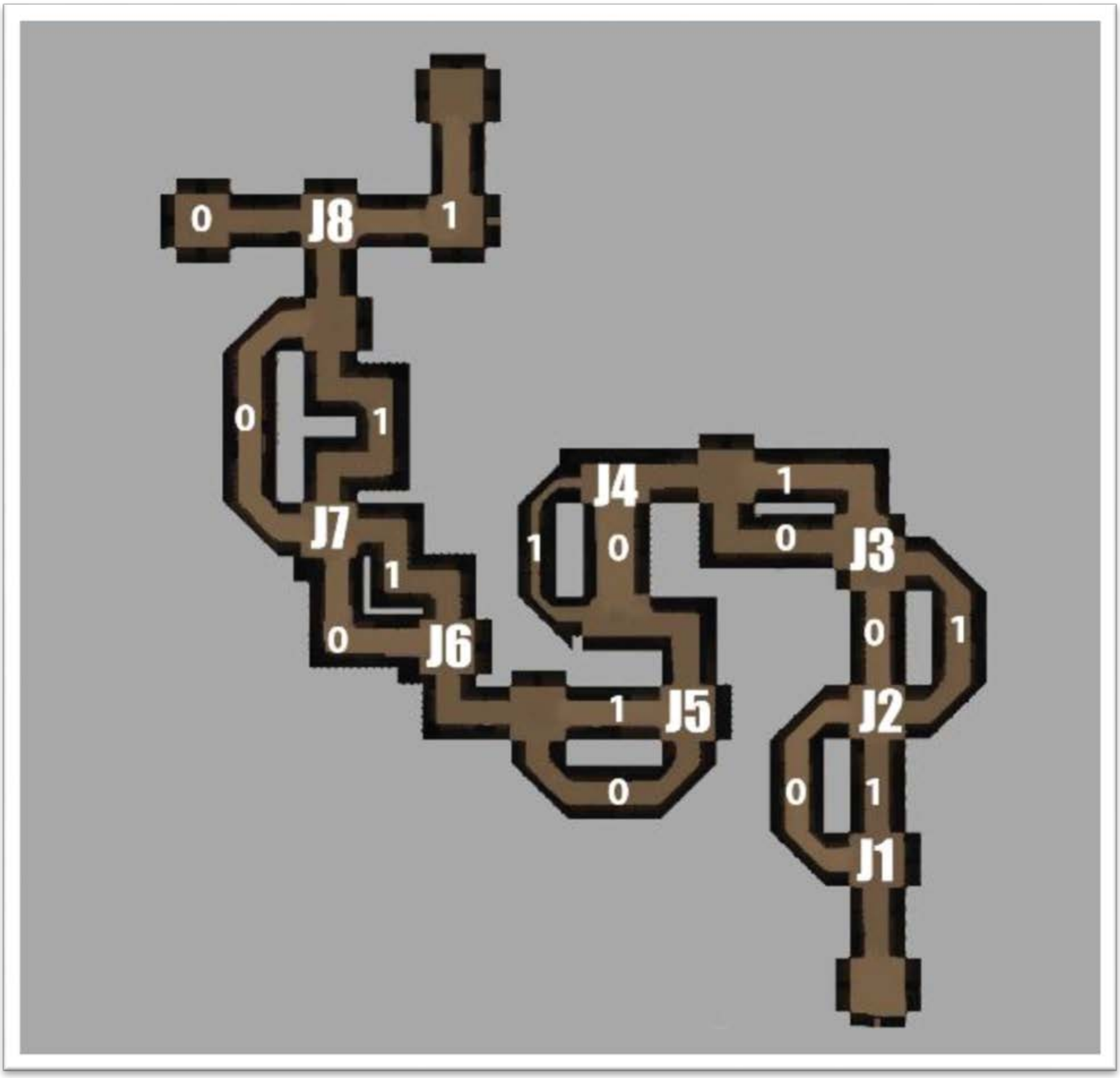


*Figure 161.* **The layout of the streets and junctions.**

### *10.3.3.1 LIST OF JUNCTIONS AND ASSOCIATED FUNCTIONS*

#### *10.3.3.1.1 JUNCTION 1*

***Figure 162.* Junction One tests the preference for maintaining a linear path (Dalton, 2003; Golledge, 1995; O'Neill, 1991).**

Prior research suggests that people display a strong preference for maintaining linearity when presented with diverging paths (Dalton, 2003; Golledge, 1995; O'Neill, 1991). It has also been demonstrated that paths with the longest line of sight are preferred over those with occluded sight lines (Dalton, 2003; Golledge, 1995). Junction one [*Figure 162*] offers the participant the following choices.

Option 0: Taking a 90 right-hand turn to a curving path.

Option 1: Maintaining linearity with long sight lines.

### 10.3.3.1.2 JUNCTION 2

***Figure 163.*** **Junction Two tests the preference for maintaining a linear path despite the presence of a gradient (Dalton, 2003; Golledge, 1995; O'Neill, 1991).**

As research suggests players will maintain a linear path despite a gradient change (D Chang & Penn, 1998; Dalton, 2003; Golledge, 1995; O'Neill, 1991), junction two [*Figure 163*] offered the following choices.

Option 0: A linear path with a rising gradient.

Option 1: A 90 left turn to a curving path.

### 10.3.3.1.3 JUNCTION 3

***Figure 164.*** **Junction Three tests the hypothesis that participants will prefer to take the route with the longest leg first (Dalton, 2003; Golledge, 1995; O'Neill, 1991).**

The preference for players to take the longest leg of a journey first (Dalton, 2003; Golledge, 1995; O'Neill, 1991) was tested by junction three. *Figure 164*. The participants are presented with two options that are offset from the preceding paths to reduce any influence from the preference for maintaining linearity. These options presented were:

Option 0: Taking the path where the longest leg is first.

Option 1: Taking a path where the visible first leg is approximately 1/3 of the length of the alternate path.

### 10.3.3.1.4 JUNCTION 4

***Figure 165.*** **Junction Four tests the hypothesis that participants will prefer a wide path with long sight lines over a narrow path with short sight lines.**

Junction four tested the preference for maintaining linearity but with a narrow entrance to the route against a wider route with long sightlines but offering a steep falling gradient. *Figure 165*, *Figure 166*. The two routes presented to the participant were:

Option 0: A 90 deviation from the linear path to a wide, steeply declining yet straight path that offered a clear view of a landmark.

Option 1: A narrow curved route that initially maintains linearity, but offers an impoverished line of sight.

***Figure 166.*** **Participant perspectives of the wide [left] and narrow [right] routes.**

### 10.3.3.1.5 JUNCTION 5

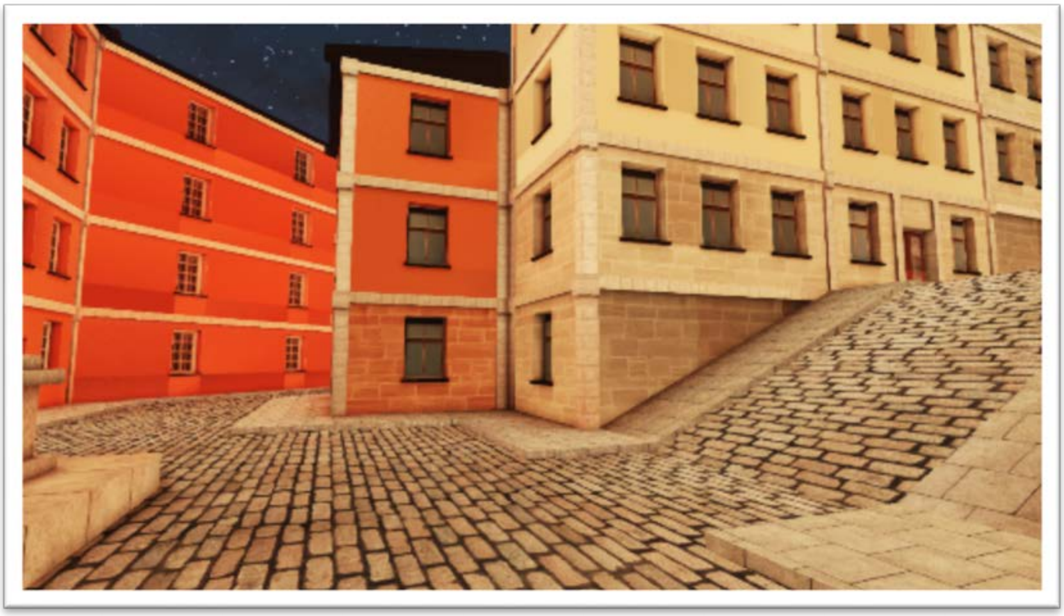

***Figure 167.*** **Junction Five tests the competing preferences of maintaining linearity with sight (Dalton, 2003; Golledge, 1995; O'Neill, 1991).**

Junction five [*Figure 167*, *Figure 168*] tests the preference for maintaining linearity against the preference for the farthest line of sight with a rising gradient (Dalton, 2003; Golledge, 1995; O'Neill, 1991), by offering a choice between:

Option 0: A linear but curved path with limited sight line.

Option 1: A 90 right hand turn up a rising gradient to a path offering improved sight lines.

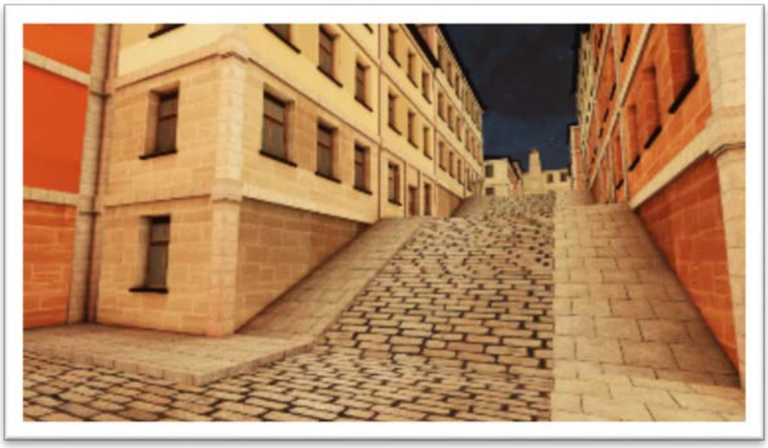

***Figure 168.*** **The sightlines at the right-hand turn of Junction Five - the next landmark visible in the mid-distance.**

##### 10.3.3.1.6 JUNCTION 6

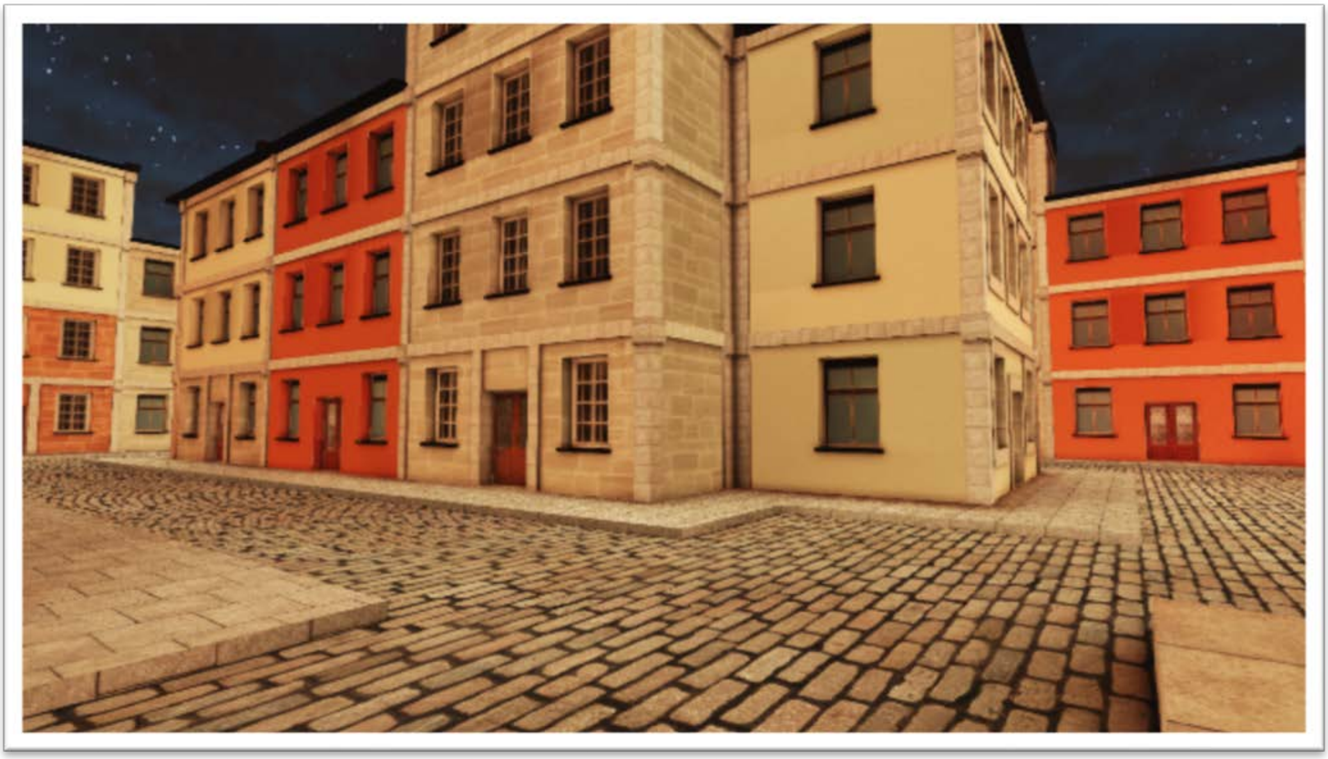

***Figure 169.*** **Junction Six tests for cue competition preference between maintaining linearity and taking the longest leg of a route first (Dalton, 2003; Golledge, 1995; O'Neill, 1991).**

Junction six [*Figure 169*] tests for the preference of taking the longest leg first (Dalton, 2003; Golledge, 1995; O'Neill, 1991) when the linear path offers the shortest leg first, the choices provided to the player are:

Option 0: To maintain linearity and therefore take the shortest leg first.

Option 1: To take a 90° right-hand turn in order to take the longest leg first.

#### 10.3.3.1.7 JUNCTION 7

*Figure 170.* **Junction Seven offer the participant the option of a curved or sharply angular route.**

Junction seven tested whether participants demonstrate as indicated in prior research a preference for curved paths over sharp turns (Dalton, 2003; Golledge, 1995; O'Neill, 1991). *Figure 170*. The entrances to both paths are offset from the exit point of the previous path to counteract the preference for maintaining linearity. The participants were presented with the following options:

Option 0: A short leg that leads to a 90° right-hand turn.

Option 1: A curved path with similar sight lines to the angular path option.

### 10.3.3.1.8 JUNCTION 8

*Figure 171.* **View down the right-hand path with the Obelisk landmark at the end of the route.**

Junction eight was a test of landmark recognition (Steck & Mallot, 2000; Tlauka & Wilson, 1994; Vinson, 1999b). A series of obelisks had denoted the correct path at each of the prior junctions. *Figure 171*, *Figure 172*. At this intersection, all participants had passed seven obelisk landmarks at each of the previous junctions; this junction tested whether they have associated these obelisks with the correct path. The two choices offered to the participant are:

Option 0: a left-hand 90° turn that provides a view of empty square or

Option1: a right-hand 90° turn that offers a view of an obelisk.

*Figure 172.* **Sight lines of the left-hand turn [left] or right-hand turn with distal landmark [right].**

#### 10.3.3.2 DISCOURAGING BACKTRACKING

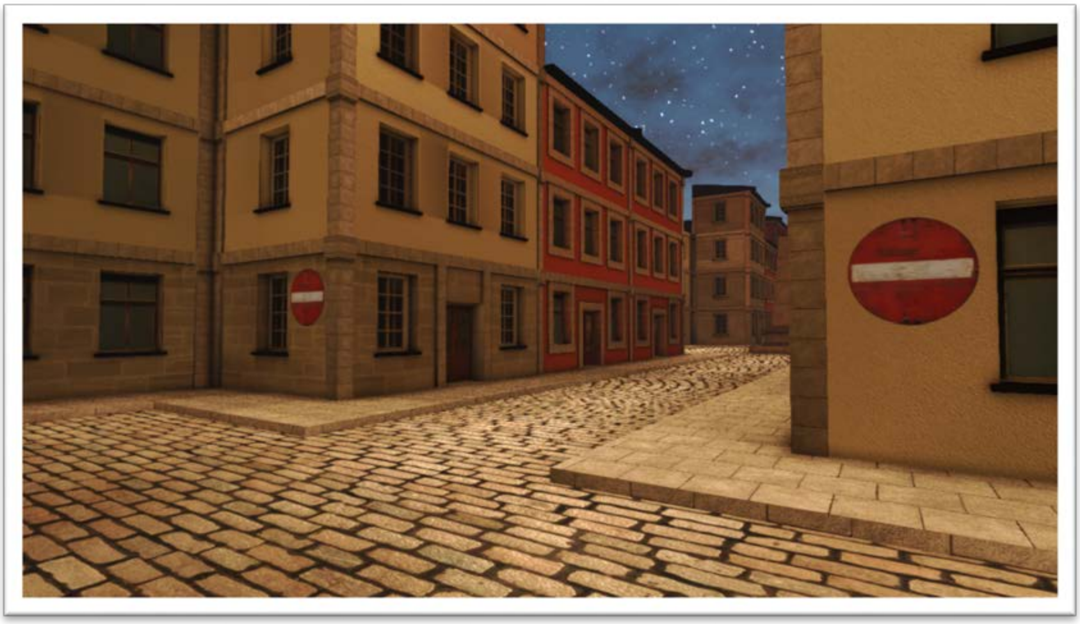

*Figure 173.* **An example of a street with clear no-entry signage.**

During initial development and testing, it was clear that the exits to prior option paths were being entered and causing confusion, this was not a deliberate backtracking issue on the part of the participant, merely that the prior optional exit offered an additional entrance to a path that offered an unexplored option. A blocking or collision volume could have been used to stop access to that route, or a geometry change could have been made, but in some instances, this may have been visible to the player. The method employed to dissuade participants from choosing a route exit was the simple inclusion of no entry signs on the return walls of each path; these, therefore, were not visible until the player had exited the prior path, but encouraged navigation in the required direction. *Figure 173*.

### 10.3.4 LIGHTING VARIANTS

Three variants were built, one being uniformly lit throughout, this level was designed to act as the control condition and to ascertain whether the navigational principles such as maintaining linearity were retained in these conditions.

The variant versions of the environment that had half of the path options lit normally and half with the lighting set to 13% of the original. As with the central goal maze study, the reduction of lighting to this value did not translate to an averaged screen brightness of the same percentage. In this instance, the screen brightness difference between the lit paths and the dark paths averaged out to 5% brightness for the dark paths and 20% for the lit paths, the dark paths, therefore, having only 25% of the brightness of the lit paths. *Figure 174*, *Figure 175*, *Figure 176*.

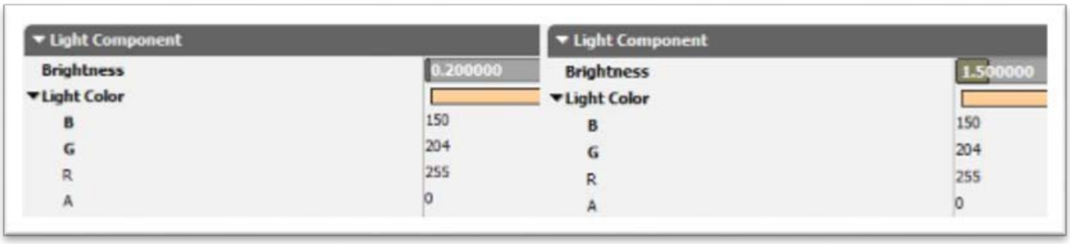


***Figure 174.*** **The lighting values of the dark [left] and brightly lit [right] path options.**

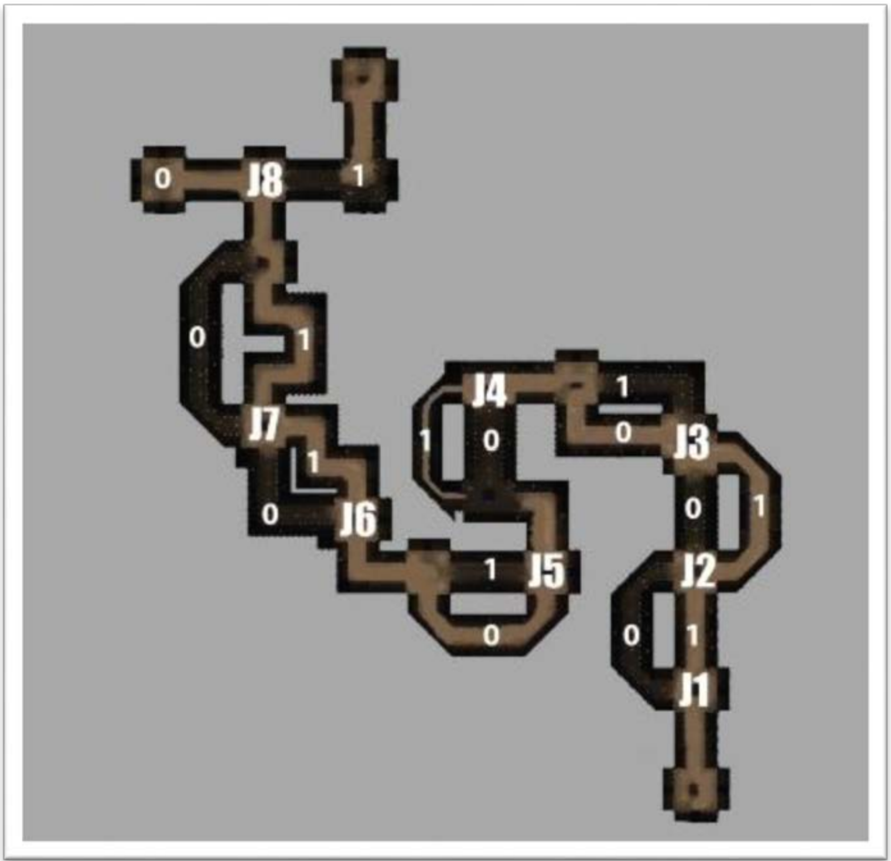


*Figure 175.* **A topographical representation of the illumination conditions of variant A.**

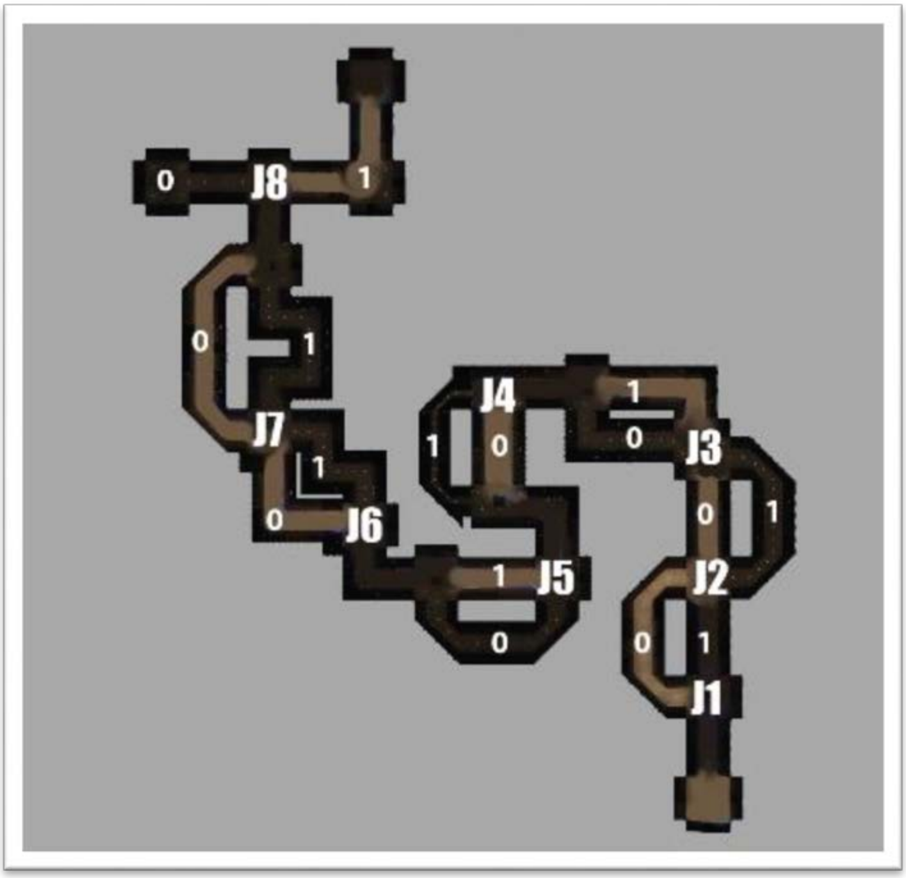


*Figure 176.* **A topographical representation of the illumination conditions of variant B.**

### 10.3.5 VIRTUAL REALITY VERSION

The virtual reality based study utilised the same virtual town environment and lighting design as the prior study. The project had been constructed in Unreal Development Kit (UDK) v.2012/07; this software was both superseded during the ongoing study and was not compatible with the newer virtual reality headsets and their associated Software Development Kits (SDK's). In order for the project to work with the Oculus Rift DK2, it was transferred to Unreal Engine 4 (UE4). All structural aspects of the project were kept as close to the original version as possible. As the results for brightly lit paths versus very dark paths had elicited strong results discussed below, this version of the apparatus included a less stark variance between the two lighting conditions.

The overall averaged on screen brightness was sampled using the same method employed in the central goal maze study. The averaged brightness of the dark pathway was 25% of the brightness of the light pathways. The dark pathways had an averaged brightness of 5%, and the lit pathways had an averaged brightness of 20%. *Figure 177*, *Figure 178*. The virtual reality version had brightness conditions that were closer together with a 50% reduction in brightness in the dark paths when compared to the lit paths. The dark pathway being illuminated at 9% averaged brightness and the lit pathway having an averaged brightness of 18%. *Figure 179*, *Figure 180.*

*Figure 177.* **An example of the lighting difference between dark paths [left] and light paths [right] in the standard monitor based version of the apparatus.**


*Figure 178.* **An example of the screen area averaging method used to determine the overall brightness of a path. The dark path [left] was only 25% as bright as the lit path [right].**


*Figure 179.* Examples of bright [left] and dark [right] paths in the virtual reality version of the apparatus.

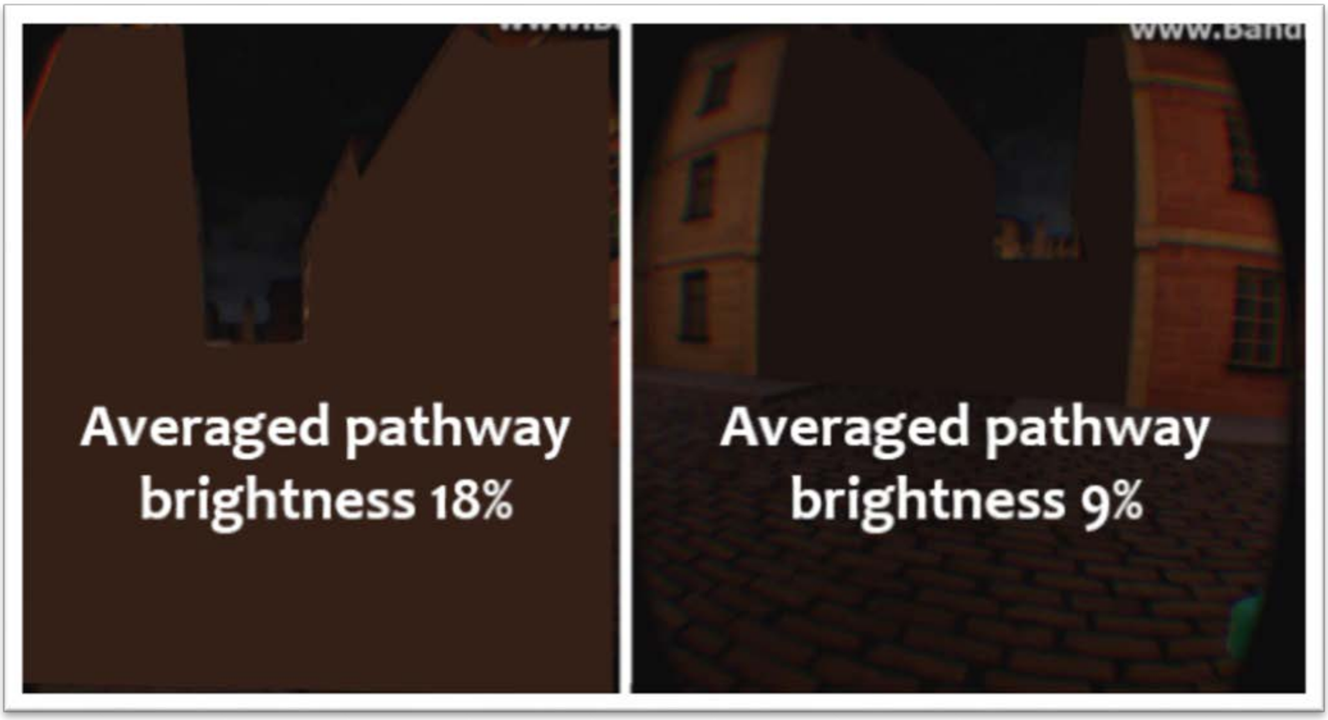


*Figure* 180. An example of the screen area averaging method used to determine the overall brightness of a path in the VR version of the apparatus. The dark path [right] was only 50% as bright as the bright path [left].

## 10.4 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4th generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch-wide-screen monitor. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

## 10.5 PROCEDURE - VIRTUAL REALITY VERSION

All participants were tested individually, and they supplied informed written consent in advance.

All participants performed the tests wearing a virtual reality headset, specifically an Oculus Rift 2nd Generation Development Kit the headset was connected to a PC with 4th generation Intel i7 CPU, Nvidia 970 graphics cards; user input was via a Microsoft X-Box 16 button controller. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum. Screen capture software was used to record players

## 10.6 RESULTS AND DISCUSSION

### 10.6.1 DEFINITION OF JUNCTIONS

As there are 96 different path options across all of the variants in this study, the following annotations are used to define each path option:

Apparatus Type / Lighting Variant / Path Option

The main apparatus was presented either on a

- A standard monitor (S)
- A virtual reality headset (V)

The three lighting options presented were:

- Uniformly lit throughout (U)
- Lighting variant A (A)
- Lighting variant B (B)

Each variant of the apparatus contains eight two-way junctions.

Left and right path options are represented by a binary digit preceded by an underscore:

- A left-hand path (0)
- A right-hand path (1)

Therefore, a right-handed path at junction six in the uniformly lit condition in VR would be denoted as path VU6_1.

### 10.6.2 HEAT MAPS

Heatmap data was only available for the standard monitor version (S) due to Unreal Engine 4 not having this functionality at the time of development. The heat map data for the standard version clearly demonstrates that there are distinct differences between paths taken by participants in the three variant conditions, the heat map for the neutral lighting condition, for instance, begins with a distinct preference for maintaining linearity that was absent from the two lighting variants. The lighting variants themselves show a clear preference for staying on a lit path. *Figure 181*, *Figure 182*.

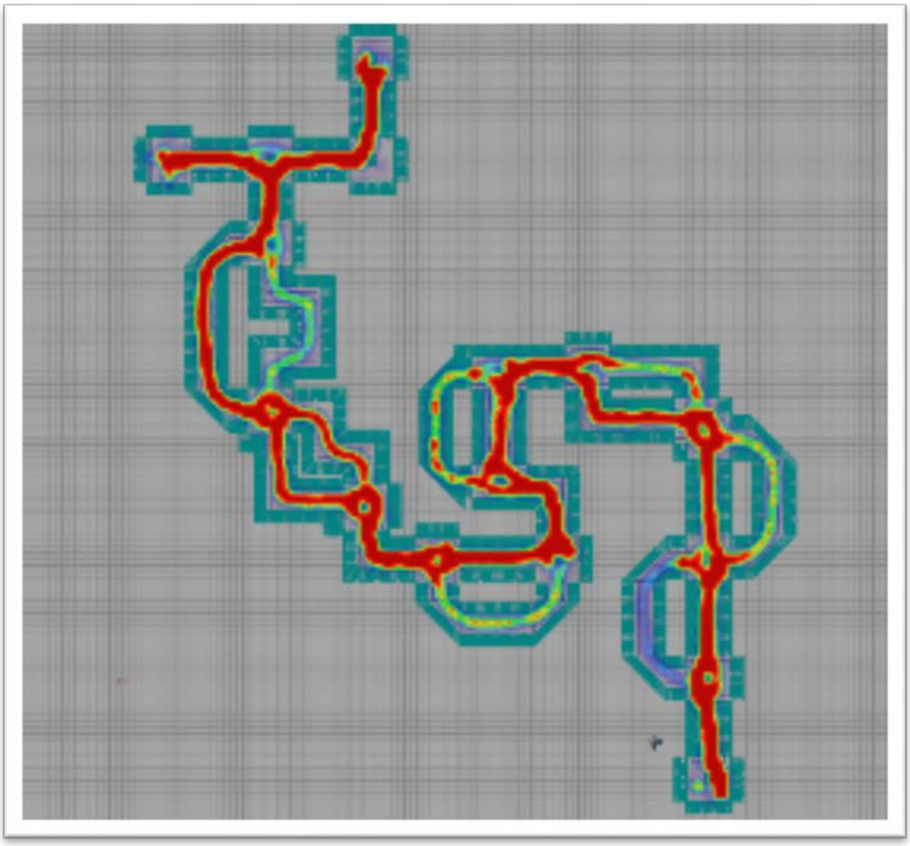

***Figure 181.*** **The combined heat map data for the uniformly lit variant.**

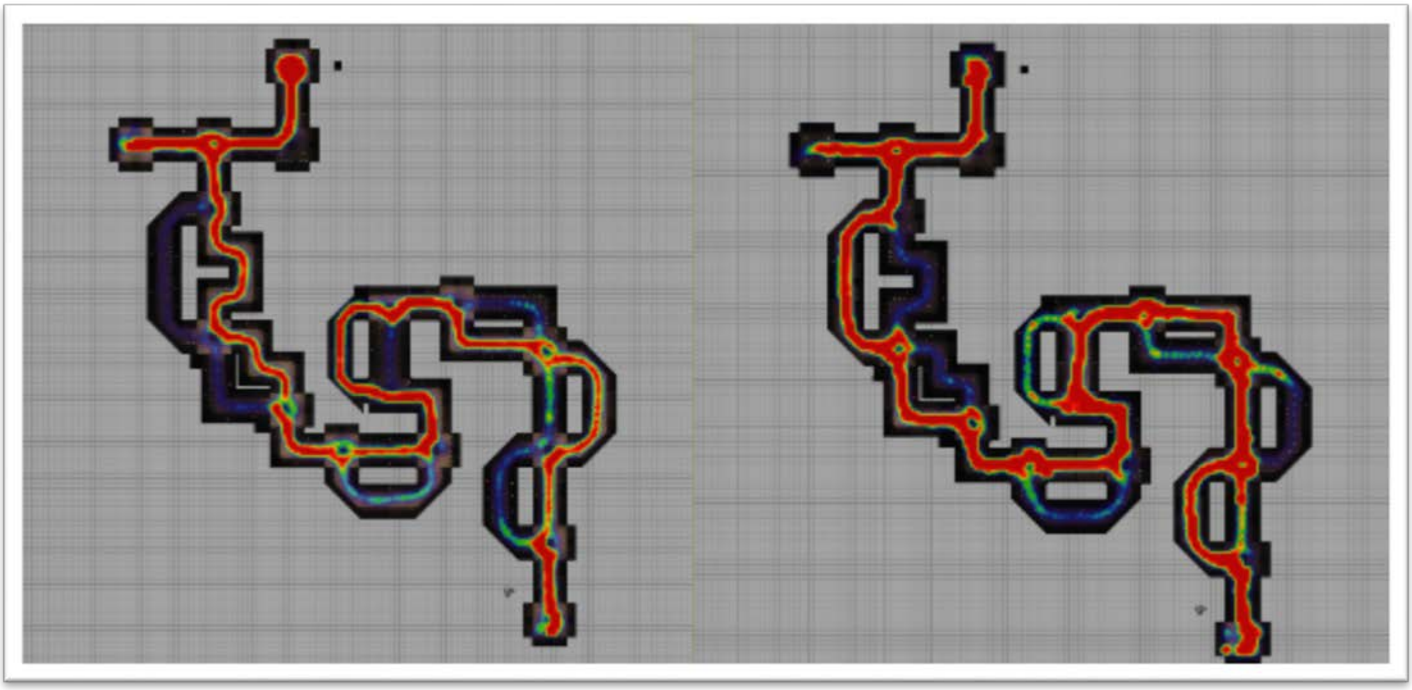

*Figure 182.* The combined heatmaps for the lighting variants A [left] and B [right].

### 10.6.3 JUNCTION 1

Prior research suggests that people prefer maintaining linearity – following a linear path. Junction one offered the participant a choice between the following options. *Figure 183*.

Option 0: Taking a 90° right-hand turn to a curving path.

Option 1: Maintaining linearity.

Variant SA: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 0 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 1 to 50% of the standard brightness.

| | J1 1 | J1 0 |
|---|---|---|
| Uniform | 80.76 | 19.23 |
| Uniform VR | 70 | 30 |
| Light Dark A | 61.53 | 38.46 |
| Light Dark A VR | 55.55 | 44.44 |
| Light Dark B | 31.81 | 68.18 |
| Light Dark B VR | 42.10 | 57.89 |

***Table 10.*** **Percentage results of path choices at junction one.**

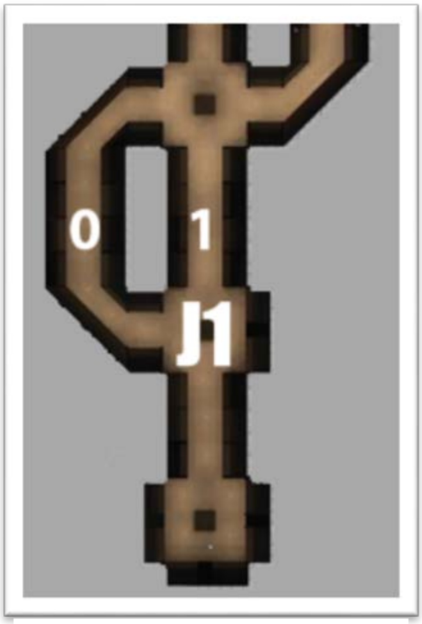


***Figure 183.*** **A topographical representation of junction one.**

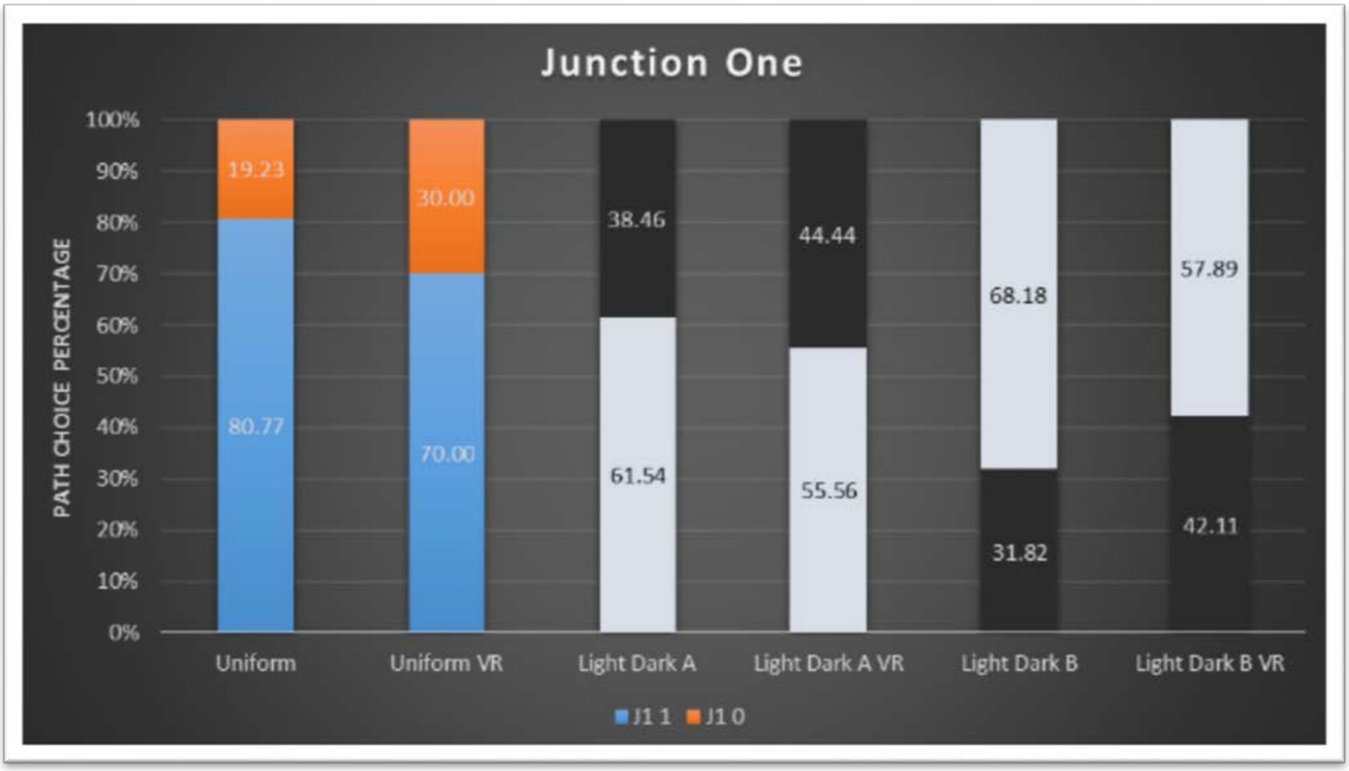


***Figure 184.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction one.**

The results from junction one [*Figure 184*] demonstrate that in the uniformly lit condition between both the standard and VR variants, participants as anticipated, do maintain linearity (SU1_1 & VU1_1). The introduction of lighting differences for this junction produced unexpected results with fewer participants taking the linear path even when it was the lit option than in the uniformly lit condition (SA1_1 & VA1_1). The curving path when lit became the more popular option. It was clear in this instance that lighting played a factor in path choice and perhaps it is possible that the novelty of a dark path when the path into the distance was clearly illuminated was an attracting factor due to contrast. The greater contrast in lighting conditions offered by the standard screen based study has a small additional influence in both cases (SA1_1 & SB1_0).

### 10.6.4 JUNCTION 2

As research suggests players will maintain a linear path despite a gradient change, junction two offered the following options: *Figure 185*.

Option 0: A linear, rising gradient.

Option 1: A 90° left turn to a curving path.

Variant SA: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 0 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 1 to 50% of the standard brightness.

| | J2 1 | J2 0 |
|---|---|---|
| Uniform | 30.76 | 69.23 |
| Uniform VR | 35 | 65 |
| Light Dark A | 65.38 | 34.61 |
| Light Dark A VR | 55.55 | 44.44 |
| Light Dark B | 13.63 | 86.36 |
| Light Dark B VR | 52.63 | 47.36 |

***Table 11.*** **Percentage results of path choices at junction two.**


***Figure 185.*** **A topographical representation of junction two.**

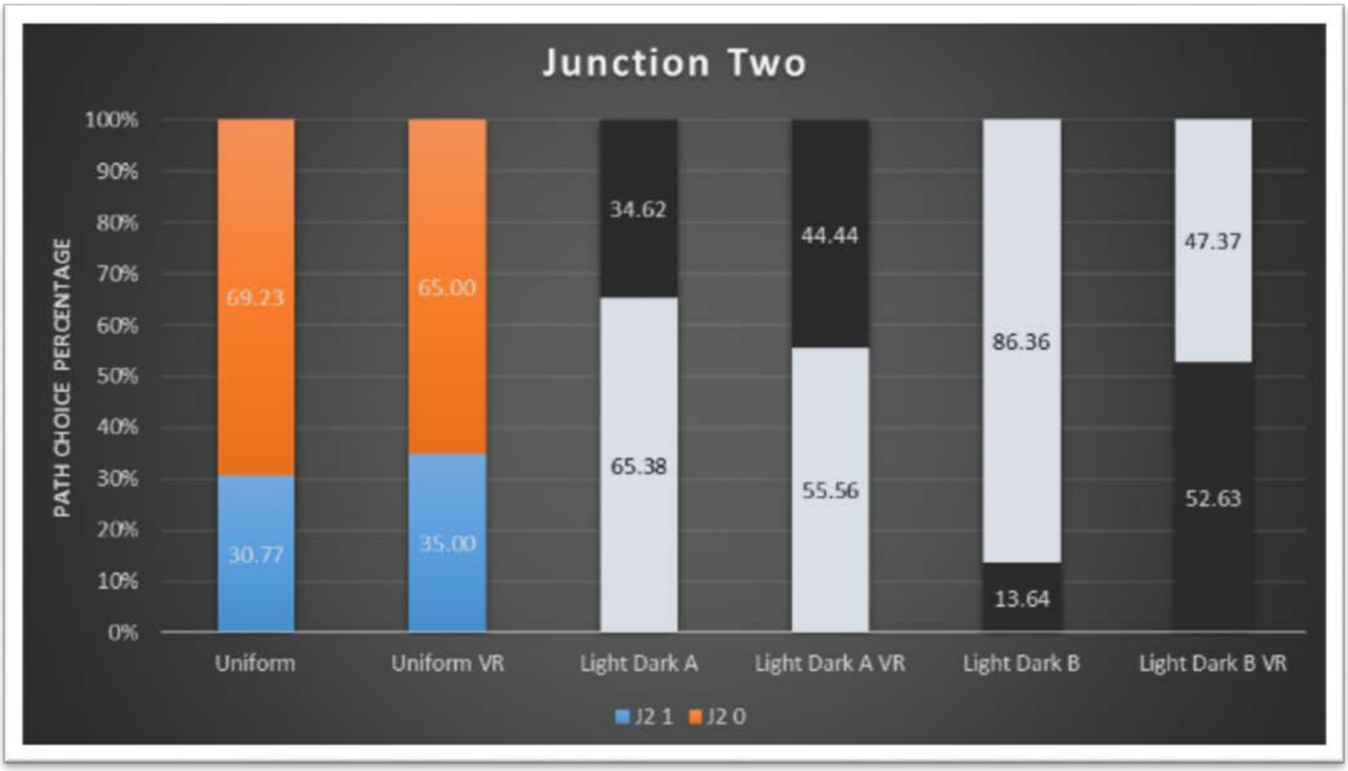


***Figure 186.* A percentage bar graph of the proportions of participants taking each of the routes at junction two.**

At junction two, [*Figure 186*] the participants in the uniformly lit conditions in both variants made very similar decisions with less than 5% variance (SU2 & VU2). Again as with junction one, the majority of participants maintained linearity in this instance with a minor increase in favouring the linear path (SU2_0 & VU2_0). The introduction of lighting differences in variant A. encouraging greater exploration of the curved path (SA2_0 & VA2_0). Of note was that where the curved path was very dimly lit in the screen version of variant B (SB2_1), only 14% of participants opted for the dark path. When the difference, in contrast, was not so pronounced in the VR version (VB2_1), there was increased exploration of the curved path. This choice again could be due to the contrast between the rest of the environment and this path option.

### 10.6.5 JUNCTION 3

The preference for players to take the longest leg of a journey first was tested by junction three [*Figure 187*] – the participants are presented with two options that are offset from the preceding paths to reduce any influence from the preference for maintaining linearity, these options being:

Option 0: Taking the path where the longest leg is first.

Option 1: Taking a path where the visible first leg is approximately 1/3 of the length of the alternate path.

Variant SA: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 1 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 0 to 50% of the standard brightness.

| | J3 1 | J3 0 |
|---|---|---|
| Uniform | 30.76 | 69.23 |
| Uniform VR | 25 | 75 |
| Light Dark A | 26.92 | 73.07 |
| Light Dark A VR | 27.77 | 72.22 |
| Light Dark B | 72.72 | 27.27 |
| Light Dark B VR | 52.63 | 47.36 |

***Table 12.* Percentage results of path choices at junction three.**

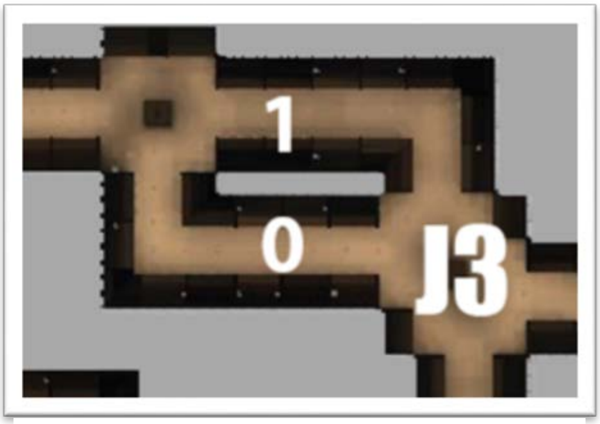


***Figure 187.* A topographical representation of junction three.**

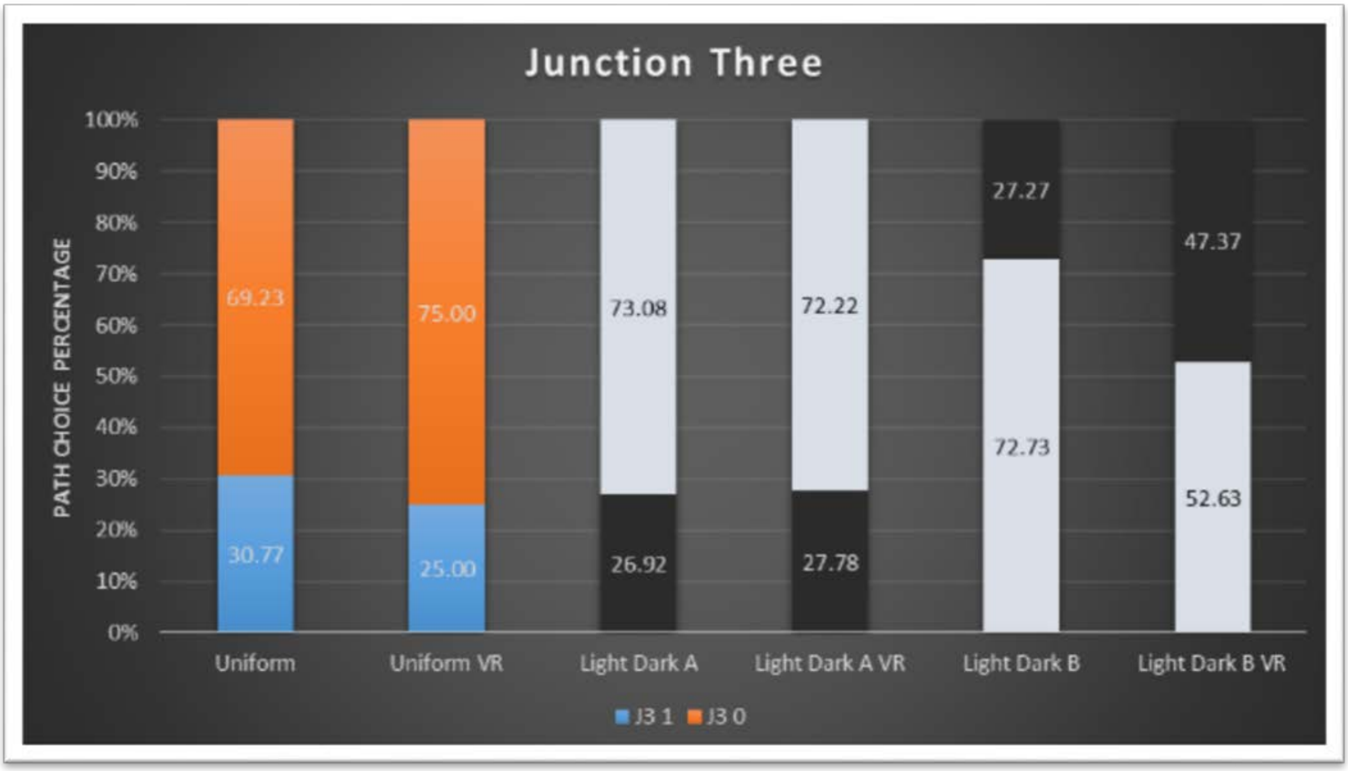


***Figure 188.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction three.**

The architectural hypothesis at junction three [*Figure 188*] was that participants would demonstrate a preference for taking the longest leg of a journey first. This was clearly demonstrated with roughly three-quarters of participants opting for that route (SU3_0 & VU3_0). Again, in the lit variants, the lighting of the architecturally preferred path reinforces that path choice (SA3_0 & VA3_0), and there was an inverse of this decision-making when the lighting was reversed (SB3_0 & VB3_0). Once more, the lighting variation was reflected in path choices with brighter lighting contrast eliciting a stronger response.

### 10.6.6 JUNCTION 4

Junction four offered the player the options of taking: *Figure 189*.

Option 0: A 90° deviation from the linear path to a wide, steeply declining yet straight path that offered a clear view of the next junction.

Option 1: A narrow curved route that initially maintains linearity, but offers an impoverished line of sight.

Variant SA: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 0 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 1 to 50% of the standard brightness.

| | J4 1 | J4 0 |
|---|---|---|
| Uniform | 30.76 | 69.23 |
| Uniform VR | 30 | 70 |
| Light Dark A | 76.92 | 23.07 |
| Light Dark A VR | 27.77 | 72.22 |
| Light Dark B | 27.27 | 72.72 |
| Light Dark B VR | 47.36 | 52.63 |

***Table 13.*** **Percentage results of path choices at junction four.**

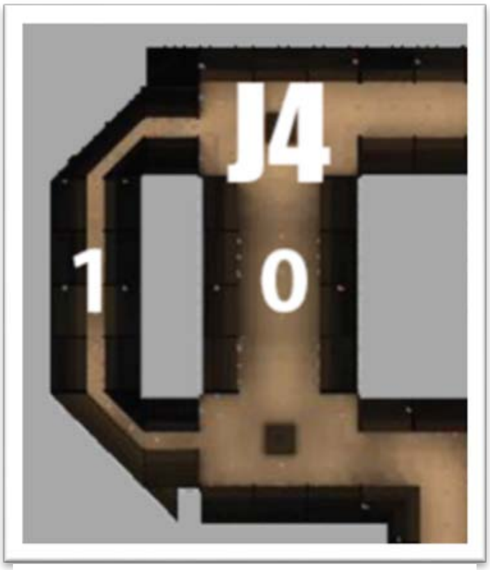


***Figure 189.*** **A topographical representation of junction four.**

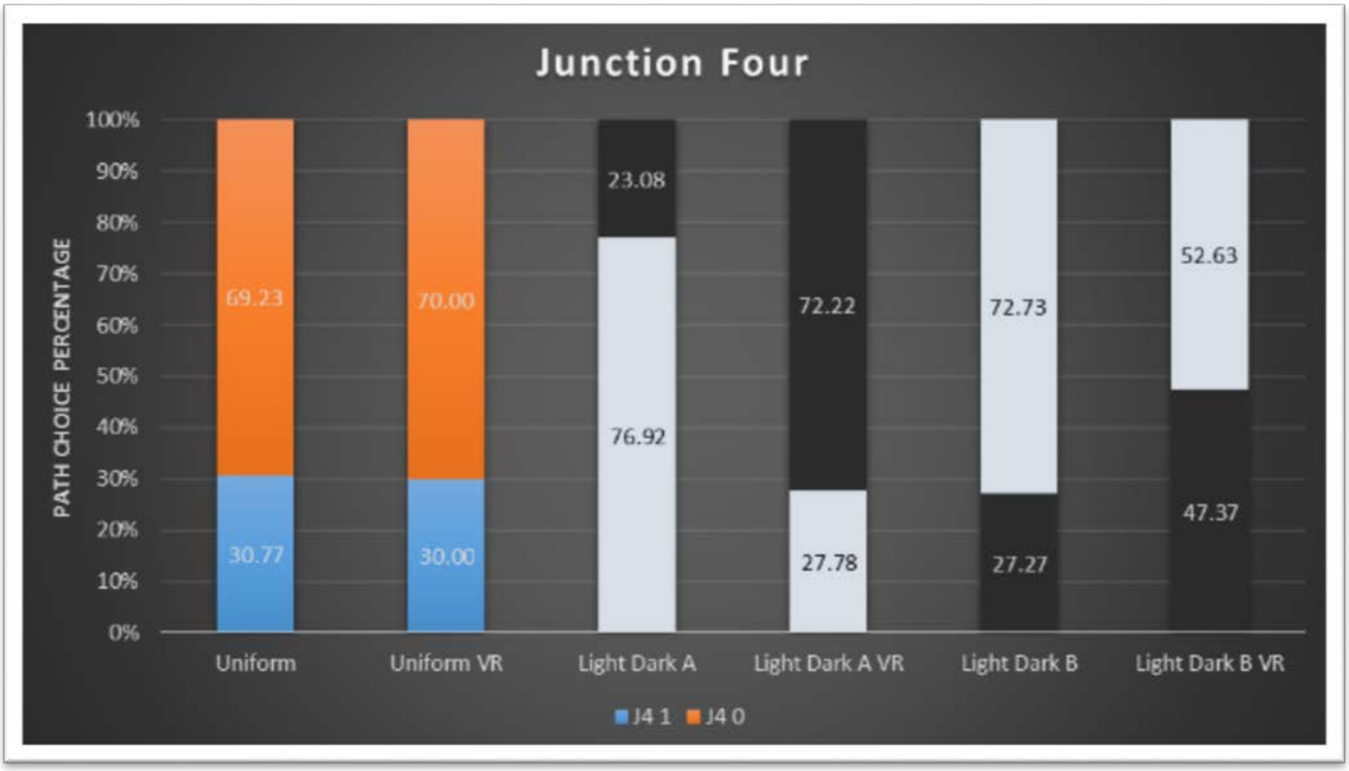


***Figure 190.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction four.**

Junction four [*Figure 190*] produced unexpected results. The downward sloping pathway was wide with good sight lines to a landmark; however, the majority of participants in both of the uniformly lit studies opted to continue in a linear fashion towards a narrow passageway with very short sight lines (SU4_1 & VU4_1). This reinforces the propensity for maintaining linearity. In the strongly contrasting screen based version, the alleyway was very dark (SB4_1), and again, participants opted for the brightly lit pathway (SB4_0). However, in the VR version where the contrast of the passageway was only half of that in the other variant, the percentage of participants opting for the narrow passage (VB4_1) was in the same proportion as the uniformly lit control (VU4_1).

### 10.6.7 JUNCTION 5

Junction five tested the preference for maintaining linearity, but reversed the path type options of junction one by offering a choice between: *Figure 191*.

Option 0: A linear but curved path with limited sight line.

Option 1: A 90° right-hand turn to a path offering improved sight lines.

Variant SA: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 1 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 0 to 50% of the standard brightness.

| | J5 1 | J5 0 |
|---|---|---|
| Uniform | 73.07 | 26.92 |
| Uniform VR | 80 | 20 |
| Light Dark A | 69.23 | 30.76 |
| Light Dark A VR | 55.55 | 44.44 |
| Light Dark B | 77.27 | 22.72 |
| Light Dark B VR | 84.21 | 15.78 |

***Table 14*. Percentage results of path choices at junction five.**

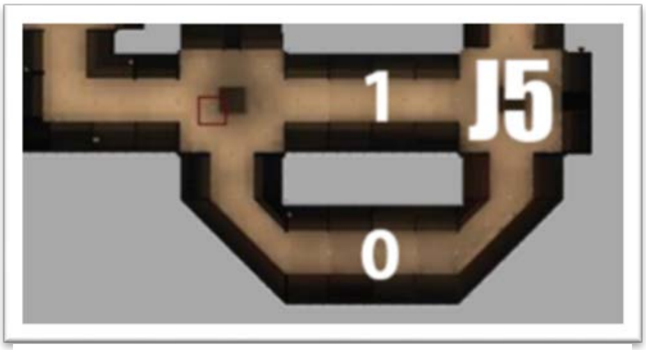


***Figure 191*. A topographical representation of junction five.**

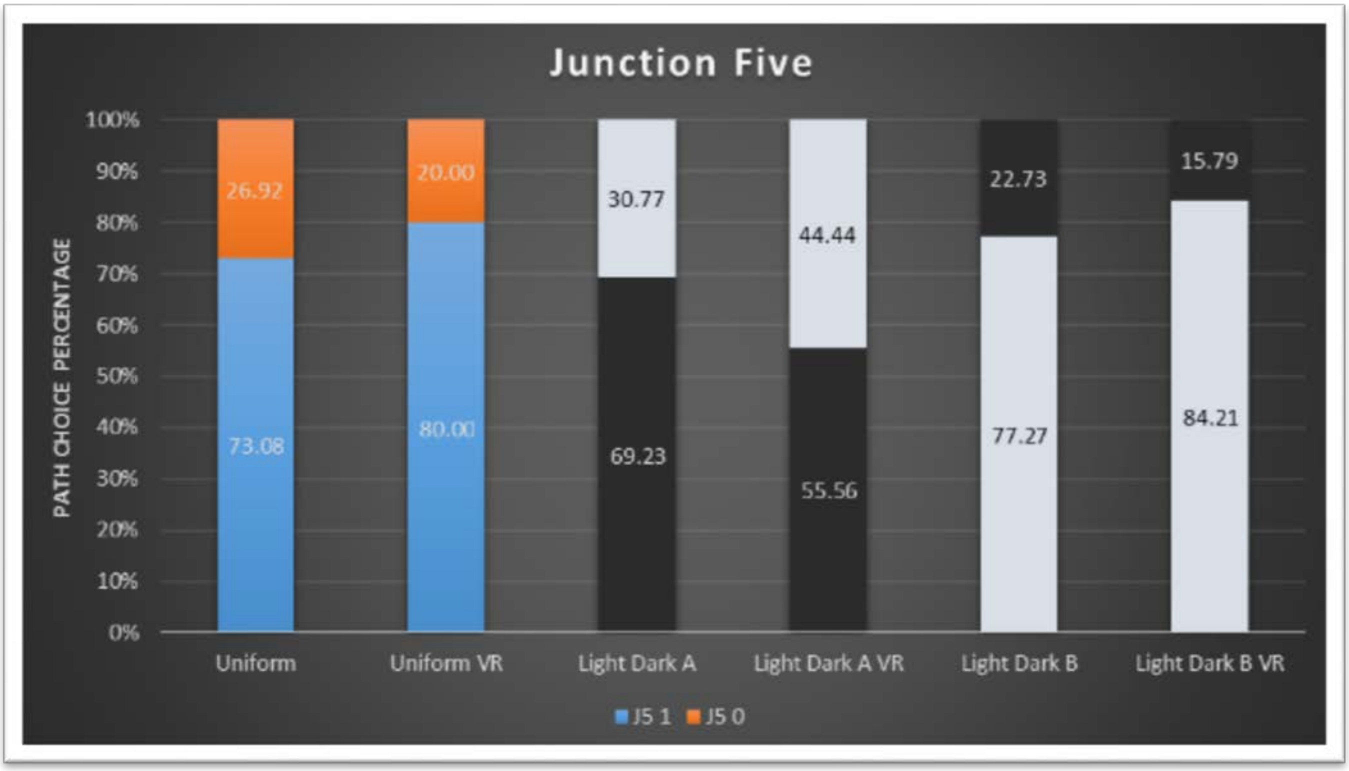


***Figure 192.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction five.**

The participants at junction five [*Figure 192*] opted very strongly to take the path with the longest sight lines in favour of maintaining linearity. Of interest, in this case, was that variant A had only a short dark path with a clearly illuminated path beyond (SA5_1 & VA5_1). This distal lighting cue was very likely responsible for the lit path in these variants being less influential than the lit paths at the previous junctions. In variant B, there was a reinforcing effect of lighting the architecturally preferred path (SB5_1 & VB5_1).

### 10.6.8 JUNCTION 6

Junction six tested for the preference of taking the longest leg first when the linear path offered the shortest leg first, the choices provided to the player are: *Figure 193*.

Option 0: To maintain linearity and therefore take the shortest leg first.

Option 1: To take a 90° right-hand turn in order to take the longest leg first.

Variant SA: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 0 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 1 to 50% of the standard brightness.

| | J6 1 | J6 0 |
|---|---|---|
| Uniform | 46.15 | 53.84 |
| Uniform VR | 25 | 75 |
| Light Dark A | 80.76 | 19.23 |
| Light Dark A VR | 27.77 | 72.22 |
| Light Dark B | 13.63 | 86.36 |
| Light Dark B VR | 10.52 | 89.47 |

***Table 15.*** **Percentage results of path choices at junction six.**

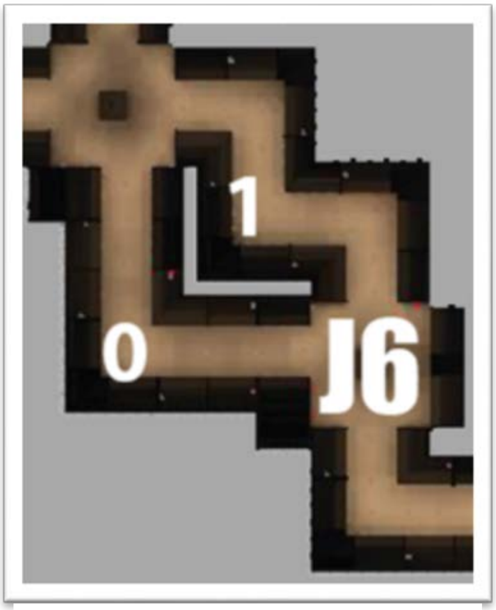


***Figure 193.*** **A topographical representation of junction six.**

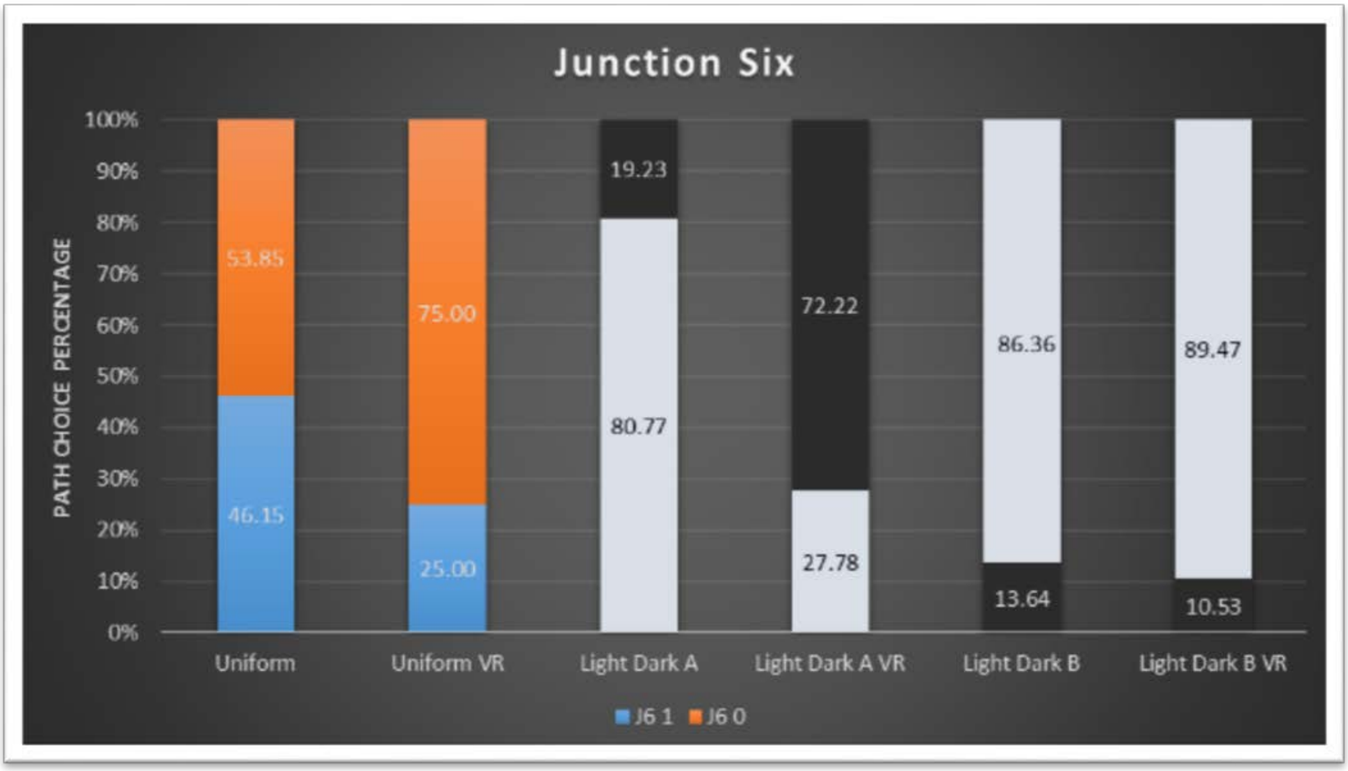


***Figure 194.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction six.**

Junction six [*Figure 194*] presented the participants with competing routes, route 1 allowed for the maintaining of linearity and route 0 offered longer sightlines and longest leg first. There was variance between the VR and screen based versions in the uniform condition. Participants in the screen base variant maintained linearity more than in the VR variant. This was also true for the VR version of variant A (VA6). However, in all other cases lighting was a major contributory factor, reversing the preference in the more strongly contrasting screen version of variant A and in variant, B lighting reinforced the participant's navigational choices (SA6_1 & SB6_0).

### 10.6.9 JUNCTION 7

Junction seven tests whether participants demonstrated as indicated in prior research a preference for curved paths over sharp turns by offering the participant the choice of the following options: *Figure 195*.

Option 0: A short leg that leads to a 90° right-hand turn.

Option 1: A curved path with similar sight lines to the angular path option.

Variant SA: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 0 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 1 to 50% of the standard brightness.

.

| | J7 1 | J7 0 |
|---|---|---|
| Uniform | 26.92 | 73.07 |
| Uniform VR | 30 | 70 |
| Light Dark A | 84.61 | 15.38 |
| Light Dark A VR | 27.77 | 72.22 |
| Light Dark B | 18.18 | 81.81 |
| Light Dark B VR | 42.10 | 57.89 |

***Table 16.* Percentage results of path choices at junction seven.**


***Figure 195.* A topographical representation of junction seven.**

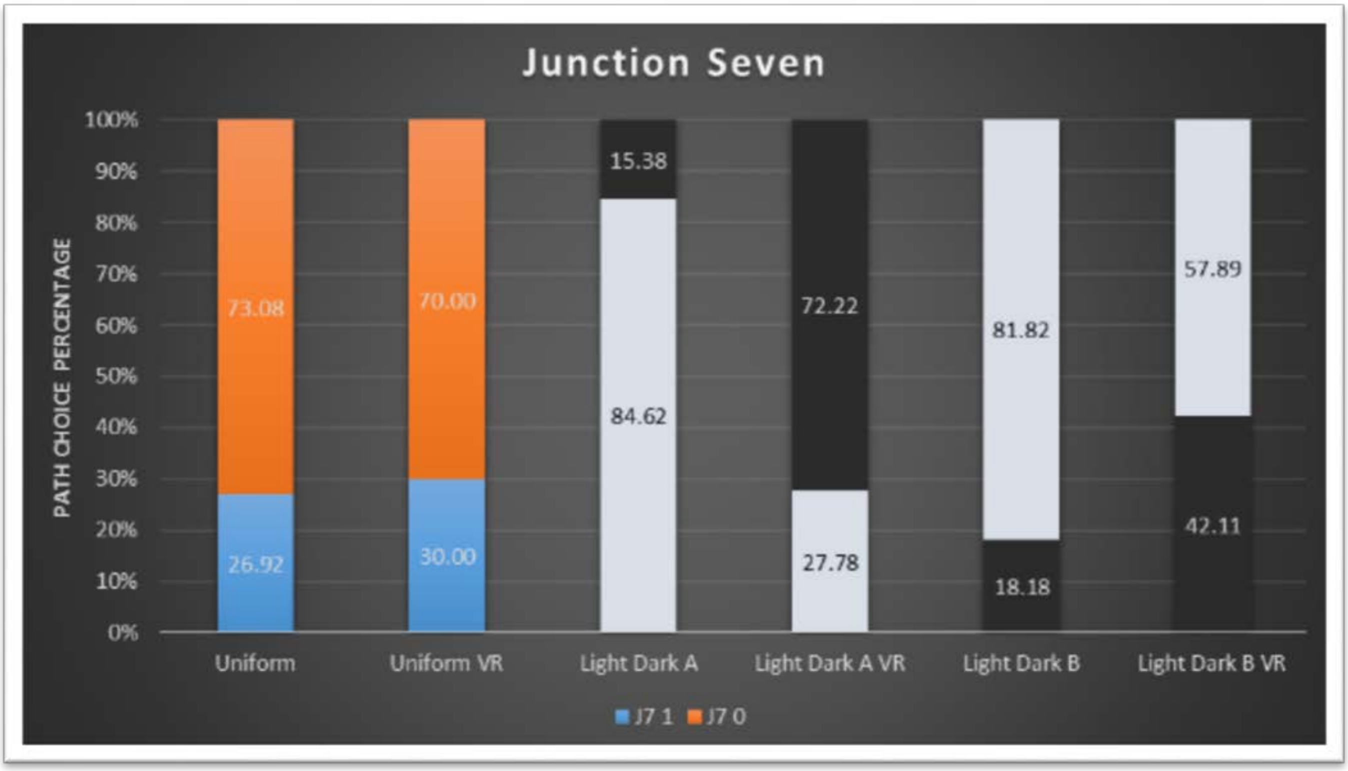


***Figure 196.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction seven.**

As predicted by the architectural research, participants in the uniformly lit condition demonstrate a clear preference for a curved path over an angular stepped path. Lighting variation in the VR versions of the apparatus (VA7_1 & VB7_1) has a limited effect, but in the more strongly contrasting screen based variants, the lighting was the strongest navigational cue, reversing the path decisions in variant A (SA7_1) and reinforcing it in variant B (SB7_1). *Figure 196*.

### 10.6.10 JUNCTION 8

Junction eight was a test of landmarks to denote the correct path as reflected in each of the prior junctions. All participants had at this stage passed seven obelisk landmarks at each of the previous junctions, this junction tested whether they had associated these obelisks with the correct path the two choices offered to the participant were: *Figure 197*.

Option 0: A left hand 90° turn that provides a view of an empty square.

Option1: A right hand 90° turn that offers a view of an obelisk.

Variant SA: Reduces the illumination of path option 1 to 25% of the standard brightness.

Variant SB: Reduces the illumination of path option 0 to 25% of the standard brightness.

Variant VA: Reduces the illumination of path option 1 to 50% of the standard brightness.

Variant VB: Reduces the illumination of path option 0 to 50% of the standard brightness.

| | J8 1 | J8 0 |
|---|---|---|
| Uniform | 53.84 | 46.15 |
| Uniform VR | 55 | 45 |
| Light Dark A | 30.76 | 69.23 |
| Light Dark A VR | 44.44 | 55.55 |
| Light Dark B | 54.54 | 45.45 |
| Light Dark B VR | 52.63 | 47.36 |

***Table 17.* Percentage results of path choices at junction eight.**


***Figure 197.* A topographical representation of junction eight.**

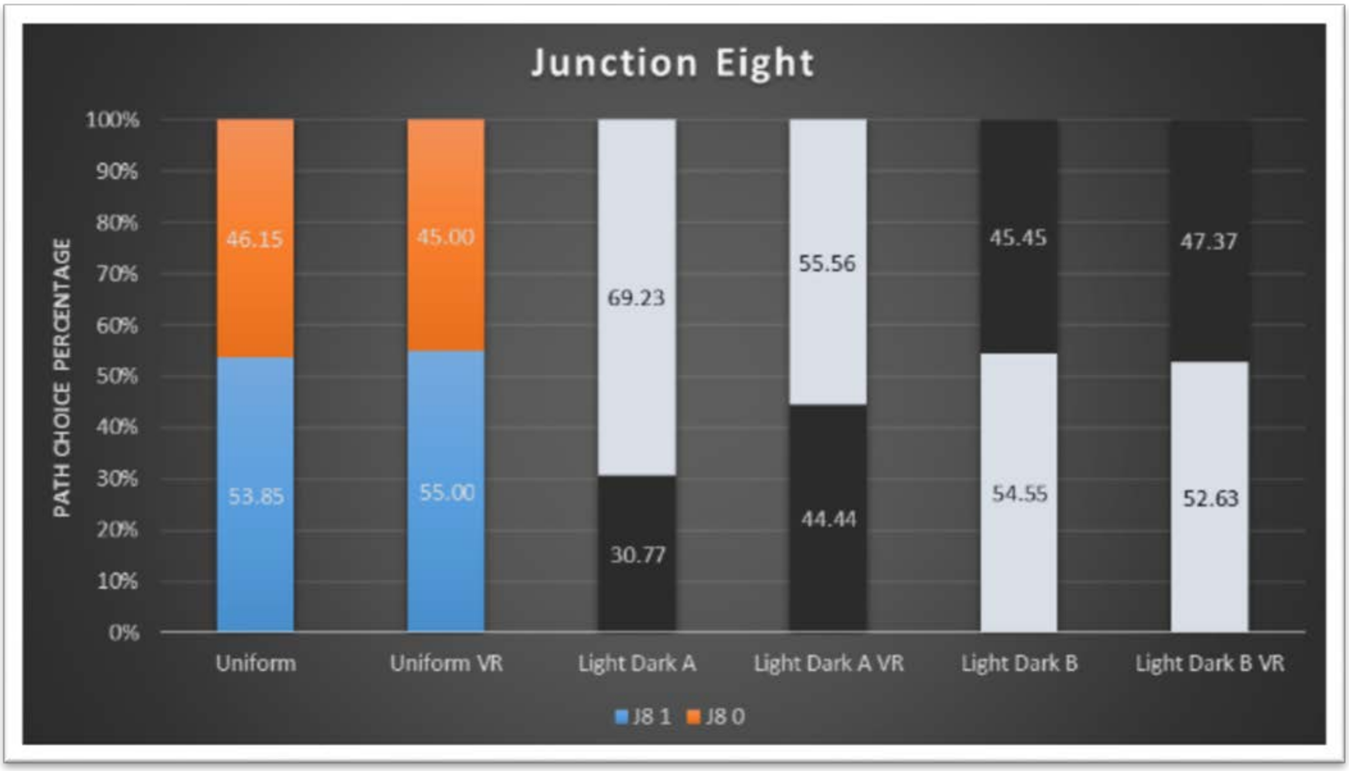


***Figure 198.*** **A percentage bar graph of the proportions of participants taking each of the routes at junction eight.**

Junction eight [*Figure 198*] shows very similar results between the two test groups in the uniform lighting condition, in both instances, a slightly larger percentage opt to take the path leading to the landmark (SU8_1 & VU8_1). Results when the paths to the landmark are illuminated (SA8_1 & VA8_1) do increase slightly, but it was apparent that the lighting cue did not override the architectural path choice. There was a 14% increase in those opting for the lit route between the standard and VR versions (SB8_1 & VB8_1); this again was a demonstration that a strong lighting contrast has a greater effect than a smaller lighting contrast.

### 10.6.11 KEY FINDINGS

This study aimed to discover whether navigational choice exhibited within virtual environments were affected by the introduction of lighting and whether (on both a standard monitor and in a virtual reality scenario) the following navigational principles held true in a games context:

- Preference for taking the shortest path
- Preference for maintaining a linear path
- Preference for maintaining linear path despite gradient
- Preference for path with the farthest line of sight
- Path with more turns perceived to be longer than an equal length path with fewer turns
- Longest leg first preferred to shortest leg initially
- Preference for curved paths over sharp angled turns
- Angle of exit routes from a junction relative to the entry

The results of the uniformly lit control version of the apparatus in both on screen and VR variants confirm the findings of prior research and the associated design principles(Dalton, 2003; Montello, 1991, 1997; Sadalla et al., 1980). Notably, the principles held at very similar values across both variants and cue competition resulted in the preferences detailed in previous literature being reflected in choices made by participants in these studies.

In this study, the junction landmarks did not act as a distinct navigational cue. Where this was the only distinction between paths at junction eight, 53.85% (SU8_1) and 55% (VU8_1) of participants opted for the variant with the landmark and the only other uniformly lit junction to have a split result was the deliberately ambiguous junction six. It is possible that the participants did not associate the landmarks with a specific path, or that the frequency of similar landmarks made them seem unimportant.

#### 10.6.11.1 COMPARISON OF MEANS

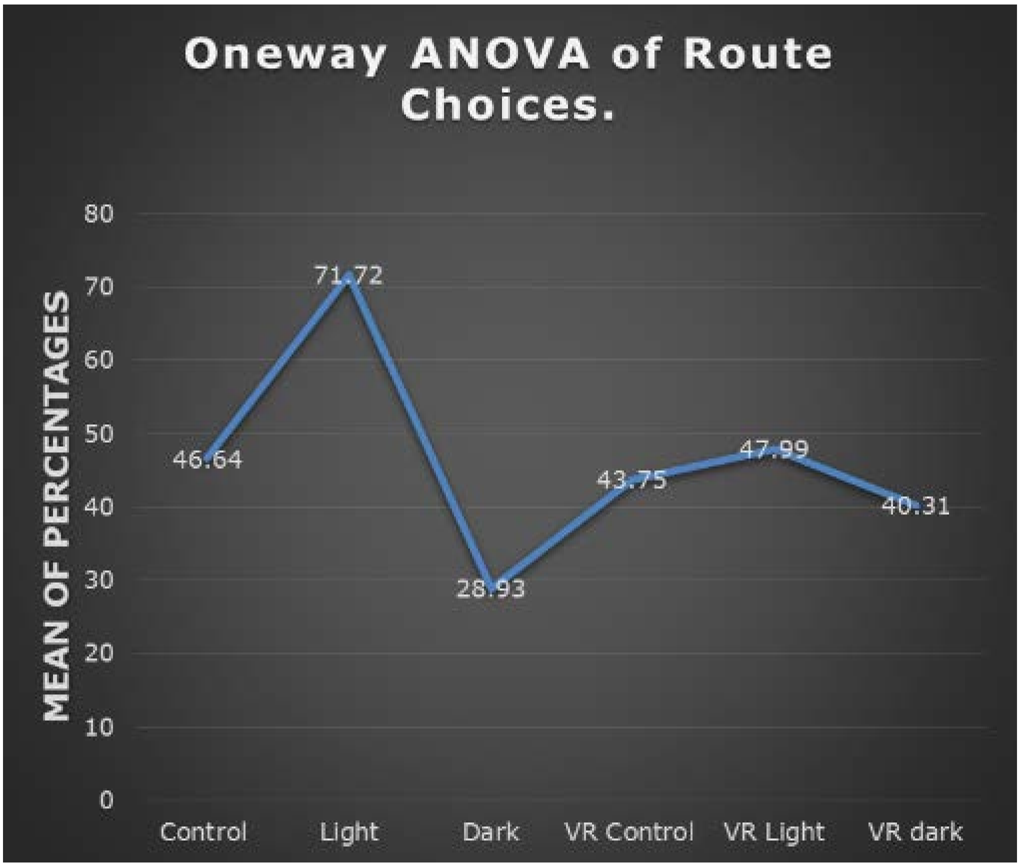


***Figure 199.*** **A comparison of the influence of route lighting across all variants.**

A Bonferroni multiple comparison analysis of the combined means of all of the lighting variants demonstrated a significant main effect for lighting in the wider contrast standard screen variant of the apparatus. $F(2, 23) = 10.665$, $p=0.001$. No significant main effect for lighting was detected when the contrast between lighting states was halved in the virtual reality version of the apparatus, $F(2, 23) = 0.342$ $p=0.715$. A significant main effect was therefore found between the two main groups $F(5, 47) = 4.936$, $p=0.001$. *Figure 199*.

It was evident in the study that architectural cues within a video games context continue to work in the same manner as their real world counterparts. The key finding of this study was that the introduction of lighting does make significant differences to the navigational decision-making of participants and the greater the contrast in those differences the more pronounced the effect.

Humans have evolved to avoid dark spaces, and this natural affinity for lit areas has a clear influence on path choices in virtual worlds. This remains true, whether they are on a monitor screen or presented via a virtual reality headset. The design principles stemming from space syntax along with strong lighting cues can significantly influence player navigation. This study confirms that lighting cues at a distance in contrast to a darker foreground do indeed, effectively 'pull' the participant along that path as suggested by the designers of Left 4 Dead (Valve Corporation, 2008) (Lundeen, 2009). These results demonstrate for the first time under controlled conditions that both architecture and lighting work in isolation to direct player navigation. They also demonstrate that when used in reinforcing combination architecture and lighting can influence up to 90% of participants to opt for one route over another.

These results provide significant data that inform novel design principles for the thresholds and design of illumination of an environment with regards to reinforcing navigational cues derived from its architectural layout.

# 11 CHAPTER ELEVEN:

# WAYFINDING IN A LARGE OPEN WORLD ENVIRONMENT WITH DIFFERING LIGHTING CUES

## 11.1 INTRODUCTION

The design of large-scale virtual wayfinding environments requires an understanding of the way in which the spatial nature of an environment is processed and the strategies that are employed in wayfinding tasks. The objective of this study was to investigate if the addition of dynamic lighting can act as a guidance cue and positively affect player navigation.

Open world environments in video games require some element of guidance; otherwise, the player would wander aimlessly with no goals in mind. Even when primed with a goal, the cues required such as landmarks and topological features must be designed in a clear manner if they are to be of use to the player.

Wayfinding strategies fall into three key categories: (Darken & Sibert, 1996)

1. Naïve Search: A pursuit of a specified goal but without any spatial knowledge of where the goal is located.
2. Primed Search: A task such as finding a known location using available data.
3. Exploration: Where no goal is specified, and an environment is explored in an open manner.

These categories are mutually exclusive but can form sequences of search, for instance, one may know the broad area where a goal may be located, and use primed search wayfinding strategies to locate that main area, followed by a naïve search in order to locate a specific goal. Initial exploration may lead to a narrative element providing a primed search.

#### 11.1.1 ACQUISITION OF SPATIAL INFORMATION

In order to successfully navigate an environment, spatial knowledge needs to be acquired; this knowledge can come in two forms:

- Primary knowledge: Via direct exposure to and exploration of an environment
- Secondary knowledge: Via external information sources such as a map

These two methods of knowledge acquisition are key to the development of a cognitive map (Tolman, 1948). Cognitive maps themselves are an amalgamation of three distinct forms of environmental knowledge; landmark knowledge, route knowledge and survey knowledge (Siegel & White, 1975).

- Landmark knowledge is constructed from information about the specific features of a location
- Route knowledge is information about specific pathways that join two locations.
- Survey knowledge is usually regarded as two-dimensional relational knowledge based upon distances between known landmarks. It is considered to be stored as spatial relationships and distance estimations, being similar to a traditional map.

In practice in the real world, people use maps to navigate using one of two distinct strategies, either a route strategy or an orientation strategy (Lawton, 1994). These strategies both require a cross-referencing of survey knowledge with either the route knowledge in order to choose an appropriate path or location knowledge which may come in the form of triangulation based upon known landmarks.

## 11.2 HYPOTHESIS

It was predicted that in a virtual wayfinding exercise in a virtual open world environment would utilise real-world navigational techniques (Darken & Banker, 1998; Lynch, 1960) to solve a series of connected primed and naïve searches and that the addition of dynamic lighting as an additional navigational cue would affect the participant's navigational choices.

The following hypotheses were proposed:

1. Participants would utilise maps, markers, distal cues and paths in a virtual environment as they would in the real world (Dalton, 2003).
2. There would be navigation, route selection and solve differences due to the introduction of prominent lighting cues.
3. Prominent lighting cues will act as a more compelling method of guidance than a subtle path texture.
4. Participants would get lost less frequently, where dynamic lighting cues were provided.

## 11.3 METHOD

Building upon and drawing precepts from Lynch (1960) and Arthur (P. Arthur & Passini, 1992), Foltz (1998) suggested a set of design principles for the construction of successfully navigable virtual environments. Navigable, in this context meaning that information presented about the virtual space allows for the navigator to move from the point of origin to destination in conformity with Downs (1973) four step wayfinding theory:

5. Orientation: The process of determining the current specific location by the use of proximal objects, structures and their relationship to the target location.
6. Route Decision: Formulating a route that will lead to the desired destination.
7. Route Monitoring: Continual analysis of chosen route in order to confirm that the bearing is still correct.
8. Destination Recognition: Confirming the identification of the correct destination or that the destination is close by.

Foltz (1998) suggests eight design principles for effective urban wayfinding:

9. Create an identity at each location, different from all others.
10. Use landmarks to provide orientation cues and memorable locations.
11. Create well-structured paths.
12. Create regions of differing visual character.
13. Don't give the user too many choices in navigation.
14. Use survey views (give navigators a vista or map).
15. Provide signs at decision points to help wayfinding decisions.
16. Use sight lines to show what's ahead.

These principles were formulated with the construction of architectural or similar urban areas in mind, as natural or wild spaces are by definition not constructed environments, no such design principles exist for the development of a more distributed, rural or wilderness environments.

Therefore, this list was amended and extended to accommodate more relevant features and principles for pseudo-natural virtual environments.

17. Provide boundaries, that form, natural walls, these may be high cliffs or simply impenetrable obstructions such as dense undergrowth an extension of this would be to use water as a boundary.
18. Use large scale distal cues (Weenies).

Based upon the virtual orienteering exercise employed by Darken et al. (1998) this study presented a virtual orienteering exercise employing navigational cues and requiring the use of wayfinding strategies, the results demonstrating an assimilation of natural environmental cues and terrain familiarisation.

## 11.4 PARTICIPANTS

83 participants volunteered to take part in these studies, 82 male, and 1 female. Of these 5 male participants withdrew from the study before completing the exercise.

Of the participants completing the study:

41 were allocated to the uniformly lit condition: 40 male, 1 female aged between 18 and 37 (mean 22.7)

37 were assigned to the dynamically lit condition: 37 males aged between 18 and 29 (mean 21.8)

All reported having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants were recruited primarily from students and staff in the School of Computing and Engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

Participants were asked to follow the clues they found in the environment and to note down the four numbers of the completion code that were located at specific landmark points in the environment and note the icon that was displayed at the completion point.

## 11.5 MATERIALS AND APPARATUS

In order to build a map that could test the hypotheses listed above, a virtual island environment was built in Unreal Development Kit (UDK) v.2012/07 taking into account the expanded design principles proposed by Foltz and Lynch (1998; 1960). *Figure 200*.


***Figure 200.*** **Survey map of waypoints [named] and objectives [numbered]**

### 11.5.1 CREATE AN IDENTITY AT EACH LOCATION, DIFFERENT FROM ALL OTHERS

The island was separated into regions such as marshlands, deciduous and evergreen woodlands, beaches, coves, and open grassland. Each major landmark was a unique structure. *Figure 201*.


***Figure 201.*** **Elevated view of the distinct regions differentiated by ground material and flora.**

### 11.5.2 USE LANDMARKS TO PROVIDE ORIENTATION CUES AND MEMORABLE LOCATIONS

Landmarks of varying scales were provided in the form of unique built structures such as the Outlook Bunker. *Figure 202*.

***Figure 202.*** **Unique and distinct architectural structures sit at each waypoint: The Outlook Bunker.**

### 11.5.3 CREATE WELL-STRUCTURED PATHS

Each architectural structure on the map had a naturalistic worn path leading to it; these paths contrast as either lighter or darker than the surrounding grass. *Figure 203*, *Figure 204*. They are not straight and meander through the trees; therefore, if the participant followed the path, this should be clear from the heat map data.

***Figure 203*. Textural differences delineate clear paths through the trees.**

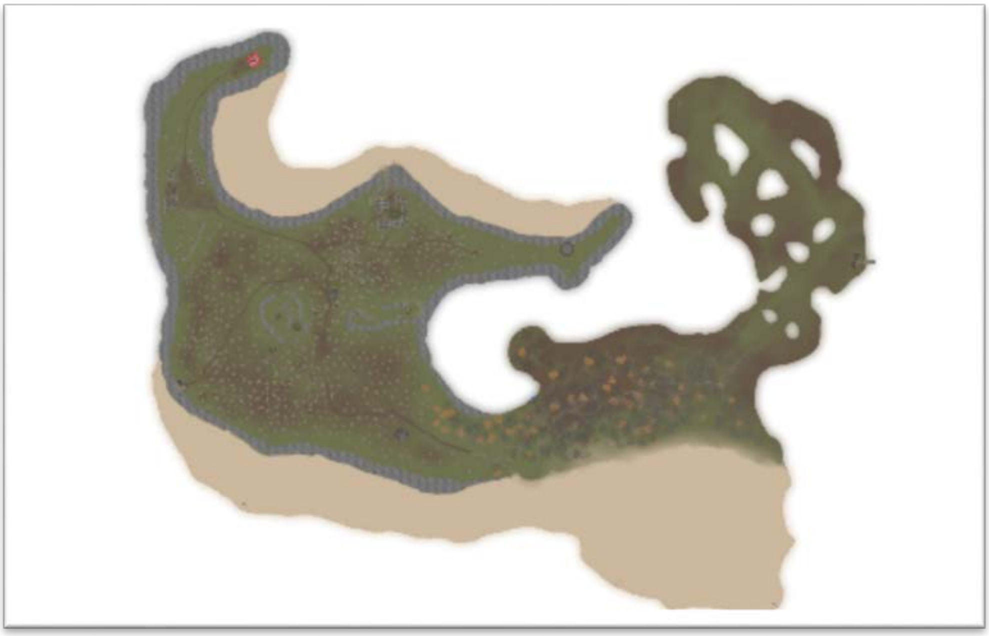

***Figure 204.* Pathways link each waypoint.**

### 11.5.4 CREATE REGIONS OF DIFFERING VISUAL CHARACTER

The use of ground textures such as sand, [*Figure 205*] grass or changes in tree type were used to define distinct regions. The manner in which objects were distributed also adds to the distinctiveness of each area, beaches having no plant life, the Marshlands having a sparse distribution of trees and the Autumn Woods being particularly densely populated with deciduous trees.

***Figure 205.*** **The beach surrounded by cliffs, a distinct region of the island environment.**

### 11.5.5 DON'T GIVE THE USER TOO MANY CHOICES IN NAVIGATION

Areas of water, narrowing of the land and changes in elevation aim to restrict and redirect the player's motion. Pathways and promontories lead to specific locations that lie at the outer edges of the navigable space. Elsewhere, wire fences delineate specific the boundaries of specific locations. *Figure 206*.

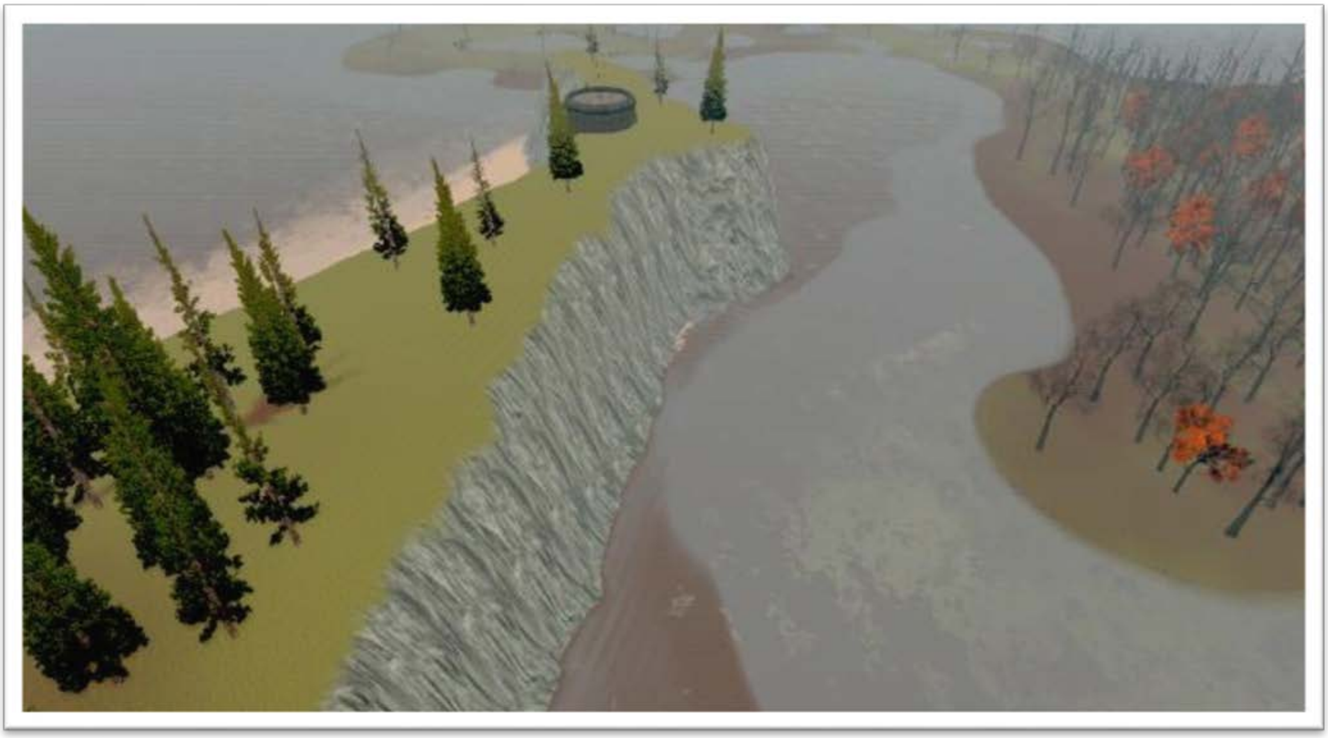

***Figure 206.*** **Water and cliff faces form natural boundaries.**

## 11.5.6 USE SURVEY VIEWS (GIVE NAVIGATORS A VISTA OR MAP)

As this study was concerned with navigation without the use of auxiliary navigational cues and aims to determine the effect of intrinsic cues, a portable map was not supplied. However, static survey view maps were located at each waypoint. *Figure 207*.


***Figure 207.*** **Maps of the island are located at each of the waypoint buildings.**

### 11.5.7 PROVIDE SIGNS AT DECISION POINTS TO HELP WAYFINDING DECISIONS

Colour coded path marker posts designate the path to individual structures that in turn have an allocated colour that was displayed on the static maps. Path markers were positioned either side of junctions to indicate the appropriate path for the player to take. *Figure 208*.

*Figure 208.* **Colour coded marker posts are distributed at key points along each path.**

### 11.5.8 USE SIGHT LINES TO SHOW WHAT IS AHEAD

The environment provides many long sight lines, often leading to distinct landmarks. For instance, gaps in trees or exits from buildings clearly frame upcoming objectives. In the lit condition, buildings are clearly illuminated. *Figure 209*.

***Figure 209.*** **The Outlook Bunker, clearly visible at the end of the path and through gaps in the trees.**

### 11.5.9 PROVIDE BOUNDARIES THAT FORM NATURAL WALLS

The island had natural boundaries in the form of water and cliff edges [*Figure 210*] with architectural elements such as fences creating boundaries to architectural structures. These boundaries created both natural barriers and guides to navigation either by forming path edges or by being easily referenced from the overhead maps provided at each waypoint.

***Figure 210.*** **An example of how the cliff faces provide a natural boundary.**

### 11.5.10 USE LARGE SCALE DISTAL CUES (WEENIES)

A large distal cues or weenie was provided in the form of a large communications mast with a flashing red light that was clearly visible from most points on the map unless obscured by trees. It was located at the most North-Westerly point on the map, potentially allowing the players to orient themselves from any other location on the island. *Figure 211*.

***Figure 211.*** **The Radio Tower was visible from most points on the island.**

### 11.5.11 GUIDING WITH LIGHT

The lit variant of the environment reduced overall scene lighting to twilight levels and introduced dynamic lighting that was activated when the player approached a zone and was removed once they have passed through. The lighting specifically illuminated the individual waypoints and objectives and adds subtle lighting to paths. *Figure 212*.

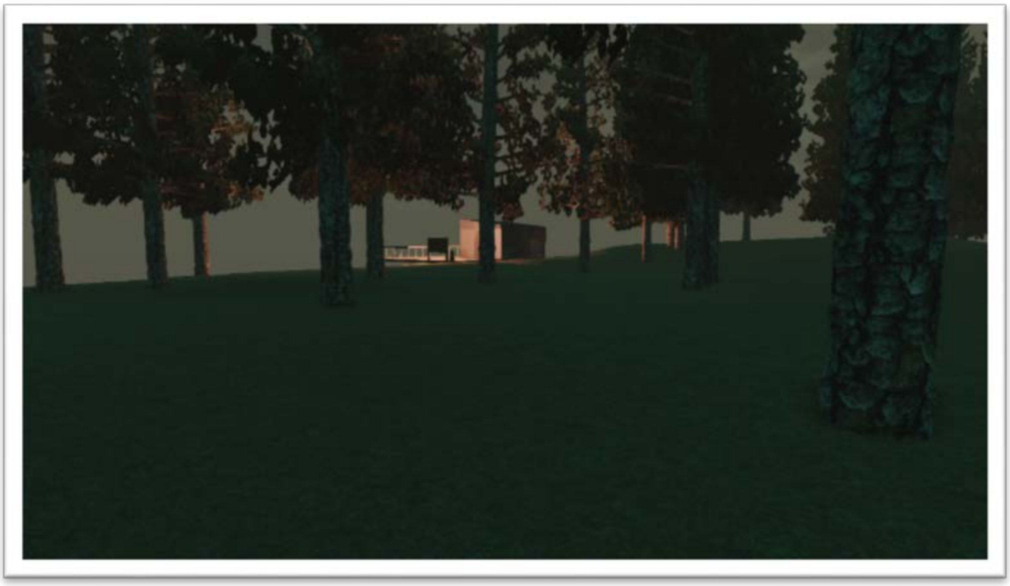

***Figure 212.* The use of lighting and contrast to guide the player towards a waypoint. The Cliff Edge Outpost illuminated [above] and without additional lighting [below]**

The use of lighting in some areas followed the textural paths that were used in the uniformly lit variant. *Figure 213*. However, prior to the Cliff Edge Outpost, it specifically deviated from that path in order to analyse route preferences.

***Figure 213.*** **Clear sightlines allow the player to either follow the path [above] or allow the illuminated building to be a focal point [below]**

### 11.5.12 GOALS

Each Naïve search required the finding of a specific object in the environment [*Figure 214*], at these locations; a number was clearly marked on the goal object.

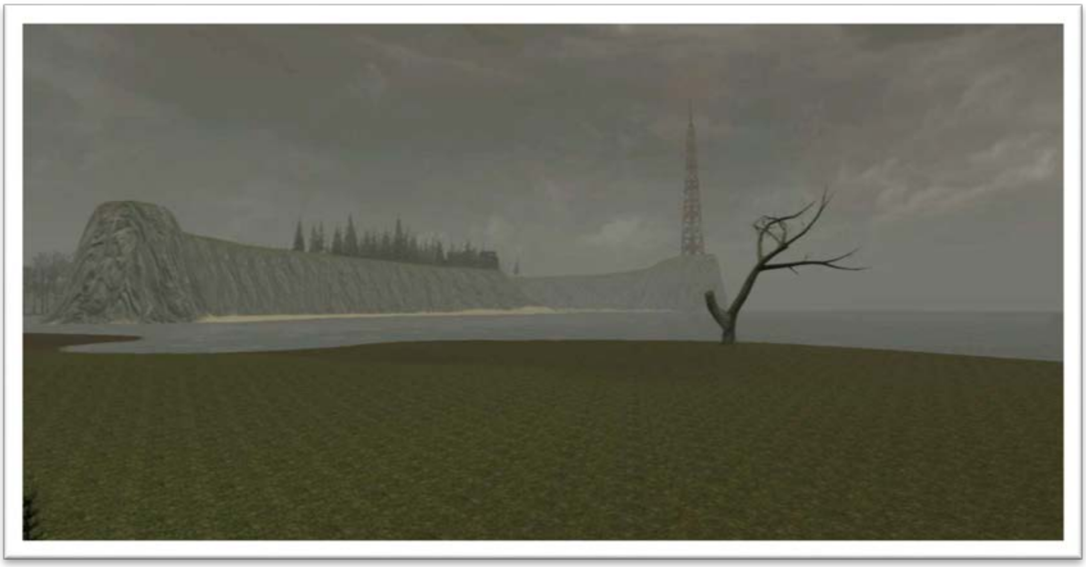

***Figure 214.*** **The objectives are unique objects such as the Twisted Tree [above], and the Crates [below] each have a number painted on them.**

## 11.6 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4th generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch wide-screen monitor. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

Participants were each provided with a pen and note sheet and asked to navigate using only information provided in the environment

The starting location was directly in front of a fixed location map, four crates and a signboard.

The board read, "Follow the clues to discover the four-digit number. The first step to success can be found at the Marshlands Fishing Spot." *Figure 215*.


***Figure 215.* The starting point and each subsequent waypoint have a static map and written instructions as to where to find the upcoming goals.**

Participants were able to draw close enough to the map to read it clearly, as can be seen in the image above, *[Figure 215]* the key structures are labelled both with text and a coloured marker that corresponds to the colour of the path marker posts. The participant would then need to complete 9 tasks in sequence in order to complete the exercise and provide the required number sequence: *Figure 216*.

1. Primed Search: Locate the Marshlands Fishing Spot
2. Naïve Search: Locate the first number at the Twisted Tree
3. Primed Search: Locate the Cliff Edge Outpost in The Pines
4. Naïve Search: Locate the second number on the Large Rock on the way to the Shoreside Outpost
5. Primed search: Locate the Shoreside Outpost
6. Naïve Search: Locate the third number on the Wooden Crate in the North Bay
7. Primed Search: Locate the Overlook Bunker
8. Primed Search: Locate the fourth number on the Large Water Tank at the Pumping Station
9. Primed Search: Locate the Radio Tower

Once the participants had successfully navigated to the Radio Tower, they were asked to note down the four-digit code and the symbol located at the Radio Tower.


***Figure 216*. The island map, showing the colour coded locations of waypoints and the numbered locations of the items.**

## 11.7 RESULTS

### 11.7.1 UNIFORMLY LIT VARIANT

The combined heatmaps from all participants in the uniformly lit variant show that three participants took routes that did not conform to the instructions provided on the waypoint maps. *Figure 217*. The heatmap data demonstrates that some participants did not follow the instructions provided at waypoints, lost their bearings or in other ways failed to follow the set paths. However, the majority of participants were successful in navigating and followed both the instructions and set paths accurately enough to aggregate on the combined heatmap resulting in red paths on the map. In other cases, there was tight packing of individual paths if not direct overlap.

In total, 38 (92.68%) of the 41 participants completed the task of obtaining all four numbers in the code, 37 of these 38 visited all waypoints and clue locations, the remaining participant did not visit the Cliff Edge Outpost and subsequently got the number order wrong.

Six participants ventured down the beach when attempting to reach the Cliff Edge Outpost five of these realised the mistake and doubled back to the correct path, one participant continued and walked around the perimeter of the island.

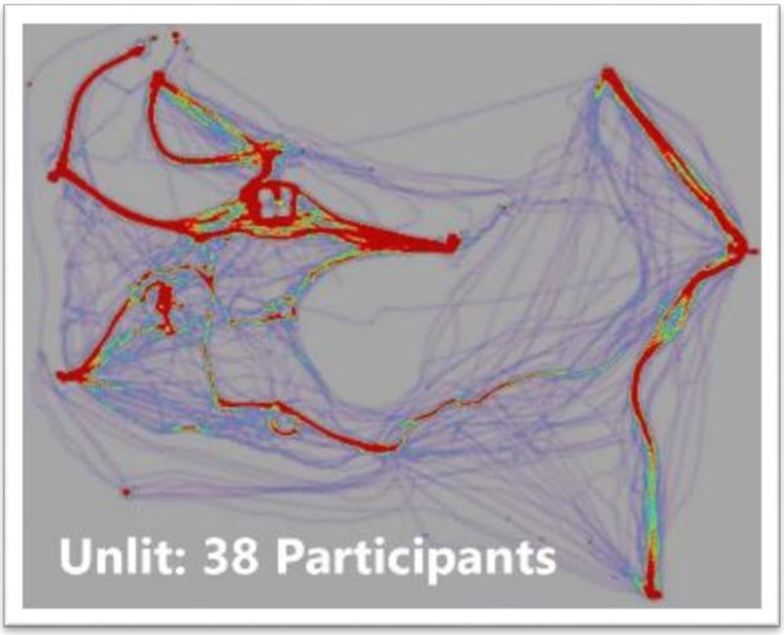


*Figure 217*. A combined heatmap of all participants in the uniformly lit condition.

Removal of the participants who took the beach path produced the following heatmap *[Figure 218]*; which while showing some deviations from the main routes, has clear, strong paths highlighted in red demonstrating that the participants broadly adhered to routes that were delineated by variance in texture.

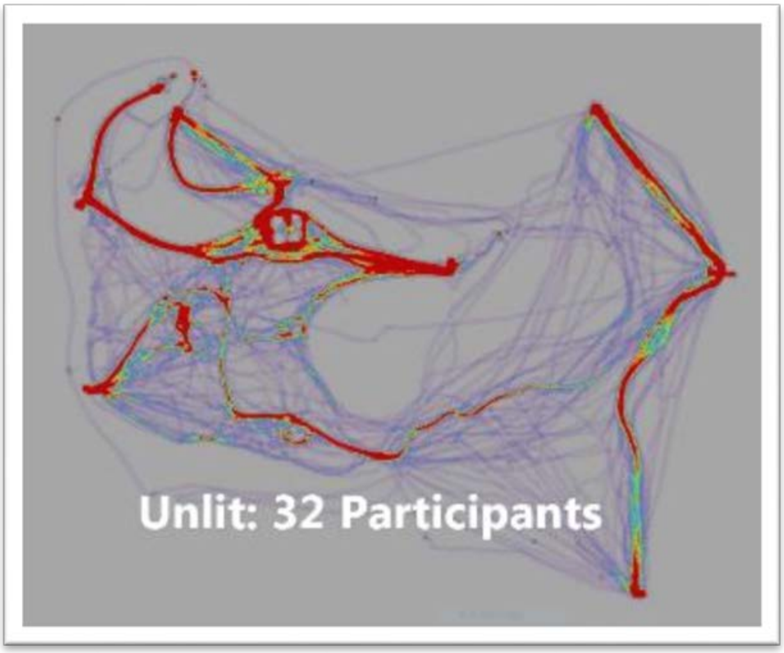


*Figure 218.* A combined heatmap of all participants in the uniformly lit condition with those that returned to the southern beach removed.

### 11.7.2 WAYFINDING FROM POINT TO POINT

#### *11.7.2.1 START TO WAYPOINT 1 (PRIMED SEARCH)*

From the start point, the 41 participants were given a primed search task to head to Waypoint 1 at the Marshlands Fishing Spot; this initial goal required the participants to use distal landmarks and variation in ground type to orient themselves:

- 33 (80.48%) of the participants located themselves on the map, oriented themselves and headed directly towards Waypoint 1.
- 3 (7.32%) of the participants initially headed north-west until they hit the edge of the Autumn woods and then proceeded in the correct direction to Waypoint 1.
- 1 (2.44%) participant headed to the Autumn Woods, doubled back to the sign and then oriented them self and headed directly to Waypoint 1.
- 4 (9.76%) participants either did not read the sign or could not find their bearings and became lost (3 of these 4 eventually located the waypoint out of sequence).

#### *11.7.2.2 WAYPOINT 1 TO OBJECTIVE 1 (NAÏVE SEARCH)*

Waypoint 1 at the Marshlands Fishing Ground gave the player a naïve search task to locate the Twisted Tree at the northern most point of The Marshlands. The sign at his location also gave the participants the next primed search to complete afterwards stating that the 'Next clue is at Cliff Edge Outpost in The Pines'

40 (97.56%) participants located the and subsequently set off from the Marshlands Fishing Ground all made it to the Twisted Tree, of these:

- 39 (95.12%) navigated directly to the twisted tree.
- 1 (2.44%) initially headed south before doubling back to the twisted tree.

#### 11.7.2.3 OBJECTIVE 1 TO WAYPOINT 2 (PRIMED SEARCH)

20 (48.78%) of the 40 (97.56%) participants that located the Twisted Tree returned to the instructions located at a previously visited location, 18 (43.90%) returned to the Marshlands Fishing Spot and two to the start point on the South Beach. The participants next destination was the Cliff Edge Outpost located at the South West of the map, but above the beach line. Of the 40 (97.56%) participants that set off:

- 28 (68.29%) participants successfully navigated directly to the Cliff Edge outpost. However, 6 (14.63%) of this number did head on to the beach and had to double back to get above the cliff line into The Pines.
- 10 (24.39%) participants became lost or disoriented and visited a different location or locations before eventually locating the Cliff Edge Outpost.
- 2 (4.88%) participants failed to find waypoint 2.

#### 11.7.2.4 WAYPOINT 2 TO OBJECTIVE 2 (NAÏVE SEARCH)

Two (4.88%) participants failed to find the Cliff Edge Outpost but did visit the Large Rock. The remaining 39 (95.12%) participants were instructed to locate the Large Rock where they could find the next number clue and then continue straight until they reached the Shoreside Outpost where they would find the next clue. Of these participants:

- 31 (75.61%) located the Large Rock by following a broadly linear route.
- 3 (7.32%) took a minor detour but re-oriented themselves and discovered the Large rock.
- 2 (4.88%) became disoriented and visited a different location prior to eventually discovering the Large Rock.
- 3 (7.32%) had visited the Large Rock prior to visiting the Cliff Edge Outpost.

#### 11.7.2.5 OBJECTIVE 2 TO WAYPOINT 3 (PRIMED SEARCH)

Only 33 (80.49%) of the participants set off from the Large Rock with the Shoreside Outpost as their goal. One (2.44%) participant failed to visit the Shoreside Outpost. Of the 40 (97.56%) that visited:

- 13 (31.71%) navigated a direct path with little deviation.
- 4 (9.76%) veered towards the north-west before orienting and following a direct path.
- 6 (14.63%) veered off to the northeast and visited the Overlook Bunker first.
- 6 (14.63%) found the Shoreside Outpost prior to finding the Large Rock.
- 5 (12.20%) veered to northeast and visited the Pumping Station prior to visiting the Shoreside Outpost.
- 3 (7.32%) headed west at first and reoriented after becoming lost.
- 1 (2.44%) located the outpost out of sequence and did not visit the Large Rock.

#### 11.7.2.6 WAYPOINT 3 TO OBJECTIVE 3 (NAÏVE SEARCH)

Participants visiting the Shoreside Outpost were instructed to locate the number clue on a Crate in the North Bay and then to move on to the next clue located at the Overlook Bunker. Only one (2.44%) participant failed to find the Crate and its associated number. Of the 40 (97.56%) that did find it:

- 35 (85.37%) successfully followed a direct path to the Crate.
- 3 (7.32%) visited the Overlook Bunker first and took a short cut over the cliff edge.
- 1 (2.44%) went directly from the Large rock by taking a short cut over the cliff edge.
- 1 (2.44%) visited the Pumping Station and then took a shortcut over the cliff edge.

#### 11.7.2.7 OBJECTIVE 3 TO WAYPOINT 4 (PRIMED SEARCH)

Two (4.88%) participants failed to visit the Overlook Bunker. Of the 39 (95.12%) that did locate it:

- 26 (63.41%) took a route directly from the crate, following the instruction provided at the Shoreside Outpost.
- 13 (31.71%) located the Overlook Bunker prior to visiting the Crate.

#### 11.7.2.8 WAYPOINT 4 TO OBJECTIVE 4 / WAYPOINT 5 (PRIMED SEARCH)

Of the 41 participants two (4.88%) did not visit the Overlook Bunker. Of those that did:

- 27 (65.85%) participants navigated in linear fashion towards the Pumping Station.
- 10 (24.39%) set off from the Overlook Bunker visited the Crate or Shoreside Outpost and then navigated to the Pumping Station.
- 1 (2.44%) became lost before eventually reorienting and locating the Pumping Station.
- 1 (2.44%) walked past the Pumping Station and straight on to the Radio Tower.

#### 11.7.2.9 WAYPOINT 5 TO FINAL WAYPOINT (PRIMED SEARCH)

The final goal was visited by 39 (95.12%) of the 41 participants. Of these:

- 37 (90.24%) navigated directly towards the Radio Tower.
- 1 (2.44%) walked past the Pumping Station and straight on to the Radio Tower.
- 1 (2.44%) participant managed to scale the cliff from the beach where the Crate was located and did not visit the Pumping Station.

### 11.7.3 DYNAMICALLY LIT VARIANT

The combined heatmaps from all participants in the dynamically lit variant show that seven participants took routes that did not conform to the instructions provided on the waypoint maps. However, the heatmap data demonstrates that fewer participants did not follow the instructions provided at waypoints when compared to the uniformly lit group. *Figure 219*. The majority of participants were successful in navigating and followed both the instructions and set paths and lighting guidance very accurately, these combined heatmaps resulting in closely packed red paths on the map. The blues paths represent individual trails and

All 37 (100%) participants completed the task of obtaining all four numbers in the code. However, on obtaining the code in the correct order, one (2.70%) did not visit the Radio Tower and chose to end the session once they had completed the number sequence.

Six participants ventured down the beach when attempting to reach the Cliff Edge Outpost before realising the mistake and doubling back.

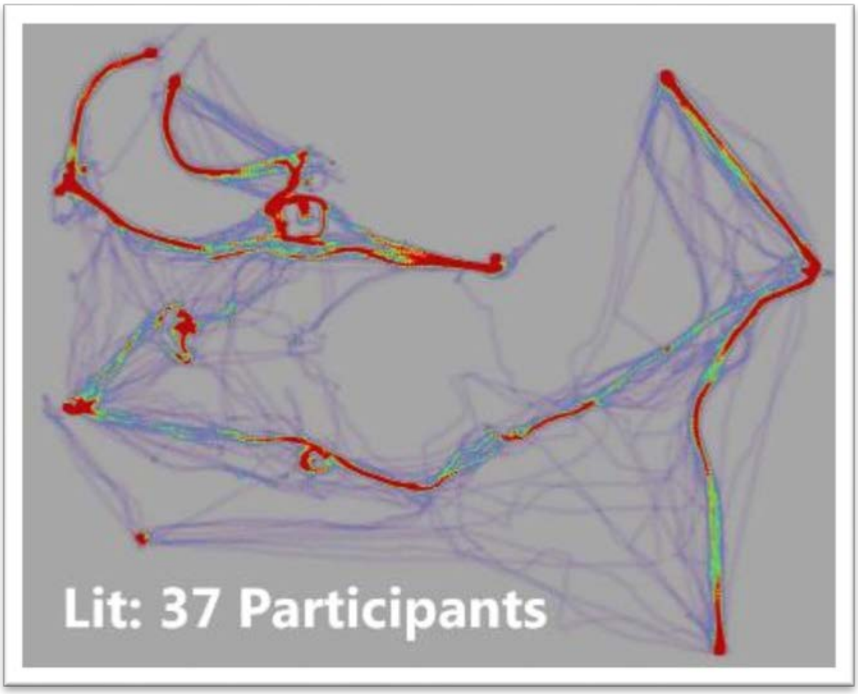


***Figure 219.*** **A combined heatmap of all participants in the dynamically lit condition.**

Removal of the six participants who took the beach path produced the following heatmap, which clearly demonstrates that the participants have stayed very close to the suggested optimal paths provided by the dynamic lighting in conjunction with the embedded paths. *Figure 220*.

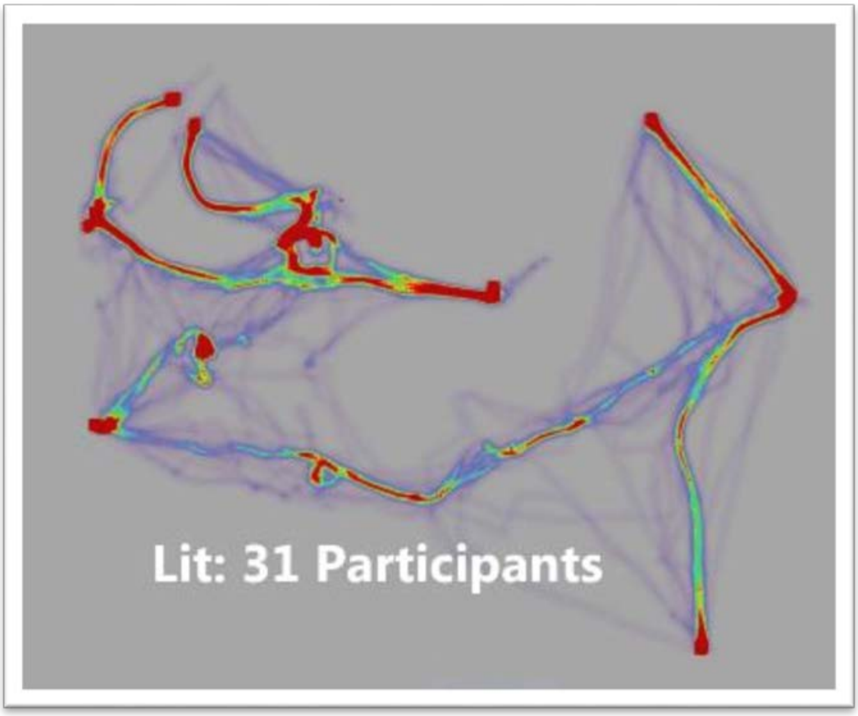


***Figure 220.*** **A combined heatmap of all participants in the dynamically lit condition with those that returned to the southern beach removed.**

### 11.7.4 WAYFINDING FROM POINT TO POINT WITH DYNAMIC LIGHTING GUIDANCE

#### 11.7.4.1 START TO WAYPOINT 1

From the start point, the 37 participants were given a primed search task to head to Waypoint 1 at Marshlands Fishing Spot; this initial goal required the participants to use illuminated distal landmarks and variation in ground type to orient themselves:

- 36 (97.30%) of the participants located themselves on the map, oriented themselves and headed directly towards Waypoint 1.
- 1 (2.70%) participant headed to the Autumn Woods, doubled back to the sign and then oriented them self and headed directly to Waypoint 1.

#### 11.7.4.2 WAYPOINT 1 TO OBJECTIVE 1 (NAÏVE SEARCH)

Waypoint 1 at the Marshlands Fishing Ground gave the player a naïve search task to locate the Twisted Tree at the northern most point of The Marshlands. The sign at this location also gave the participants the next primed search to complete afterwards stating that the 'Next clue is at Cliff Edge Outpost in The Pines'.

All 37 participants successfully navigated to the Marshlands Fishing Ground, and all made it to the Twisted Tree without deviation from the direct route.

#### 11.7.4.3 OBJECTIVE 1 TO WAYPOINT 2 (PRIMED SEARCH)

18 (48.65%) of the 37 participants starting from the Twisted Tree returned to the instructions located at a previously visited location, 13 (35.14%) returned to the Marshlands Fishing Spot and five to the start point on the South Beach. The participants next destination was the Cliff Edge Outpost located at the South West of the map, but above the beach line, of the 37 participants that set off:

- 31 (83.78%) participants successfully navigated directly to the Cliff Edge outpost. However, 6 (16.22%) of this number did head on to the beach and had to double back to get above the cliff line into The Pines.
- 5 (13.50%) participants became lost or disoriented and visited a different location or locations before eventually locating the Cliff Edge Outpost.
- 1 (2.70%) participant failed to find waypoint 2.

#### *11.7.4.4 WAYPOINT 2 TO OBJECTIVE 2 (NAÏVE SEARCH)*

One (2.70%) participant failed to find the Cliff Edge Outpost but did locate the Large Rock. The remaining 35 participants were instructed to locate the Large Rock where they could find the next number clue and then continue straight until they reached the Shoreside Outpost where they would find the next clue. Of these participants:

- 31 (83.78%) located the Large Rock by following a broadly linear route.
- 3 (8.11%) took a minor detour but re-oriented themselves and discovered the Large Rock.
- 1 (2.70%) failed to locate the Large Rock.

#### *11.7.4.5 OBJECTIVE 2 TO WAYPOINT 3 (PRIMED SEARCH)*

All 37 participants visited the Shoreside Outpost. However, three of these did not visit the Large Rock beforehand. Of the 34 (91.89%) that set off from the Large Rock:

- 27 (72.97%) navigated a direct path with little deviation.
- 1 (2.70%) veered towards the north-west before orienting and following a direct path.
- 3 (8.11%) Veered to northeast and visited the Pumping Station prior to visiting the Shoreside Outpost.
- 3 (8.11%) veered off to the northeast and visited the Overlook Bunker first.

#### 11.7.4.6 WAYPOINT 3 TO OBJECTIVE 3 (NAÏVE SEARCH)

Participants visiting the Shoreside Outpost were instructed to locate the number clue on a Crate in the North Bay and then to move on to the next clue located at the Overlook Bunker. One (2.70%) participant visited the Shoreside Outpost and then failed to locate the Crate, and its associated number, the remaining 36 (97.30%) participants all took a direct path to the Crate.

#### 11.7.4.7 OBJECTIVE 3 TO WAYPOINT 4 (PRIMED SEARCH)

Three participants failed to visit the Overlook Bunker. Of the 34 (91.89%) that did locate it:

- 32 (86.49%) took a route directly from the Crate, following the instruction provided at the Shoreside Outpost.
- 2 (5.41%) located the Overlook Bunker prior to visiting the Crate.

#### 11.7.4.8 WAYPOINT 4 TO OBJECTIVE 4 / WAYPOINT 5 (PRIMED SEARCH)

Visitors to the Overlook Bunker were instructed to locate the final number at the Pumping Station, and to then continue on to the Radio Tower. All 37 participants visited the Pumping Station and of these:

- 34 (91.89%) participants navigated in linear fashion towards the Pumping Station from the Outlook Bunker.
- 3 (8.11%) did not visit the Outlook Bunker.

#### 11.7.4.9 WAYPOINT 5 TO FINAL WAYPOINT (PRIMED SEARCH)

Despite all participants visiting the Pumping Station, one participant (10.81%) did not visit the Radio Tower and chose to end the session once they had completed the number sequence. The Radio Tower was visited by the remaining 36 (97.3%) navigated directly with little deviation.

## 11.7.5 COMPARISON OF DATA

The following graphs illustrate the effect that lighting had on navigation. Only where participants have embarked from the correct point and navigated directly to the objectives have they been counted in the Direct Navigation column. Those deviating from the path but not visiting other locations out of sequence are counted in the Indirect Navigation columns, and all other cases are combined into the Failure to Navigate column. Failure to navigate in this context does not mean that the participant failed to visit that location, only that that they failed to visit a given location in the predetermined sequence. *Figure 221*-229.


***Figure 221.*** **A comparison of the primed search navigation results from the start point to waypoint one.**

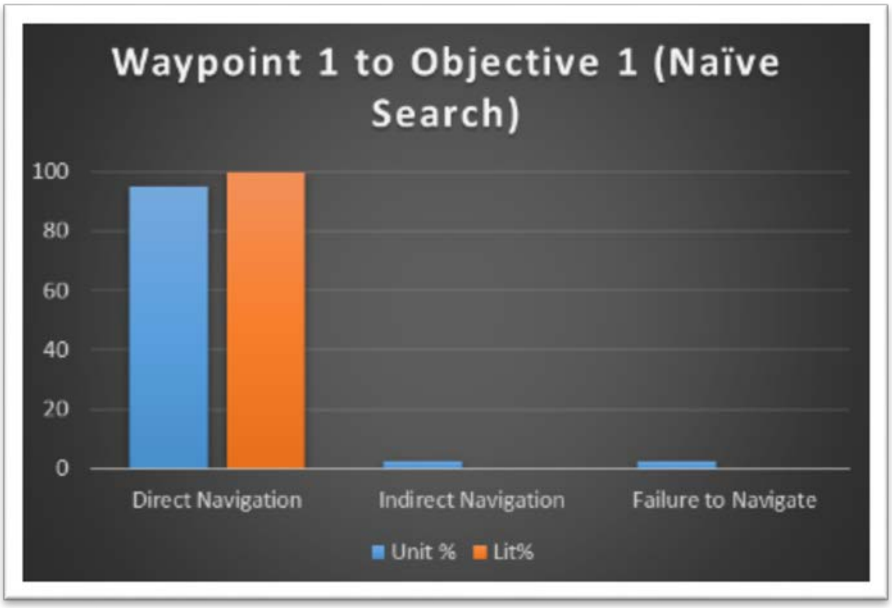


*Figure 222.* A comparison of the naive search navigation results from waypoint one to objective one.

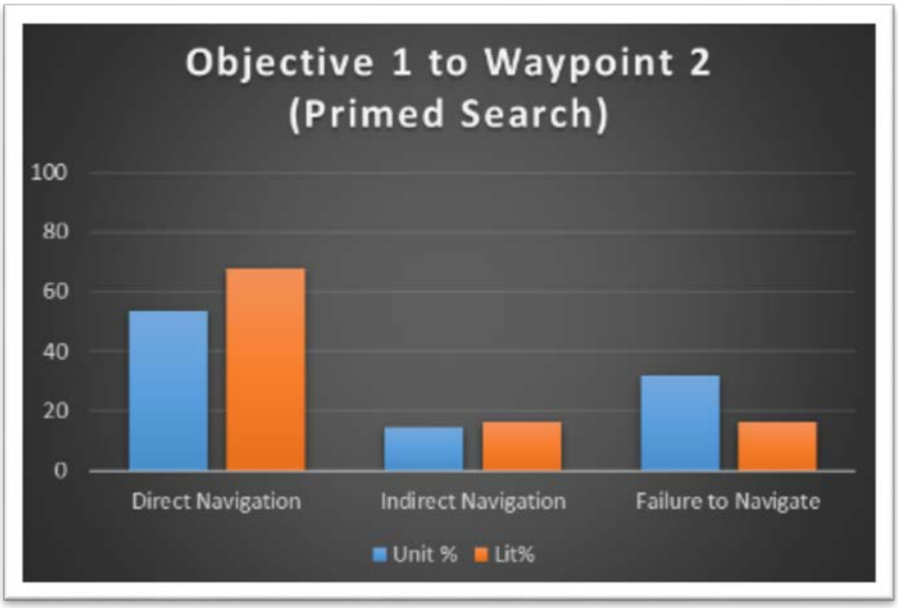


*Figure 223*. A comparison of the primed search navigation results from objective one to waypoint two.

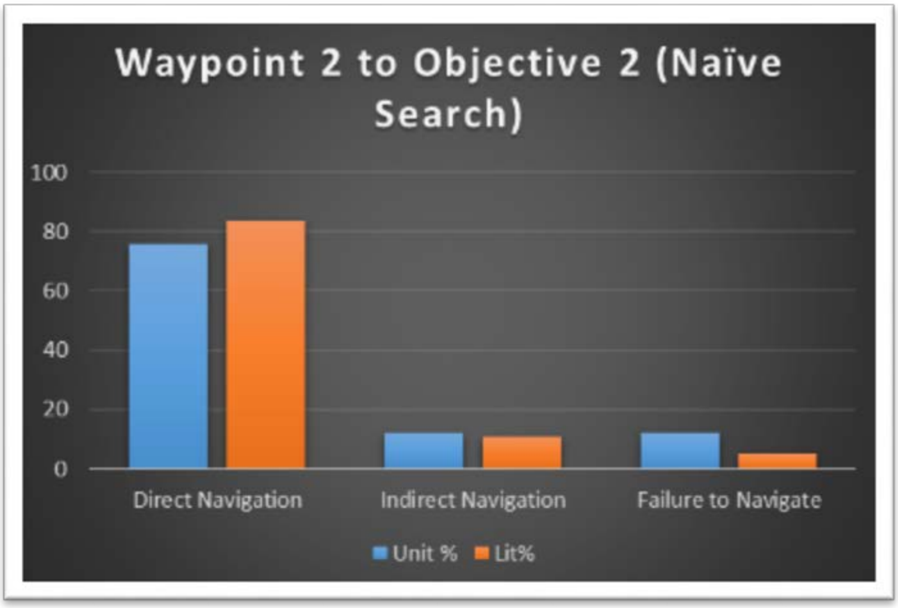


***Figure 224.*** **A comparison of the naive search navigation results from waypoint two to objective two.**

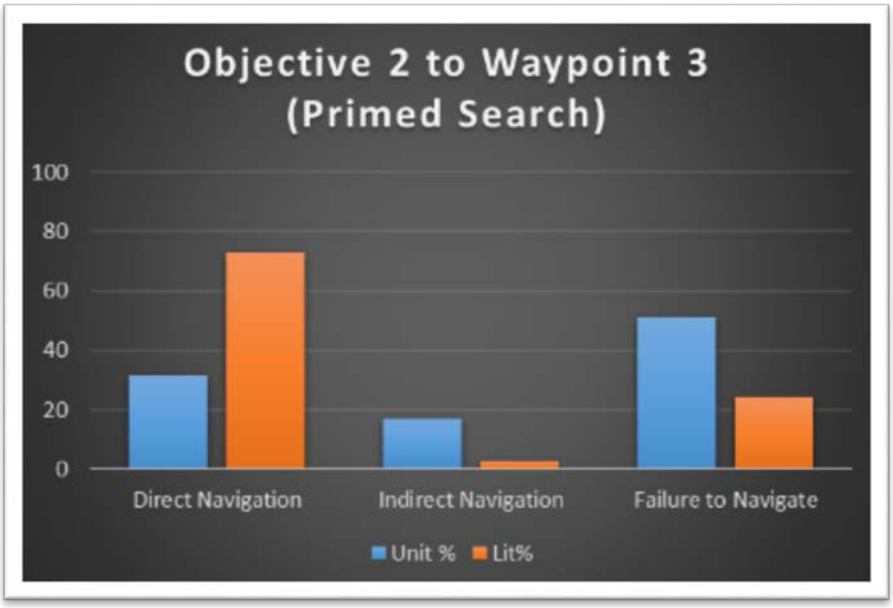


***Figure 225.*** **A comparison of the primed search navigation results from objective two to waypoint three.**

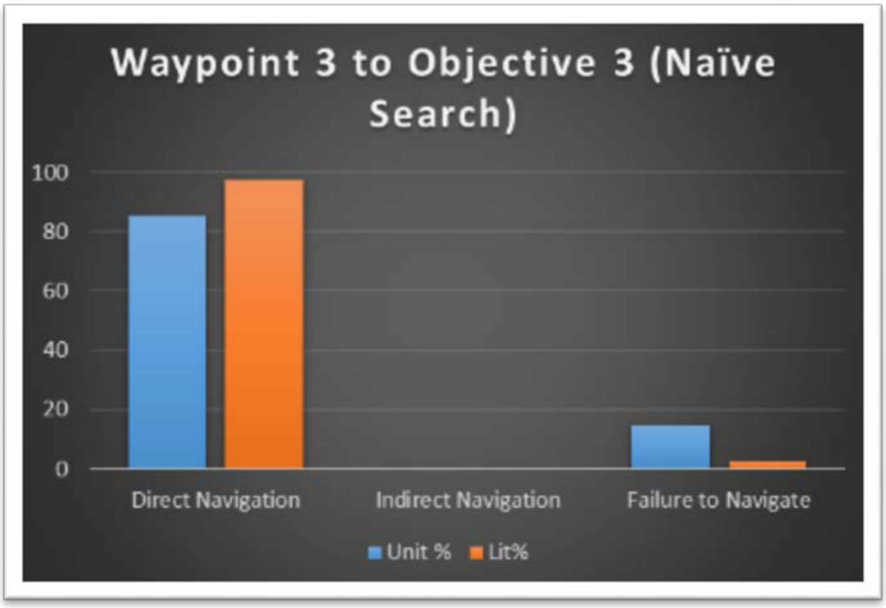


*Figure 226.* A comparison of the naive search navigation results from waypoint three to objective three.

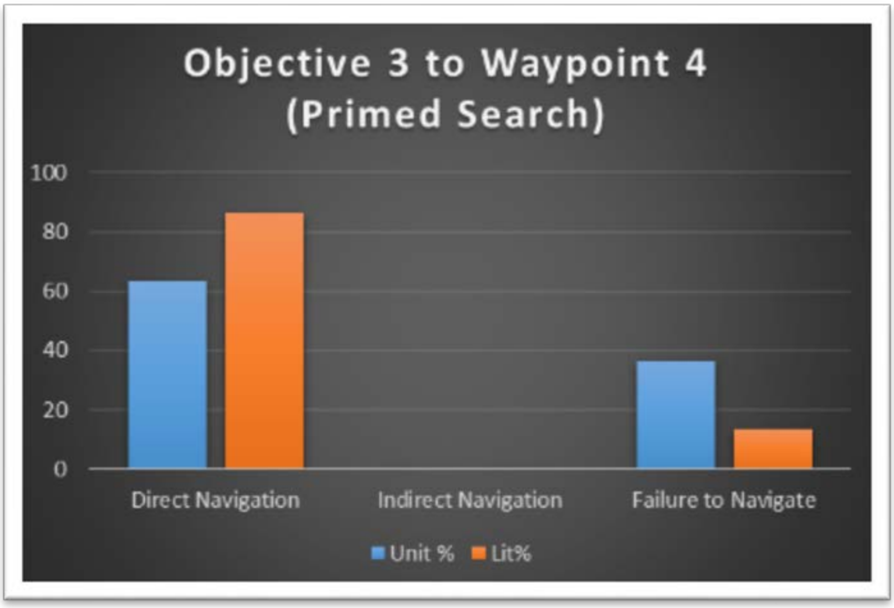


*Figure 227.* A comparison of the primed search navigation results from objective three to waypoint four.

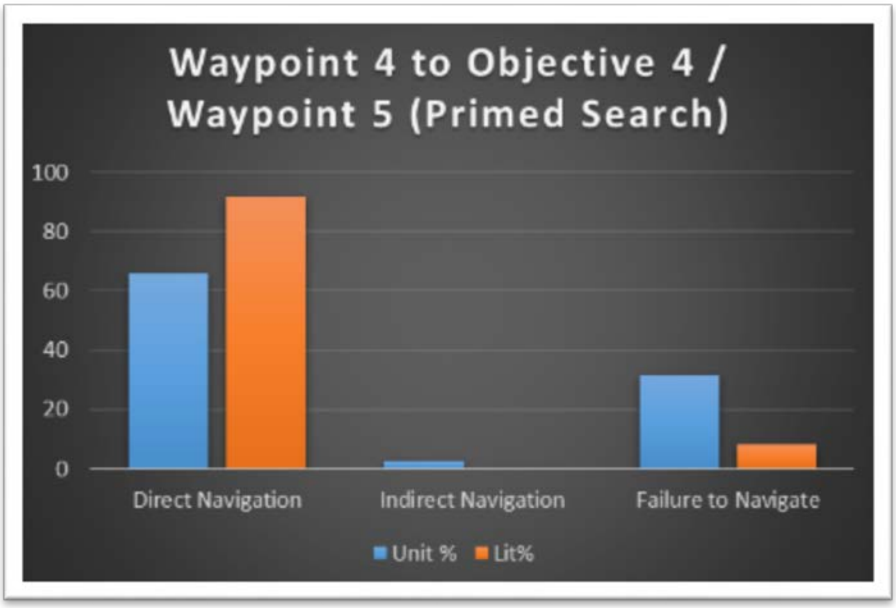


*Figure 228.* A comparison of the primed search navigation results from waypoint four to objective four / waypoint five.

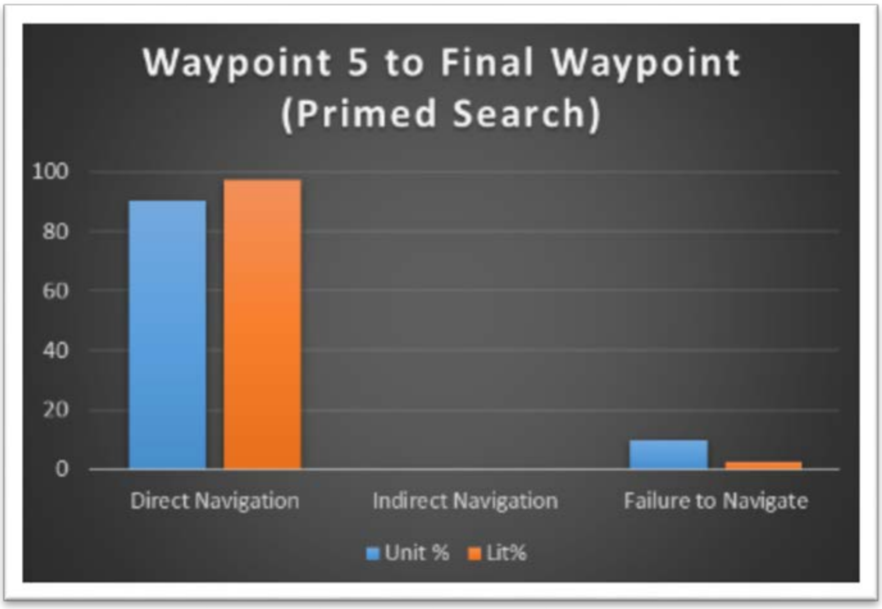


*Figure 229.* A comparison of the primed search navigation results from waypoint five to the final waypoint.

## 11.8 DISCUSSION

The environment followed the design principles suggested by Foltz (1998) building upon established design principles for the construction of successfully navigable virtual environments (P. Arthur & Passini, 1992; Lynch, 1960). Navigable in this context meaning that information presented about the virtual space allows for the navigator to move from the point of origin to destination in conformity with Downs (1973) four step wayfinding theory. The environment provides structured and diverse guidance cues in the form of static maps, pathways, path markers, landmarks, large distal landmarks, borders and regional variation. The introduction of dynamic lighting as a navigational cue was the influencing factor between the results from each of the two groups.

No prior large-scale wayfinding exercise could be found in the literature that introduced a distinct variable in the manner that this study does. Therefore, this study was not only the first to introduce lighting cues in an open world scenario and to contrast those with neutral lighting conditions but also the first to analyse wayfinding behaviour by offering A/B variance. This methodology has produced clear results and therefore suggests that this is a practical framework for further exploration of these phenomena. Prior examples of similar concepts not only restricted themselves to navigation within enclosed spaces but also in the nearest available analogue did not allow for player movement. (Blake, 2010)

Participants demonstrated a clear ability to synthesise both landmark and survey knowledge (Thorndyke & Goldin, 1983) and to develop navigational strategies in a novel environment. Where more complex tasks such as navigating from Waypoint 1 to waypoint 2 but first visiting objective 1, the complexity of this task meant that just 54% of participants managed this in the uniformly lit condition. With the inclusion of dynamic lighting guidance, the success rate rose to 68%. The task that participants under the uniformly lit condition were least successful at completing was navigating from Objective 2 to Waypoint 3; in this instance, only 32% of participants were able to navigate directly between these two points, whereas the inclusion of dynamic lighting guidance increased the success rate to 73%.

The results demonstrated that even where there are multiple associated and self-reinforcing navigational cues intrinsic to a virtual space, the addition of a dynamic lighting cue positively influenced successful navigation. Where the goal was either a short distance from the starting point or was in a location that could be oriented from the current location, the differences between the two groups were minimal. However, in cases where navigation required orientation of a more complex nature, utilising multiple landmark recognition or reference to a cognitive map the failure rate of navigation fell off dramatically in the dynamically lit variant. Lighting cues as dynamic guidance in these instances ensured that the majority of participants remained on the direct route.

### 11.8.1 KEY FINDINGS

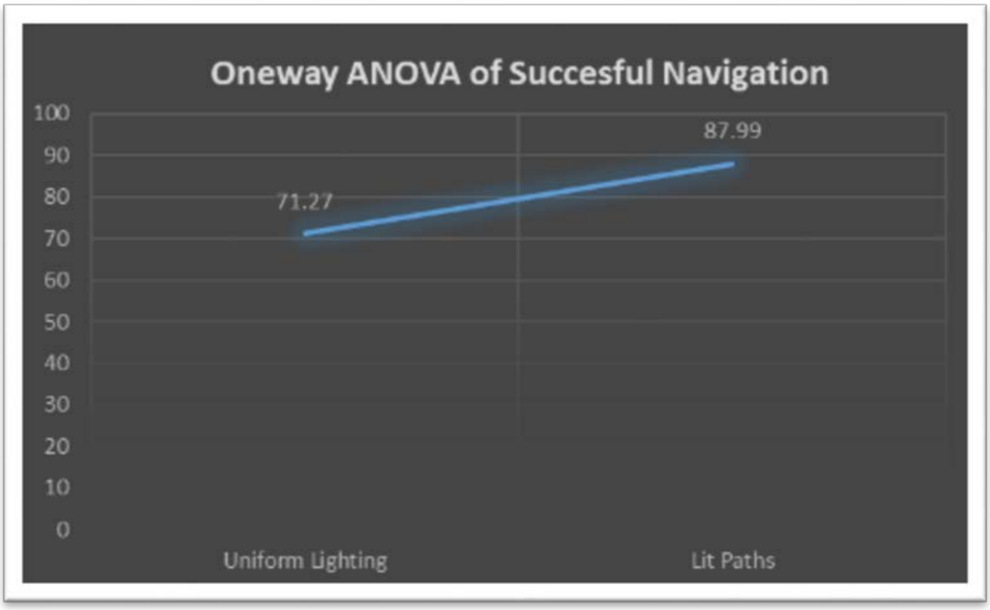


***Figure 230*. The results of a one-way ANOVA of the successful navigational choices of participants.**

The wayfinding design principles such as paths, maps and signage proved successful in directing player navigation. *Figure 230*. The aggregated mean of successful navigation in the standard apparatus was 71.27%. However, the key finding of this study is that a significant main effect for lighting is evident, with the combined means of the dynamically lit version of the apparatus resulting in a successful navigation rate of 87.99% $F(1,16)=4.605$ $p=0.048$. This result clearly demonstrates that while the physical design principles (E. Arthur et al., 1997; Darken & Sibert, 1993, 1996; Foltz, 1998; Siegel & White, 1975) when implemented effectively do indeed provide clear navigational information to players.

Additional intrinsic guidance in the form of lighting design and specifically a dynamic lighting approach have been demonstrated under controlled conditions in this study to have a significant reinforcing effect on player navigation. Alongside the results of the prior experiments in chapters seven, eight and ten, these results offer novel design principles that content creators can utilise when creating intrinsicaly navigable open world virtual environments.

# 12 CHAPTER TWELVE:

# CHANGE BLINDNESS IN AN ESCAPE THE ROOM GAME

## 12.1 ABSTRACT

In many studies over a period of over 120 years, it has been demonstrated that humans are susceptible to many different types of change blindness; essentially, if a change in a visual scene is not sudden or obvious, it fails to be detected. Virtual environments allow for the study of change blindness during dynamic tasks. This study examines participant perception of gradual broad changes to both colour and textural information across surfaces and objects in a virtual environment whilst a distracting task within that environment is undertaken. 119 participants were asked to solve a room escape puzzle; results demonstrated that perception of gradual changes to an environment across a (from 11.25 to 90 seconds) range of durations are detected only by a very small proportion of participants (4.20%).

## 12.2 INTRODUCTION

Both filmmakers and in particular conjurers have for centuries relied on the understanding that human perception and memory are imperfect. Human visual perception can be guided and deceived.

When a magician makes a coin 'disappear' a technique of misdirection is used to infer the transfer of the coin and holding that attention allows for the discreet,(Martinez-Conde & Macknik, 2008) similarly filmmakers have long known that minor differences in a scene between cuts are generally not perceived by the viewer. This is despite the fact that millions of neurones are attending to the scene and are ready and waiting to sound the alarm should they detect change (Dennett, 1991).

In the 1980 's psychologists became interested in these phenomena from a scholarly perspective (Becklen & Cervone, 1983; Neisser & Becklen, 1975) and over the intervening decades, a variety of types of change blindness (Simons & Chabris, 1999) have been identified. These include blinks or eye motion (Grimes, 1996), flashed blank images, (Blackmore, Brelstaff, Nelson, & Troscianko, 1995) or gradual, subtle changes over time (Simons, Franconeri, & Reimer, 2000).

Working memory is limited, and little information is processed in the visual cortex during saccadic eye movements (Grimes, 1996). This is compounded by the fact that less than 1% of the retinal intake is covered by the fovea centralis where most information is captured corresponding to 50% of the visual cortex (Krantz, 2012). Furthermore, the fovea as it contains the highest concentration of cone photoreceptors that are responsible for colour perception and high-resolution vision. The retina outside of the fovea contains proportionately far fewer of these cells relying on a lower stimulus monochrome detecting cell called rods. Due to the concentration of cones in the fovea, there is little perception of colour information over much of the retina. However, rods are more sensitive to light resulting in the peripheral regions of the retina having superior light and motion detection.

Human working memory (Baddeley & Hitch, 1974) is not restricted to matters of short-term memory; it is concerned with dealing with attention given to tasks that require monitoring. The manner in which the details of a scene are stored is understood to be coded in the visuospatial sketchpad and related semantically to long-term memories for instance to previously defined objects. It is due to the manner in which the brain creates shorthand associations for inputs that although the broad sense of what is being perceived is coherent, the granularity or finer detail is generally lost. Furthermore, it has been demonstrated that the limitations of working memory have direct correlations to the perception of colours relating to objects (Garden, Cornoldi, & Logie, 2002). It has further been demonstrated that specific non-colour details pertaining to an image are recalled in more depth if that image is presented in monochrome thus reducing the memory load of storing colour data (Nijboer, Kanai, de Haan, & van der Smagt, 2008). In relation to this, in attention tests with multiple differing coloured objects, where one is covered, few participants correctly identify the correct colour of the hidden object (Pilling & Gellatly, 2011). The reasons behind this are related to selective awareness governed by two visual input pathways (Wolfe, Reinecke, & Brawn, 2006) a 'selective' pathway that governs object recognition and is responsible for recognition of one or a very small number of objects at a time and a 'non-selective pathway' which is responsible for forming a broader impression of a scene. This system may give a broad understanding that there are objects in a scene, but not what those objects actually are.

From a neurological perspective, the fact that these interweaving systems appear to operate in a semi-autonomous manner can be related to the fact that it has been demonstrated that storage and processing of different types of sensory data are handled independently within the structure of the brain (Baddeley et al., 1986; Pessoa & Ungerleider, 2004). The specific subcomponent of working memory connected to the retention of visual information is the Visual Short-Term Memory (VSTM) (Phillips & Baddeley, 1971). However, for an element of a scene to be recorded in VSTM, it first must be attended to (Lamme, 2003) in so much that a conscious representation of the object and its component states are committed to memory. Given the limitations of working memory and that approximately 4 objects and their components states including colour information can simultaneously be recalled (Hollingworth, Williams, & Henderson, 2001; Luck & Vogel, 1997) in a complex environment with shifting focus, it is inevitable that much of the scene will not be recalled in detail. However, the perception of an object is related to the features of the object and its relationship to the contents of the VSTM and task goals (Hollingworth, Matsukura, & Luck, 2013). Coherence theory (Rensink, 2000) as a view of perception infers that that in fact the visual perception relies very little on actual memory and persistence after the withdrawing of attention as a scene can repeatedly be sampled and re-referenced at any given moment by the refocusing of attention (Ballard, Hayhoe, Pook, & Rao, 1997). Essentially the environment serves as “external memory.” This external memory and its associated lack of processing is also referred to as distributed cognition (Margaret Wilson, 2002) specifically where the cognitive work is offloaded to the environment, essentially having the environment work to store and in some cases manipulate information, returning to collect only that data that becomes pertinent.

Although many experiments have demonstrated that gradual change blindness can result in the non-detection of colour changes in otherwise static images,(Arrington et al., 2006; Most, Simons, Scholl, & Chabris, 2000) it has not been demonstrated what the results of changing broad environmental elements covering most of the visual field would be in a virtual environment.

## 12.3 HYPOTHESIS

It was predicted that as gradual change is not consistently perceived therefore introducing a gradual change to all major materials in a virtual environment would not be noticed by the participants if distracted by a task requiring the utilisation of working memory.

The following hypotheses were considered:

1. That colour/hue changes over time would not be perceived

2. That pattern changes made over time would not be perceived.

3. Given that filtering of salient objects occurs when initially exposed to the environment, that information recalled would relate to the initial state of the object and not the final state. It is also possible that a preference for recalling post change information would suggest late filtering or some form of attentional attenuation (Deutsch & Deutsch, 1963)

4. That variance in the time of change would have little impact on overall detection of change.

## 12.4 METHOD

### 12.4.1 PARTICIPANTS

119 participants; 102 male, 17 female, age range 17 and 54 (mean 22.28) all reporting having normal vision or corrected to normal vision. All participants had normal colour vision; those reporting a type of colour blindness were excluded from the test. Participants were recruited primarily from students and staff in the department of computing and engineering, they were not paid, but many received chocolate bars if they participated in a group of experiments.

### 12.4.2 MATERIALS AND APPARATUS

In order to test the hypotheses, an experimental virtual environment with a distraction task was created this took the form of an 'escape the room' game created in Unreal Development Kit (UDK) v.2012/07. This environment consisted of a bedsit living space (12 m2) with en-suite bathroom (4 m2), a variety of objects such as computers, drawers and other objects could be interacted with and manipulated to solve a series of interrelated problems and eventually escape the room.

The puzzle aspect of the environment acted as the distraction from the simultaneous broad changes being made to the textures of most of the surfaces and objects in the room. Figure 231. For instance, the wallpaper changed from being a neutral cream to pink and having one large lateral stripe to two; the red fabric sofa morphed into a brown leather sofa and the floor from a light beech to dark oak. In total thirteen textures were altered ranging from major elements that filled most of the visual space to smaller objects such as books. The changes were not limited to simple hue shifts but included contrast changes and pattern changes. The changing of these textural differences were instigated at the moment the player entered the room and participants would be engaged in the game for a total of 5 minutes, the changes described took place in just the initial segment of that time and were static for the remaining time.

In common with previous change blindness experiments, an image of a gorilla was included in the scene; this was embedded into a prominent picture and gradually appeared at the same rate as the other changes.

| **Object** | **Initial Texture** | **Post Change Texture** |
|---|---|---|
| Living-space Walls | Cream with one dark stripe | Pink with two dark stripes |
| Flooring | Light Beech Laminate | Dark Oak Laminate |
| Sofa | Red | Brown |
| Bed/Duvet | Purple with dark throw | Pink with dark throw |
| Curtains | Red Un-patterned | Orange with Flower Print |
| Bathroom Walls | Cream | Pink |
| Alice in Wonderland Book | Blue with Cat | Purple with Just a Smile |
| War of the Worlds Book | Red | Green |
| The Time Machine Book | Pink/Purple | Blue/Orange |
| A Princess of Mars Book | Yellow | Orange |
| Heart of Darkness Book | Red | Purple |
| Picture Frame | Green | Blue |
| Picture of Cliffs | A Sea and Cliff Scene | A Gorilla's Face is Added |

***Table 18.*** **The changes made to textures within the environment.**

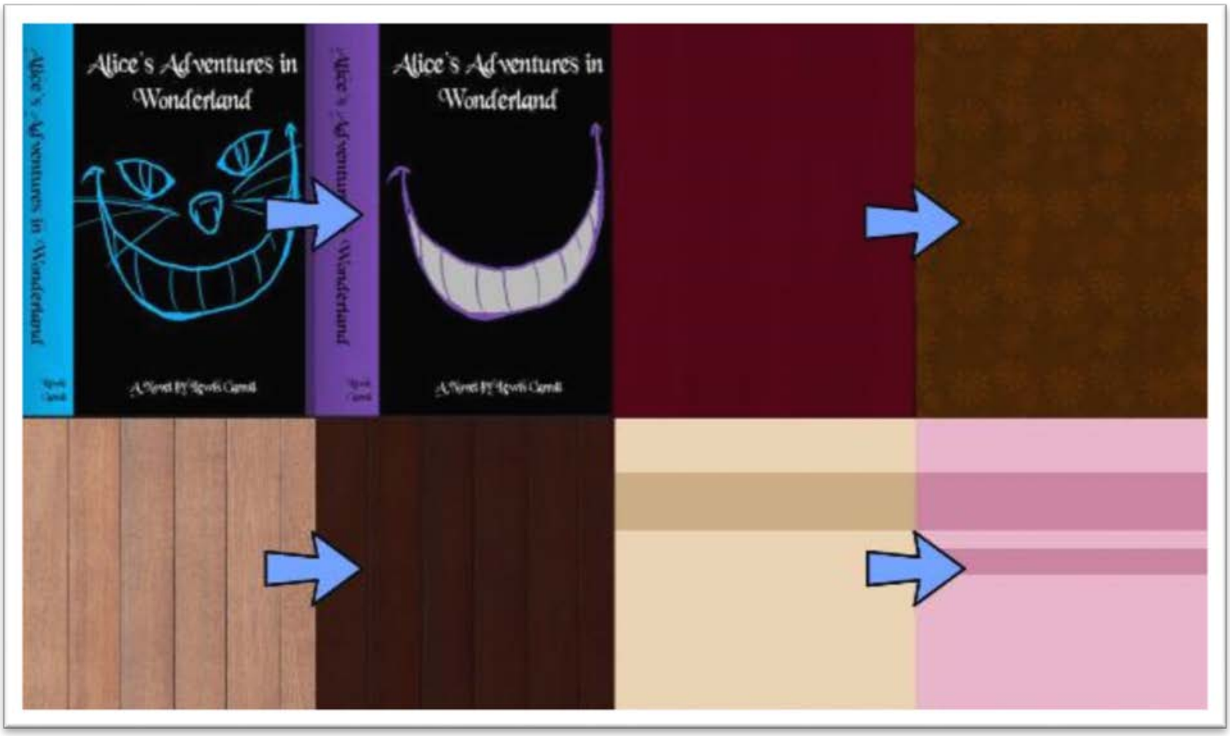


***Figure 231.*** **Examples of variants of textural change, colour, contrast, pattern and image.**

### 12.4.3 PROCEDURE

All participants were tested individually, and they supplied informed written consent in advance.

All participants used the same specification of PC with 4th generation Intel i7 CPU, Nvidia 670 graphics cards, a mouse and keyboard board for input and a 22-inch wide-screen monitor. The environment was kept as similar as possible between sessions with sound levels maintained at a minimum, lights dimmed, and blinds closed.

The participants received standardised instructions to solve the puzzle in the allocated time, and no other information about the nature of the test was provided to them.

On screen instructions explained basic interaction to the participants, and once they clicked the acceptance button, they were immediately placed in a virtual environment of a small single room apartment. The room contained interactive objects and these needed to be examined, clues located and a series of interactions with objects in sequence would allow the game to progress. For instance, the computer on the desktop required a username and password, clues to this were contained on a post-it note on the desk, and the password was the name of the artist in the painting. Further puzzles involved finding batteries to fit into a remote control unit in order that the TV could be switched on.

129 participants took part in the study; the duration of change was initially 90 seconds (31 participants), and this was halved to 45 seconds (27 participants) then 22.5 seconds (30 participants) and finally to 11.25 seconds (31 participants).

During their exploration of the environment, thirteen colour and/or pattern changes occurred to textures within the scene [*Figure 232*, *Figure 233*] and the game remained playable for a total of 5 minutes. Therefore, for the 90-second change group, there was 210 seconds where the textures remained static, 255 seconds for the 45-second group, 277.5 seconds for the 22.5-second group and 288.75 seconds for the 11.25-second group.

After 5 minutes of gameplay, the programme automatically ended the session, and the participants were asked to complete a post-test questionnaire. As they had been told that the experiment was about gameplay, the questions began with queries that related to game design issues and slowly introduced specific questions about their overall perception. These questions were designed so as not to lead the participant to provide a predetermined answer. The questions in order were; (i) Briefly describe the main focus of the game you just played (ii) What game genre do you think it belongs to? (iii) Did you notice anything unusual or peculiar whilst playing? If not, simply answer 'NO'. (iv) Did you notice anything change in the game? (v) Please list any changes you think you noticed. Or simply type 'NONE' – following multiple choice questions about the colours of particular objects, the final questions asked were; (vi) Did you spot the gorilla? (vii), If you answered YES to spotting the gorilla, where was it?

Once the participants had completed the questionnaire, they were debriefed, told the purpose of the experiment, and were shown the changes occurring in the environment with the prior knowledge of the changes occurring.

*Figure 232.* **The transition of textures in the living room area.**

*Figure 233.* **The transition of textures in the bedroom area.**

## 12.5 RESULTS

Despite the questionnaire allowing for multiple entries in colour selection when asked to describe individual objects, none of the participants chose more than one option.

### 12.5.1 DESCRIPTIVES

In a similar fashion, 52.5% of participants claimed to have noticed a change, yet only 4.2% actually identified a manipulated gradual change, a total of 5 participants out of 120. All other changes that participants claimed to notice were unrelated changes triggered by participant action, such as saying a door being opened or items being picked up and moved around the environment.

| Duration of texture changes. | Number of participants | Number reporting texture change detection. | As Percentage. |
|---|---|---|---|
| 90 seconds | 31 | 1 | 3.23% |
| 45 seconds | 27 | 2 | 7.40% |
| 22.5 seconds | 30 | 1 | 3.33% |
| 11.25 seconds | 31 | 1 | 3.23% |
| Totals | 119 | 5 | 4.20% |

The discrepancy between the two questions (did the notice a change/notice something unusual) is explained by the difference in question phrasing. As the participants were naive to the aims of the experiment a general non-leading question about unusual events was asked first, followed by a more direct question regarding whether any change was noticed.

When asked if they had noticed a gorilla in the room 11.6% claimed to have done so, though only 9.9% were able to accurately state where they had seen the gorilla (in the painting). *Figure 234*. It is important to note this question only determined whether they had seen the gorilla at some point during their experience, not whether they noticed it had gradually appeared. Indeed, only one participant when detailing the changes they had noticed stated they had seen the gorilla appear.

*Figure 234.* **The transition of a painting to display the face of a gorilla in a cliff face.**

Specific questions were asked about gradual change items that were core to the virtual experience (items close to focal points and tasks/goals) or covered a large area of the visual field (walls). As can be seen from table 19 a large proportion of participants could not identify the colour or texture property of the gradual change items. In terms of which colour or texture properties reported there was little difference between the pre-change property (16.38%) and post-change property (15.94%).

This can be further seen when simply considering the total number of pre-change and post-change properties recalled. Little difference between pre-change (M= .8, SD= .78) and post-change (M= .75, SD= .83).

| Change Item | %age Identifying Pre-Change Colour | %age Identifying Post-Change Colour | Incorrect Identification | Did Not Know |
|---|---|---|---|---|
| Curtains | 38.8 | 3.3 | 34.7 | 22.3 |
| WotW Book | 9.1 | 15.7 | 21.5 | 53.3 |
| Bedroom Walls | 6.6 | 25.8 | 44.2 | 23.3 |
| Bathroom Walls | 6.6 | 6.6 | 61.7 | 25 |
| Bed Duvet | 20.8 | 28.3 | 30.8 | 20 |
| **Mean Total** | 16.38 | 15.94 | 38.94 | 28.78 |

***Table 19.*** **Percentage identifications of gradual change item properties**

When broken down by condition (11.25, 22.5, 45 and 90 seconds) there is little difference between them in regards to the number of participants reporting something unusual related to the gradual change, correctly identifying a change, or accurately noticing the gorilla. This is largely due to the limited variance possible with so few participants correctly identifying a change in general.

| Condition | %age Identifying Pre-Change Colour | %age identifying Post-Change Colour |
|---|---|---|
| 11.25 Seconds | 18.14 | 15.64 |
| 22.5 Seconds | 12.01 | 17.34 |
| 45 Seconds | 20.72 | 16.28 |
| 90 Seconds | 15.48 | 14.86 |

***Table 20*. Total Percentage identifications of gradual change item properties by condition.**

When considering the overall difference in pre and post change identification across three of the four conditions the pre-change property is identified slightly more than the post-change, though the differences appear small (see table 20).

This is further supported by the mean number of pre and post-change properties identified (see table 21).

| Condition | Mean Pre-Change (SD) | Mean Post-Change (SD) |
|---|---|---|
| 11.25 Seconds | .87 (.87) | .68 (1.02) |
| 22.5 Seconds | .56 (.67) | .86 (.81) |
| 45 Seconds | 1.03 (.85) | .77 (.64) |
| 90 Seconds | .77 (.64) | .67 (.79) |

***Table 21.*** **Mean total identification of pre and post-change properties by condition.**

### 12.5.2 INFERENTIAL ANALYSIS

A one-way independent ANOVA found no significant main effect of condition on total change detected ($p = 0.89$)

A further mixed 4 X 2 ANOVA with condition serving as the between-subjects factor (11.25, 22.5, 45 and 90 seconds), and change property identification (pre-change, post-change) serving as the within-subjects factor. No significant main effects of condition ($p=0.54$), or change property identification ($p = 0.57$) were found. No significant interaction effect ($p = 0.28$) was found.

| **Object** | **Overall % of change detection N=119** |
|---|---|
| Living-space Walls | 0.84% |
| Flooring | 2.52% |
| Sofa | 0% |
| Bed/Duvet | 0% |
| Curtains | 0% |
| Bathroom Walls | 0% |
| Alice in Wonderland Book | 0% |
| War of the Worlds Book | 0% |
| The Time Machine Book | 0% |
| A Princess of Mars Book | 0% |
| Heart of Darkness Book | 0% |
| Picture Frame | 0% |
| Picture of Cliffs | 0.84% |

***Table 22.*** **The overall detection rate of change for each object in the scene.**

## 12.6 DISCUSSION

The aims of this research were to investigate if a gradual change is not consistently perceived therefore introducing a gradual change to all major materials in a virtual environment would not be noticed by the participants if distracted by a task requiring the utilisation of working memory.

It has been previously demonstrated that either colour changes (Simons et al., 2000) or small changes to a broader scene result in significant non-detection of those changes (Franconeri et al., 2005). However, the results of this research have suggested that when combined with a distraction task, even the broadest of changes; in this case fundamentally altering the textures of an entire environment are not detected. The results show that overall; fewer than 5% of participants perceived any of these changes, indeed many of the larger changes that were made were not detected by any of the participants. Given the limitations of Visual Short-Term Memory (Baddeley & Hitch, 1974) it is unsurprising that the participants provided incorrect responses when asked to identify specific colours of objects. In addition only 13 participants (13%) recall seeing the gorilla [*Figure 235*] in the scene when it was clearly in a prominent position and in an item required to solve a portion of the puzzle indicates that participants only commit to memory elements that they perceive to be beneficial to the goals as previously reported (Hollingworth et al., 2013).

Simons et al. (2000) demonstrated that small areas of static images could be changed over time and these changes are perceived approximately 30% of the time. It is clear that combined with a distraction task, and in a virtual representation of a scene, this detection of change even when applied to the entire field of view falls away by approximately 90%.

Memory for specific scene details correlates with current theories of memory; the results indicated that in many cases as the actual colour or texture of elements perceived to be simply background objects were not perceived as salient, no specific memory was encoded of the colour of those objects (Hollingworth et al., 2013).

Within a video games context, the results of these experiments reflect a commonly utilised method of removing temporary visual information from a scene, in many instances detail information is added to a scene in the form of bullet holes, blood splatter or simply footprints in the snow. These elements commonly disappear over time and unless the player is attending to them directly will disappear without the player noticing. While changes that are simply the removal of extraneous information will not be noticed and therefore will not break the flow of a game title, this research has demonstrated that broad changes can be gradually made to an environment without the player noticing these differences. From a design perspective, this understanding could allow for the morphing of an entire environment to be made that may relate to narrative or define a specific mood, mood or mental state. It opens new areas for visual storytelling that have not yet been explored.

***Figure 235.*** **Picture with emerging gorilla image beginning (left) and end (right) states**

# 13 CHAPTER THIRTEEN

# CONCLUSIONS

The principle aims of this thesis were to investigate the influence of intrinsic navigational cues in virtual environments and video games via a series of interrelated novel quantitative experiments. Modern video games, in particular, make effective use of architectural layout of game spaces that allow a player to flow through a level. The methods that designers use are complex and stratified and utilise principles rooted in urban architectural design and navigational cues that are intrinsic to real-world wayfinding scenarios. The studies presented in this thesis analysed not only these commonly used physical cues, but also the potential for reinforcing of these architectural cues by the addition of lighting, motion and audio. The primary focus of this thesis was a systematic quantitatively rooted analysis of the impact lighting has on navigation and the levels at which variance in lighting makes a quantifiable difference to navigational choices within a virtual environment.

## 13.1 THE INFLUENCE OF ILLUMINATION, COLOUR, MOTION, ELEVATION AND WIDTH OF PORTALS

Chapters Six and Ten analysed the effect of variation in open portals. In both of these studies, the doorways were depicted as unfamiliar openings in walls. The first study simply offered illumination and colour differences within a circular environment; this was in order to remove any left-right rotation bias. The study demonstrated that participants prefer to take shallow turns or maintain linearity of motion reinforcing earlier findings from architectural studies (Dalton, 2003; Dalton et al., 2005). The study in Chapter Six did not demonstrate that simple changes in portal brightness were considered salient by the participants. The players did not head for the doorway with the brightest light. Instead, there is evidence to suggest that a doorway that offers a contrast to all other doorways is considered salient and is, therefore, more frequently chosen. This doorway could be salient by difference by being darker, of a different colour or indeed brighter, but it is the contrast from surrounding options that is the salient attribute.

The study in Chapter Ten aimed to discover whether variance in the appearance of a portal influences player navigational decisions, the variables analysed by this study were portal width, portal elevation, motion within a portal and the illumination of a portal.

A chi-square test of independence was performed to examine the relation between all of the left-hand portals and all of the right-hand portals. The relation between these variables was significant, $X^2(1, N = 456) = 9.55$, $p < 0.002$. The results demonstrated a difference between groups with regards to a preference for right hand over left-hand paths.

Due to the discovery of this effect, a further analysis was carried out on the combined outcomes of the left/right flipped portal differences in order to compensate for this left-right bias. A chi-square test of independence was performed to examine the relation between all portals with an animated flickering flame and all portals with a static glowing torch. The relation between these variables was significant, $X^2(1, N = 76) = 19.000$, $p = 0.000$. The results demonstrated a difference between groups with regards to a preference for a path with a motion cue that was at a greater level of significance than the results of a single room. The averaged screen brightness between portals in the variance study was demonstrated to have been set at a level below the perceptual threshold and did not act as a statistically significant effect.

## 13.2 THE INFLUENCE OF SUBTLY ILLUMINATED PATHS AND AUDIO CUES IN MAZE SOLVING

Chapters Seven and Eight aimed to discover if the illumination of a maze had an impact on the time taken to solve it. No evidence was found for a significant difference in solve times when the mazes were illuminated in strong colours or if a dark path led to the goal point. However, a significant effect was discovered for maze solving times when a lit path to the goal was introduced. In this instance, the illuminated path was approximately 12% brighter than the average brightness of the remainder of the environment.

A univariate ANOVA showed that there was a significant main effect of lighting ($F(4,503) = 5.837$, $p = 0.000$).

A further goal of Chapter Eight was to analyse the effectiveness and possible cue competition of introducing other navigational cues into the environment such as aversive audio and/or landmarks in the form of graffiti. While no isolated effect was discovered for, the inclusion of graffiti, a main effect and an effect of cue competition was demonstrated for the aversive audio, and a reinforcement effect was discovered in the case of audio cue and graffiti combined.

Where there was audio at the goal, despite this sound being aversive, there was a significant effect in overall solve times, ($F(2,503) = 7.699$, $p=0.001$).

While graffiti as a navigational cue did not significantly reduce solve time, a reinforcement effect was detected in the case of the combination of audio and graffiti ($F(2,503) = 5.270$ $p=0.05$).

The results of these studies validate that a brighter lit path does influence player navigation and that the difference in illumination does not need to be dramatic to have an effect. In this study, a difference of just 12% in overall brightness led to a significant influence on player motion. As was shown in Chapter Nine, a variance of illumination of approximately 7% is not perceptible to most individuals and a variance of only 10% created a point of visual saliency. It, therefore, can be concluded that subtle lighting can be utilised to influence navigational choices and the threshold for this is approximately an increase in brightness of 10%. Further increasing the brightness of the suggested path increases the likelihood of it being chosen as the preferred route.

## 13.3 THE INFLUENCE OF HOT SPOT LIGHTING CUES ON SOLVE TIMES IN HIDDEN GOAL ENVIRONMENTS

As many video games utilise hot spots in lighting to suggest points of interest to the player, the study in Chapter Nine set out to test whether such hot spots were salient without initial context.

The study demonstrated that even in a case where participants had no prior instruction to head to the lit spot; an area of visual contrast can act as a salient cue and rapidly become associated with a goal. The study also demonstrated that this behaviour is rapidly reinforced, once the participant has made the association between the lit spot and the hidden trigger.

A univariate ANOVA showed that there was a significant main effect of lighting ($F(4, 260) = 14.351$, $p = 0.000$).

In this study, a difference in averaged pixel brightness of +7% was selected. This value was chosen because in pre-testing it had been the value at which the lighting difference had not been readily visible. In the test, the results demonstrated that the difference in illumination was not visible to participants and therefore was not utilised as a navigational cue. An increase in the difference of the brightness of a square to an adjacent square of only three percent to +10% was sufficient for participants to attend to that highlighted spot and navigate towards it. As there was a small increase in solve time for the level with a +10 brightness and projected decal cues, it is conceivable that there was a small cue competition effect of those symbols being visible.

At an increase in relative brightness of only + 26%, compared to adjacent squares the illuminated spot became a significant and dominant navigational cue and the cue competition of the surrounding projected symbols was no longer a factor. Beyond an increase in relative brightness of 26%, the effect began to level out as participants navigated directly to that spot once they had located it.

It is evident from the study that brighter areas of illumination are utilised as a navigational cue and that even at low levels of contrast they can become salient. The more clear and obvious the lighting of a point of interest is the more likely the player is to navigate towards it.

## 13.4 THE INFLUENCE OF LIGHTING IN COMPETITION WITH ARCHITECTURAL CUES.

The study in Chapter Eleven aimed to determine whether the previously discovered effects of a preference for lit paths held true in a more familiar architectural context. As humans are accustomed to navigating through built environments, a series of streets that reflected the precepts of space syntax (Dalton & Bafna, 2003; Dalton et al., 2005) was constructed that allowed for the testing of these precepts in correlation with potentially reinforcing or conflicting lighting cues. The study confirmed that the principles of space syntax do hold true in a virtual environment and that where there is a strong contrast between lit and dark areas that there is a significant effect of lighting. A Bonferroni multiple comparison analysis of the combined means of the lighting variants demonstrated a significant main effect for lighting in the wider contrast standard screen variant of the apparatus. $F(2, 23) = 10.665$, $p=0.001$. However, in a replication of the study using a virtual reality headset, where the differences between the light and dark areas were halved, no significant main effect for lighting was detected, $F(2,23) = 0.342$ $p=0.715$. A significant main effect was therefore found between the two main groups $F(5, 47) = 4.936$, $p=0.001$.

It was evident in the study that architectural cues within a video games context continue to work in the same manner as their real world counterparts. The key finding of this study is that the introduction of lighting can make significant differences to the navigational decision-making of participants and the greater the contrast in those differences the more pronounced the effect.

The results suggest that as humans have evolved to avoid dark spaces, they conversely demonstrate a natural affinity for lit areas and that those dark areas of an environment had a clear influence on path choices in virtual architectural spaces. This remains the case, whether these environments are depicted on a monitor screen or presented via a virtual reality headset. From a game development perspective, this means that it can be clearly stated that the inferences that have been made by developers since the introduction of lighting and shading in games have been correct and that in conjunction with the architectural design principles suggested by space syntax, strong lighting cues can significantly influence player navigation. Further to this, lighting cues at a distance, in contrast to a darker foreground have been confirmed to 'pull' the participant along that path as suggested by the designers of Left 4 Dead (Valve Corporation, 2008) (Lundeen, 2009). These results demonstrate that both architecture and lighting do affect navigational choices in isolation and that when used in conjunction, can influence up to 90% of participants, via a reinforcing combination, to opt for one route over another.

## 13.5 THE INFLUENCE OF DYNAMIC LIGHTING IN AN OPEN WORLD ENVIRONMENT

The objective of the study in Chapter Twelve was to investigate if the addition of dynamic lighting can act as a guidance cue and positively affect player navigation, when contrasted with both reinforcing and competing navigational cues in a wayfinding exercise.

The study demonstrated that the wayfinding design principles such as the inclusion of paths, maps and signage (E. J. Arthur et al., 1997; Darken & Sibert, 1993, 1996; Foltz, 1998; Siegel & White, 1975), when implemented effectively do indeed provide clear navigational information to players. The aggregated mean of successful navigation in the uniformly lit apparatus was 71.27%. However, the combined means of the dynamically lit version of the apparatus produced a successful navigation rate of 87.99%, thus demonstrating a significant main effect for lighting, $F(1, 16) = 4.605$ $p=0.048$. These results demonstrate that intrinsic guidance in the form of lighting design and specifically a dynamic lighting approach can have a significant reinforcing effect on player navigation. While specific thresholds of illumination were not independently tested in this study, findings in previous chapters indicate that the stronger the lighting contrast, the greater the effect of the lighting as a navigational cue.

## 13.6 THE PERCEPTION OF GRADUAL CHANGES TO CONTRAST, COLOUR AND TEXTURE

The aims of this study were to investigate if a gradual change in an environment is consistently perceived. Therefore, if a gradual change were made to all major materials in a virtual environment, would these changes be detected by the participants if distracted by a task requiring the utilisation of working memory.

It has been previously demonstrated that either colour changes (Simons et al., 2000) or small changes to a broader scene result in significant non-detection of those changes (Franconeri et al., 2005). However, the results of this research have shown that when combined with a distraction task, even the broadest of changes; in this case fundamentally altering the textures of an entire environment are not detected. The results show that overall; fewer than 5% of participants perceived any of these changes, indeed many of the larger changes that were made were not detected by any of the participants. Given the limitations of Visual Short-Term Memory (Baddeley & Hitch, 1974) it is unsurprising that the participants provided incorrect responses when asked to identify specific colours of objects.

Simons et al. (2000) demonstrated that small areas of static images could be changed over time and these changes are perceived approximately 30% of the time. It is clear that combined with a distraction task, and in a virtual representation of a scene, this detection of change even when applied to the entire field of view falls away by approximately 90%.

Memory for specific scene details correlates with current theories of memory; the results indicated that in many cases as the actual colour or texture of elements perceived to be simply background objects were not perceived as salient, no specific memory was encoded of the colour of those objects (Hollingworth et al., 2013). From a games design perspective, these results confirm that broad changes can be made to an environment and will go undetected unless the item undergoing change commands visual attention. For instance, it is common for bullet hole decals and even the bodies of fallen enemies to slowly disappear in video games and not be readily noticed unless specifically attended. These findings demonstrate that it may be possible to replace an entire environment around a player without them being conscious of any change.

## 13.7 KEY FINDINGS

The following key findings of this thesis have meaning when related to the design of intrinsic player guidance in video games and other virtual environments. While these cues have been used extensively by designers, the relationship of lighting to other intrinsic cues such as audio or architectural cues has not been quantified. The key findings listed below form a series of novel principles and design heuristics that virtual environment and games designers can utilise when developing explorable and navigable spaces in which they seek to reduce the quantity and necessity for auxiliary navigational cues.

### 13.7.1 LIGHTING

- Lighting is a key navigational cue when it meets a saliency threshold.
- An increase in brightness of approximately 10% is the lower threshold for a light source to become salient.
- The greater the contrast of the lighting to the surrounding the more effective the lighting is as acting as a navigational cue. This effect falls off once the lighting is clear and obvious.
- Illuminated paths act as a navigational cue; this is effective even when the illumination is not obvious.
- The colour of lighting is subjective, while bright colours can be visually salient; no specific colours either attract or dissuade player motion.
- Lighting in conjunction with established architectural principles produces a reinforcement effect.
- Strong illumination, when contrasted with dark path choices, can override normal architecturally based navigational decisions.
- Lighting in an open world environment with standard intrinsic cues such as paths can affect navigational choices, either reinforcing or overriding less obvious cues.
- There is an interaction between audio and lighting stimulus, and these cues can be made to either reinforce or conflict.

### 13.7.2 COLOUR AND TEXTURE

- Colours are contextual and while possibly having varying cultural significance, do not significantly influence player navigational choices.
- Colours and textures are not specifically attended to and can be gradually changed without being perceived.

### 13.7.3 AUDIO

- Audio cues draw player attention and can influence navigational choices.
- Players will investigate the source of a sound even if that sound is of an aversive nature.
- Audio cues can reinforce navigation in conjunction with both lighting and landmark cues.

### 13.7.4 MOTION

- The human vision system is drawn to motion; this has been demonstrated to be a strong navigational cue. Even small areas of motion can draw a player in a specific direction.
- A small area of motion in a scene can compete with an architectural navigational cue.

## 13.8 SUMMARY

The studies contained in this thesis have demonstrated in a novel manner that intrinsic navigational cues such as motion, architectural design, audio and lighting within virtual environments have clear effects on navigation. Where obvious lighting acts as a direct navigational aid, signposting the desired direction of travel. An aversion to dark spaces is prevalent in most cases; however, it is clear that there will be players who will actively decide to explore dark spaces, so therefore this attribute cannot be used to preclude exploration. More importantly, subtle lighting cues have been shown in isolation to provide sub-perceptual threshold player guidance. Even when a path is illuminated only approximately 10-12% more than the surroundings, players are drawn to follow that path. This can be overridden by strong competing cues such as a motion cue, but acting in reinforcement is a key finding of this thesis. Below a threshold of approximately 6-8%, variations in brightness are not generally perceived and have no influence on navigation. As the difference in lighting variance increases so too does its effect upon player navigation. This effect falls off once the lighting effect is very clear and obvious, in these studies, it is suggested that a lighting cue can become dominant at an increase in on-screen illumination of approximately 25%. As motion cues have also been demonstrated to be dominant navigational cues, the combination of motion and light creates a reinforcing navigational cue combination. These studies confirm that the navigational influence of both established architectural and wayfinding principles hold true in a virtual environment and that the influence these features have is reinforced by the addition of lighting.

The findings in this thesis confirm that the intuitive design decisions that have led to games designers using subtle lighting, audio and motion as cues are effective in drawing the players attention and where applied appropriately have a significant influence on the navigational choices that players make in virtual environments. Via a series of novel studies, it was confirmed that the principles of both wayfinding behaviour (P. Arthur & Passini, 1992; Downs & Stea, 1973; Foltz, 1998; Lynch, 1960) and architectural navigational behaviour (Dalton, 2003; Golledge, 1995; Peponis et al., 1990) not only hold true in a virtual environment, but can be significantly enhanced by the introduction of additional lighting cues.

The findings of the study into change blindness found that players do not readily process or store information about light, colour or contrast. It was predicted that light and colour variance would be entirely unnoticed as gradual change blindness experiments had shown that colour changes are barely perceived. This study demonstrated a novel approach that allowed most textural aspects of a scene to be replaced without the players being aware that this had happened. These changes include value shifts, changes to material types and broad features such as the number of stripes on a wall. The duration of these changes can be as brief as 11 seconds and remain undetected unless the item undergoing change commands visual attention.

Future work should assess the navigational influence of different types of audio. In these studies, an aversive ambient cue was navigated towards, and contextualised audio cues may have differing effects. Analysing the effect of for instance more pleasant sounds or different types of music or disembodied voices could lead to similar guidance for designers as has been produced concerning lighting and that has been validated in relation to physical and architectural cues.

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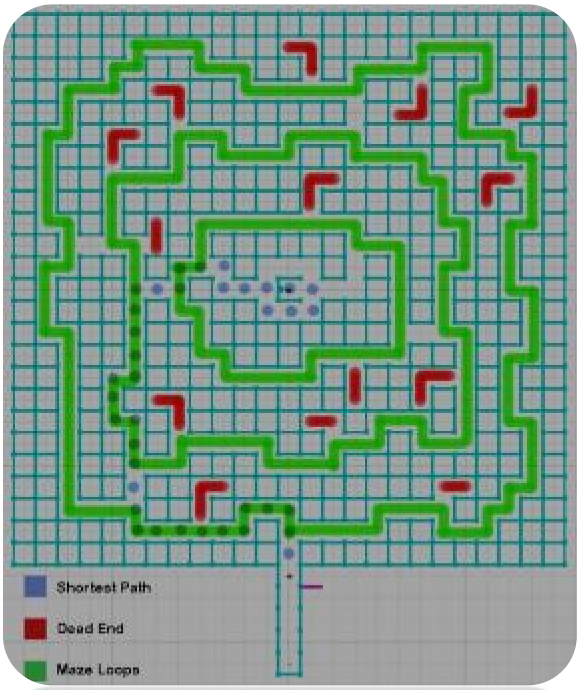
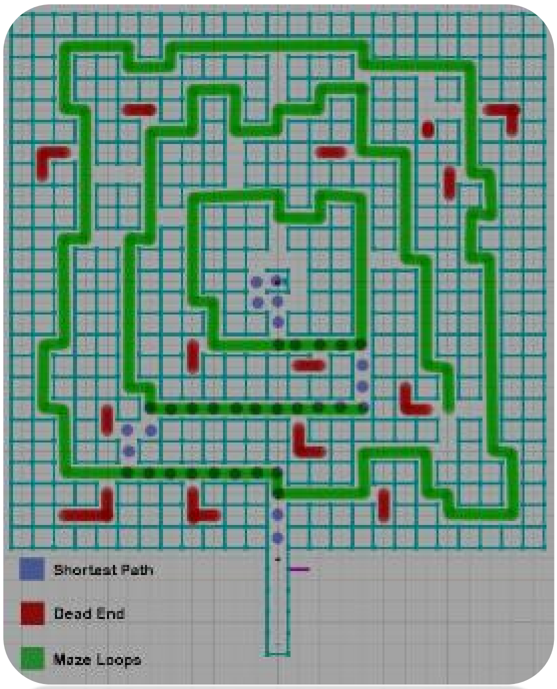
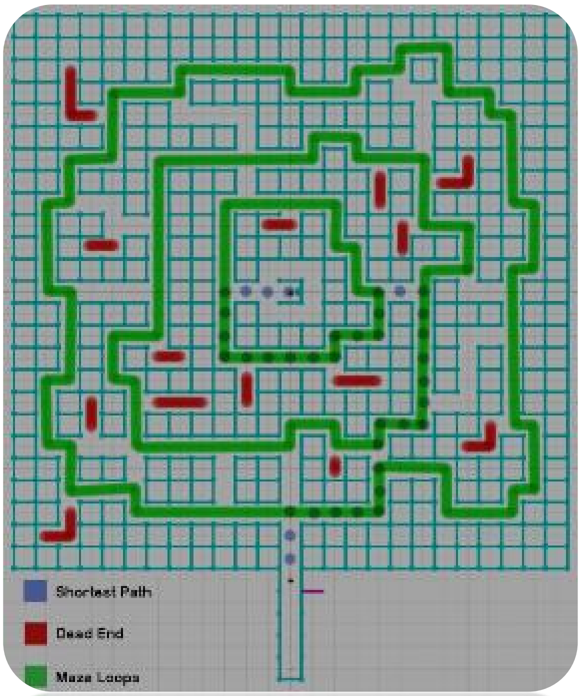
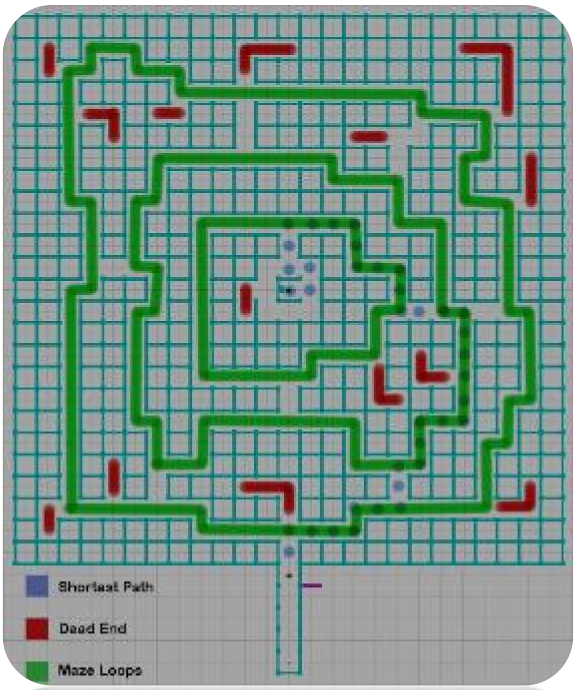
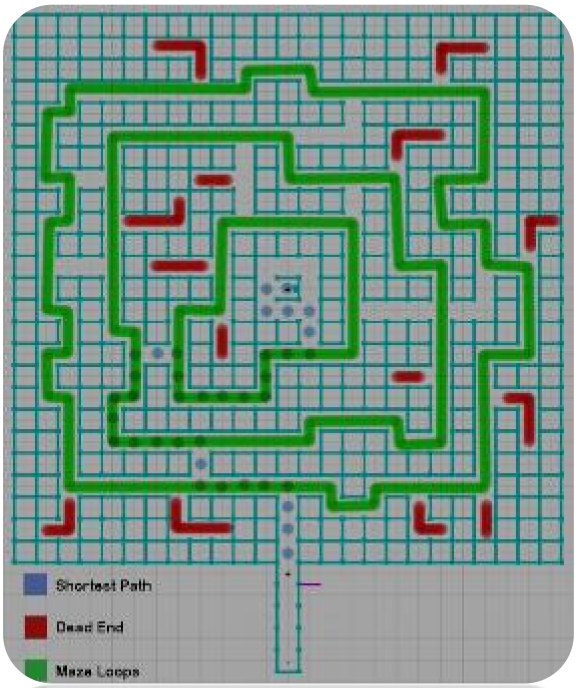
# 15 APPENDIX ONE: MAZE DIAGRAMS

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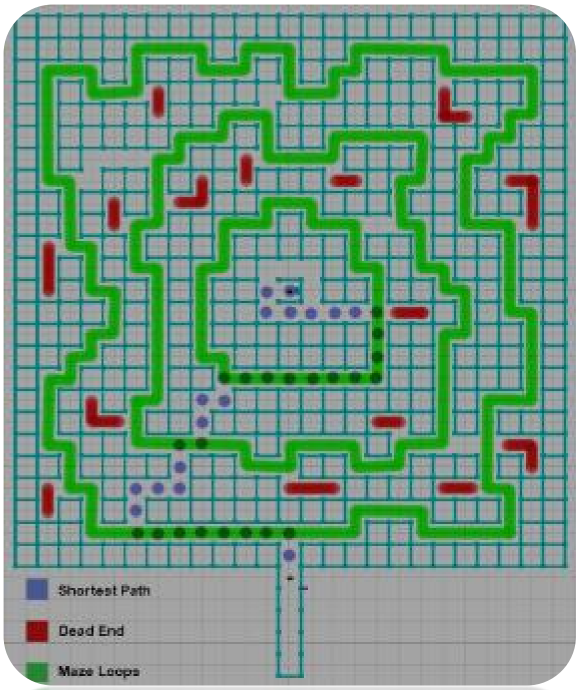
Maze Loops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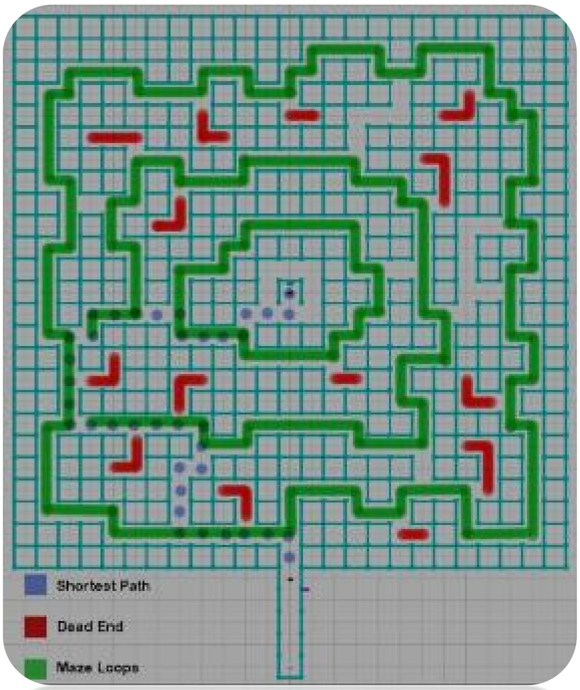
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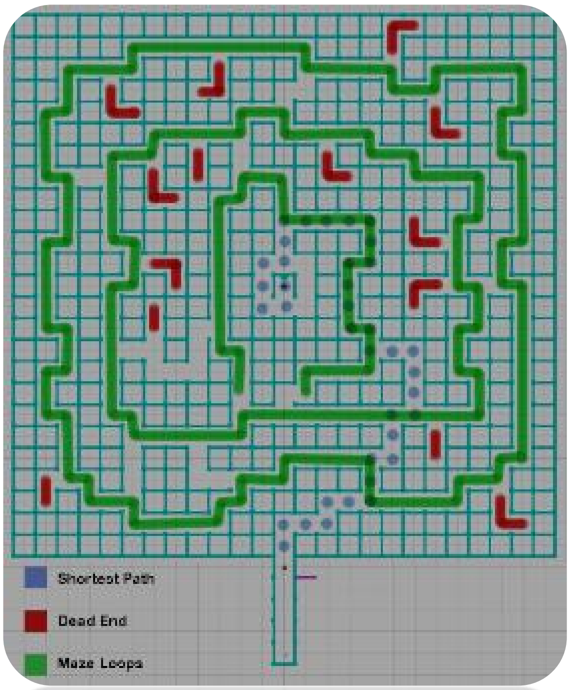
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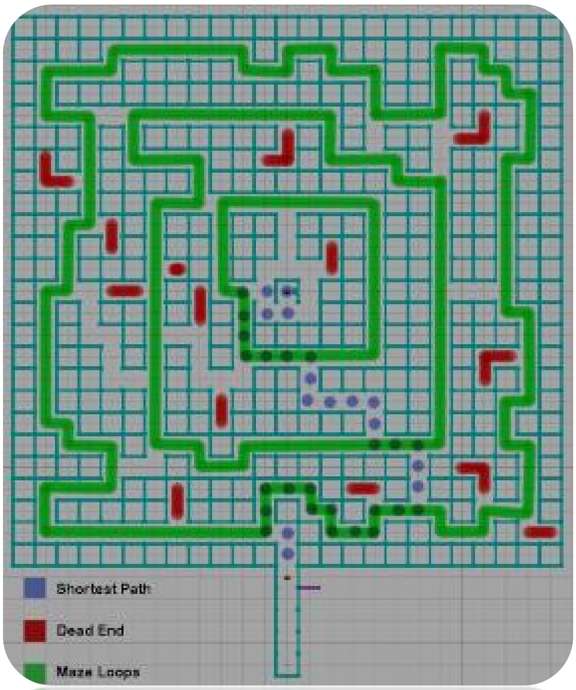
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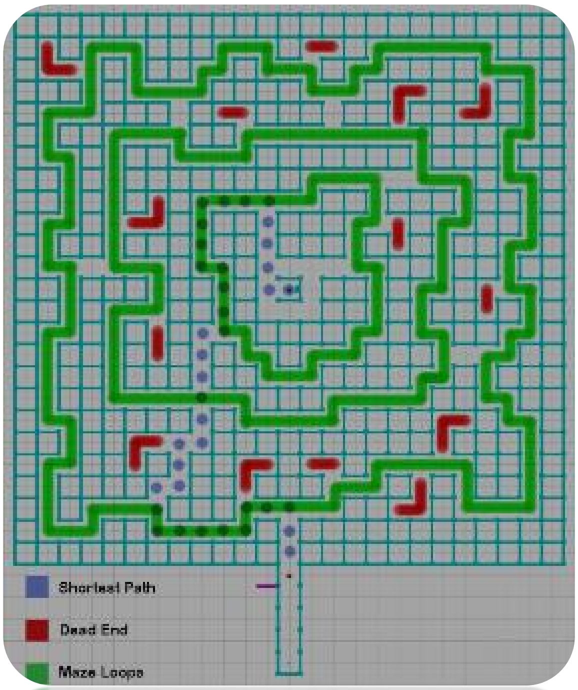
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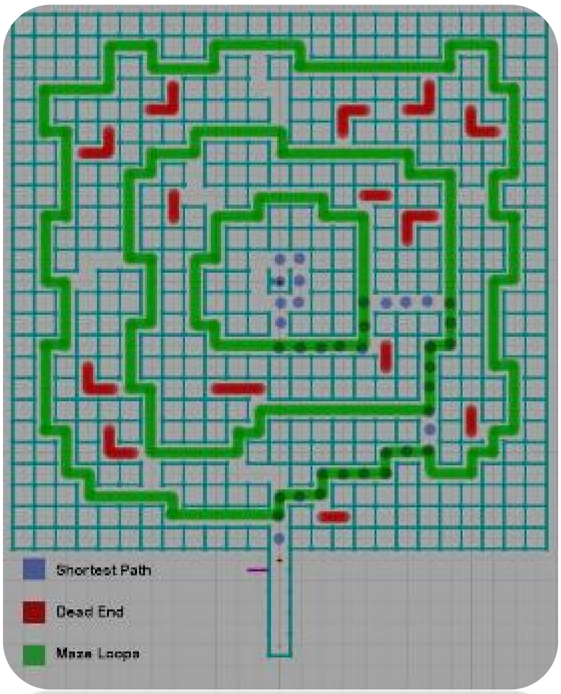
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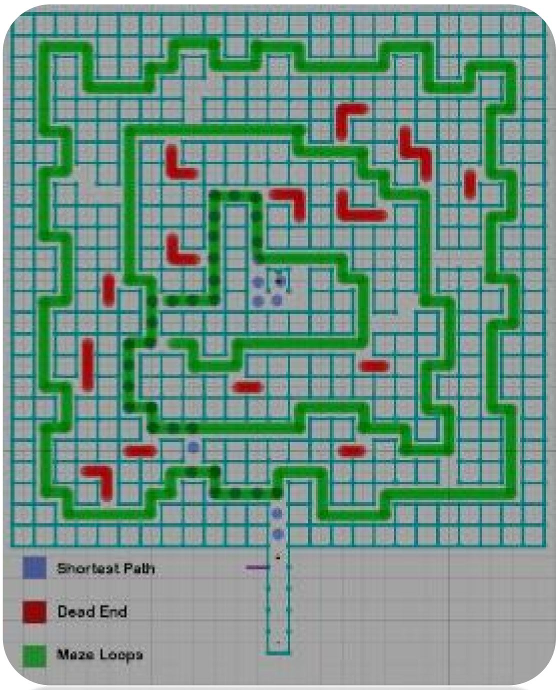
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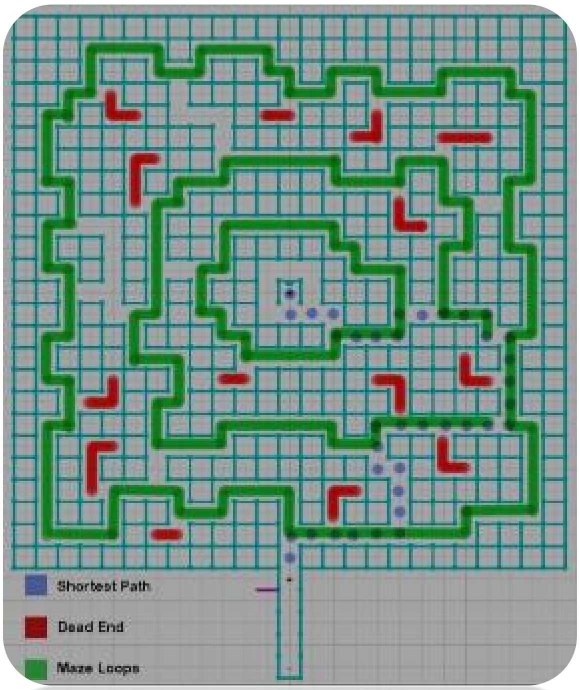
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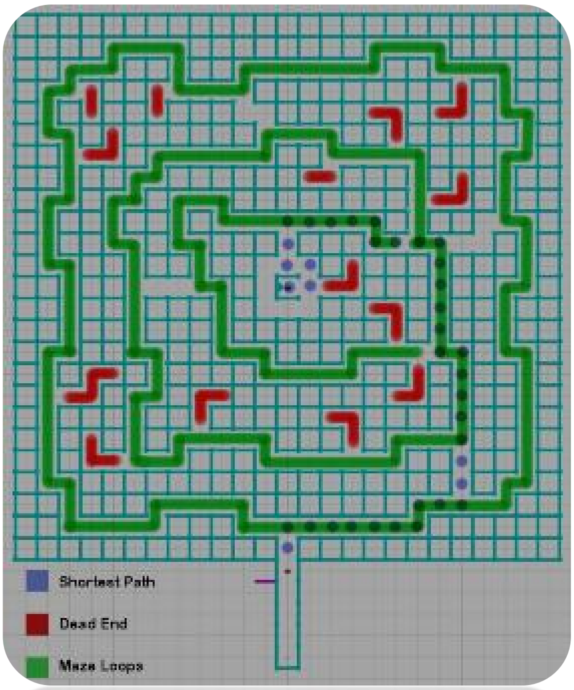
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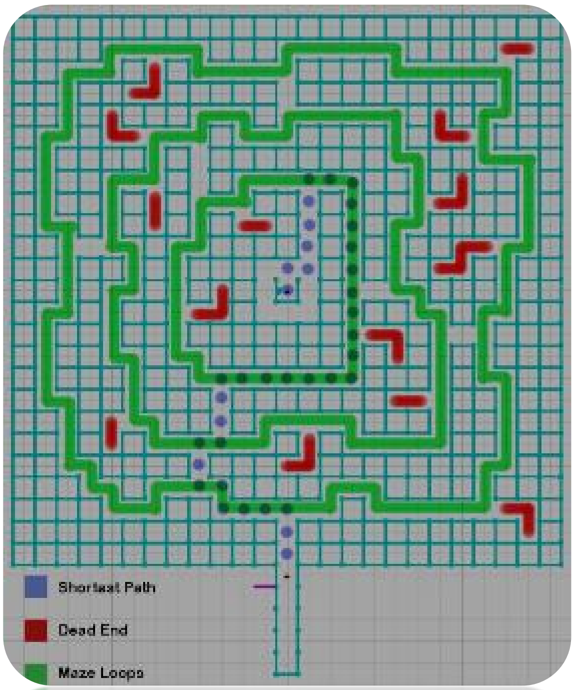
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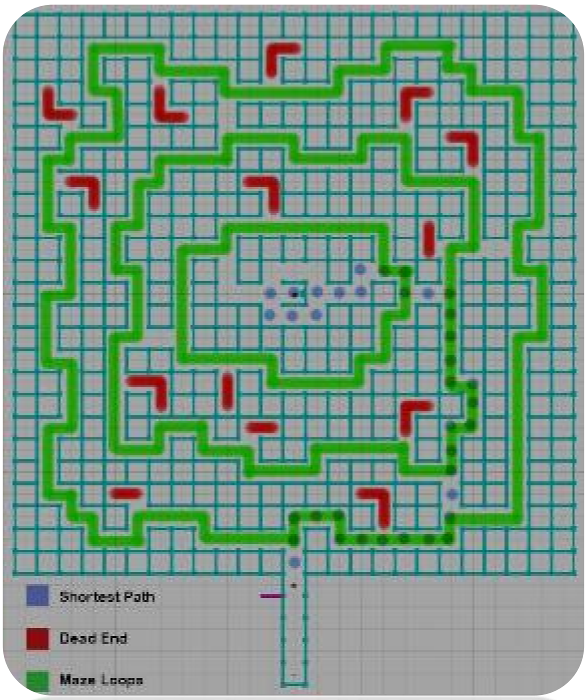
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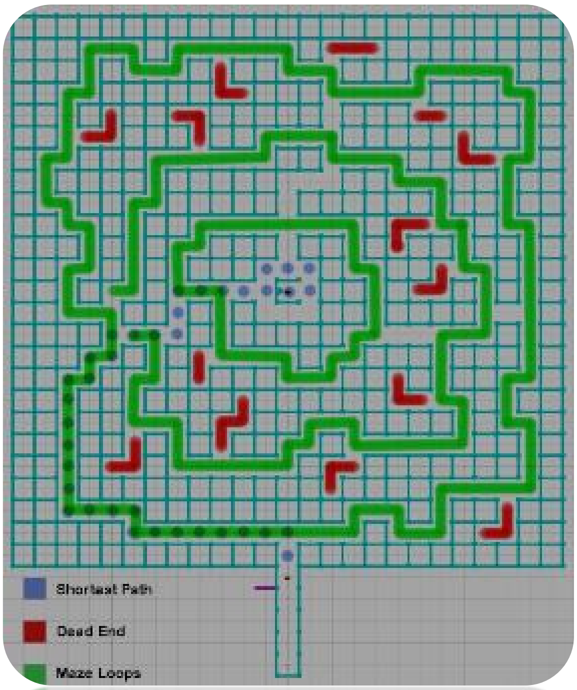
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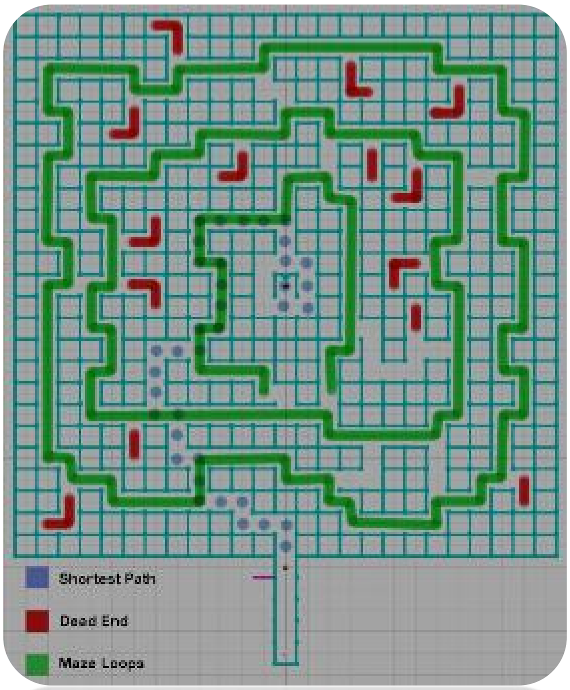
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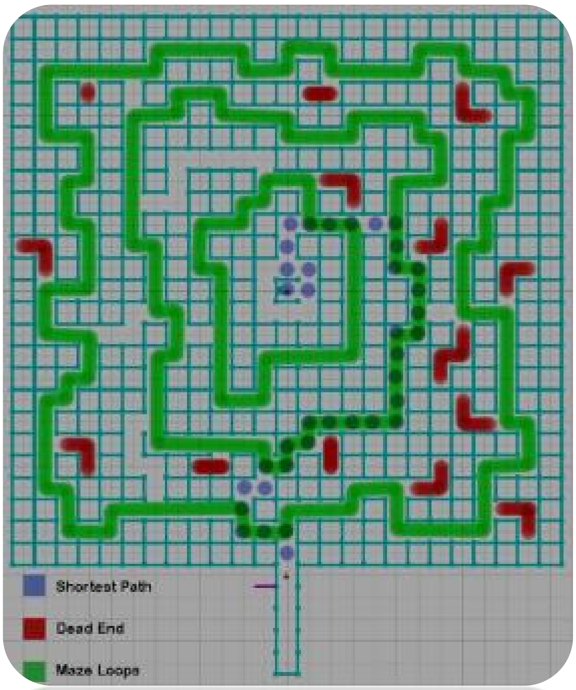
Dead End
Maze Loops


Shortest Path
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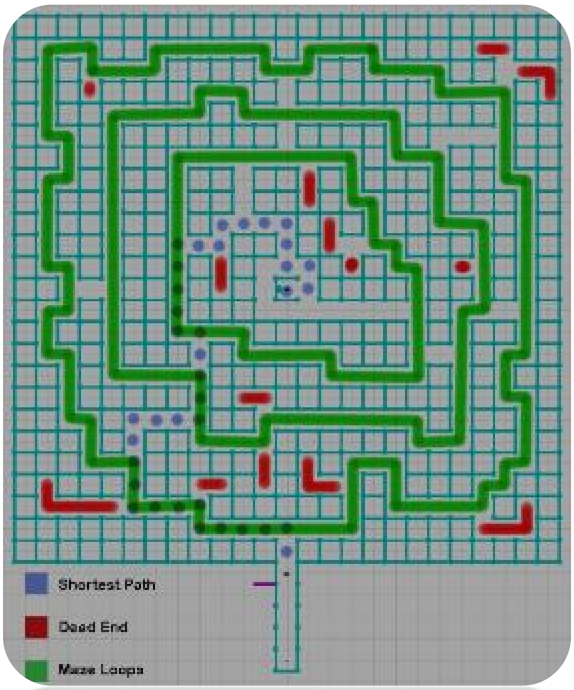
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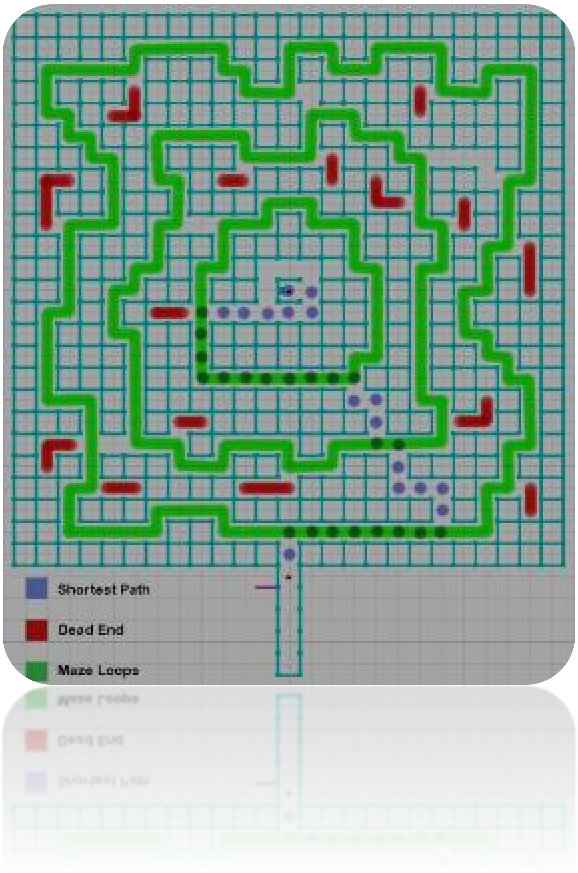
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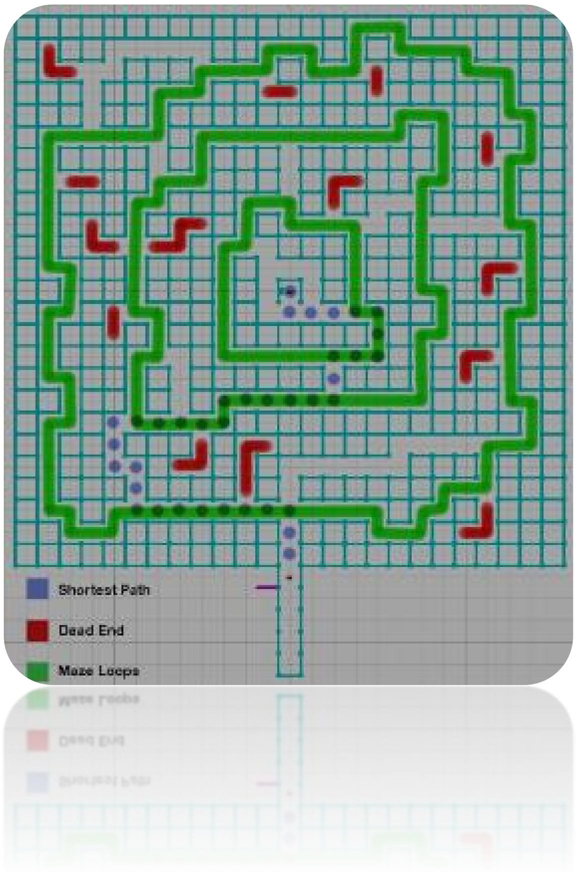
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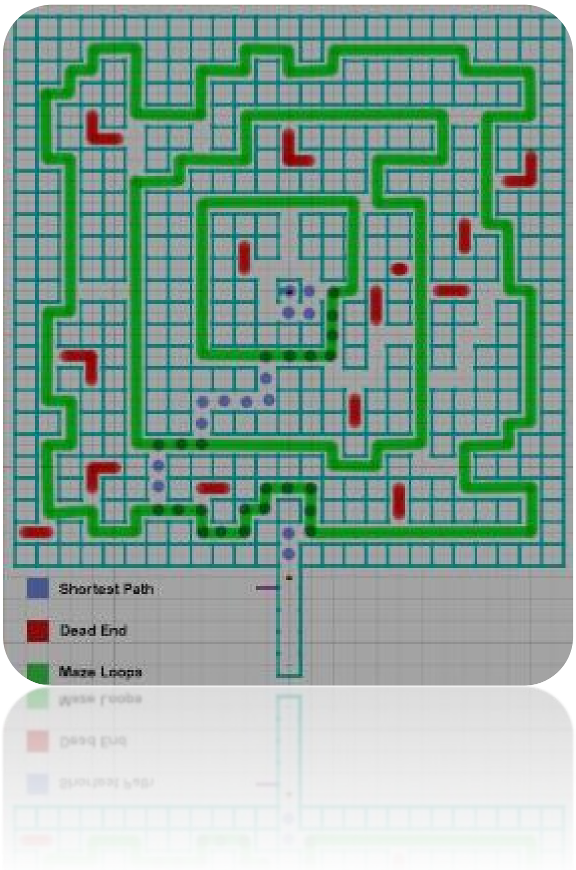
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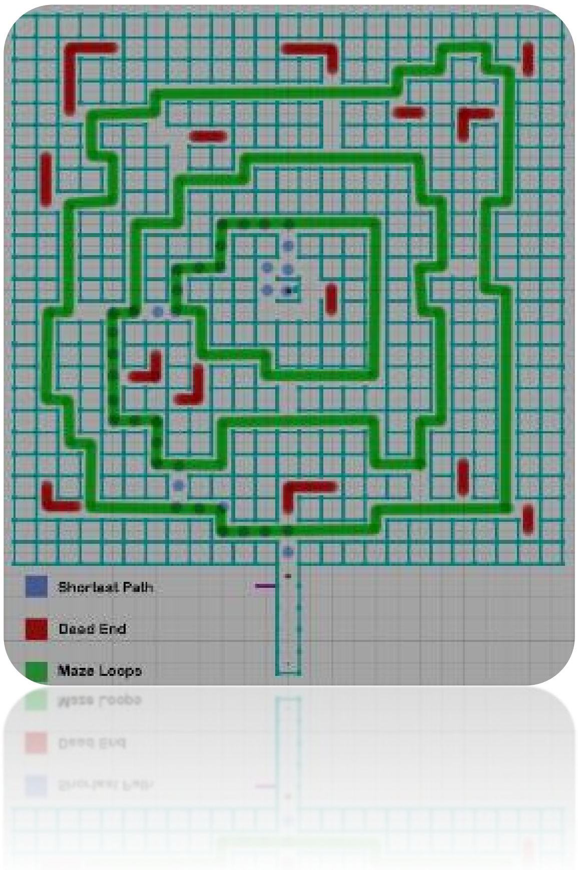
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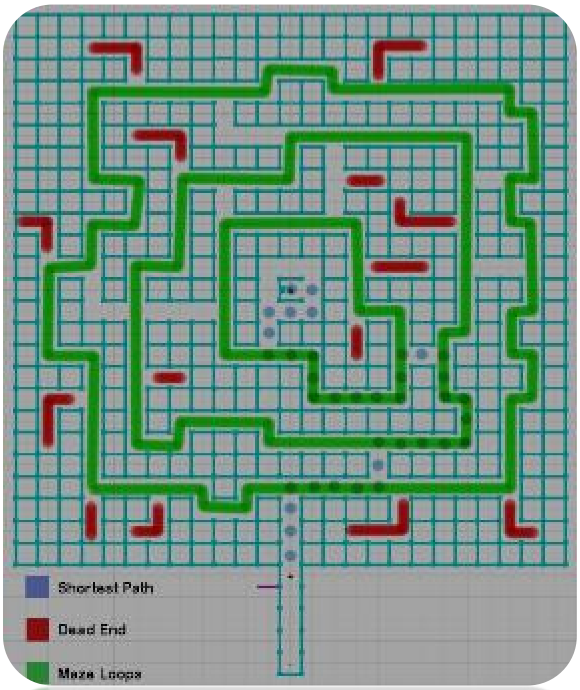
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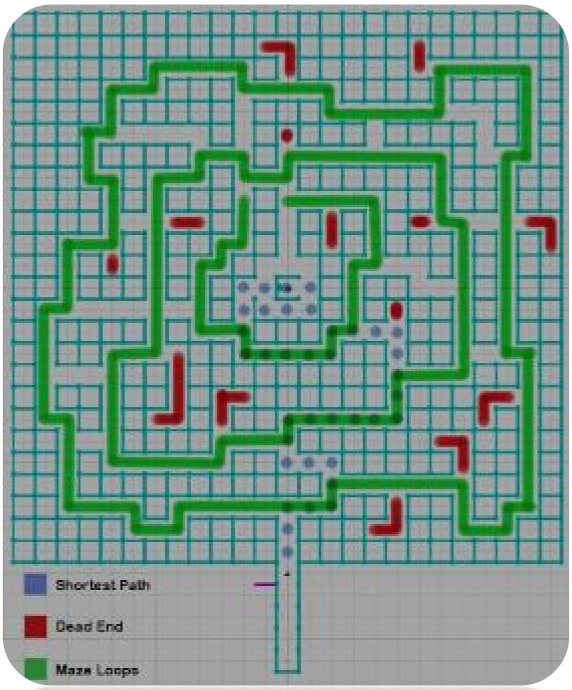
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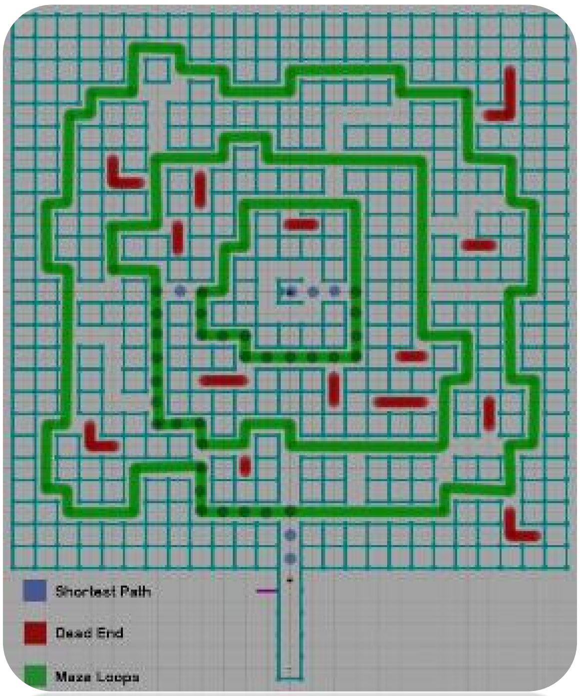
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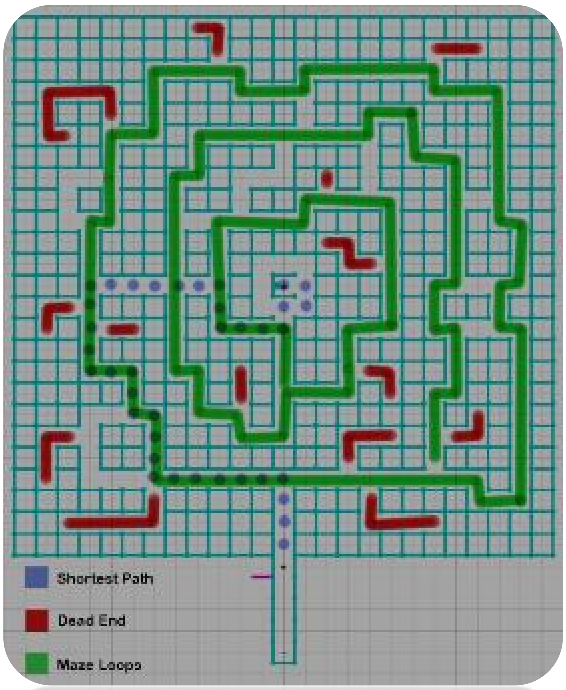
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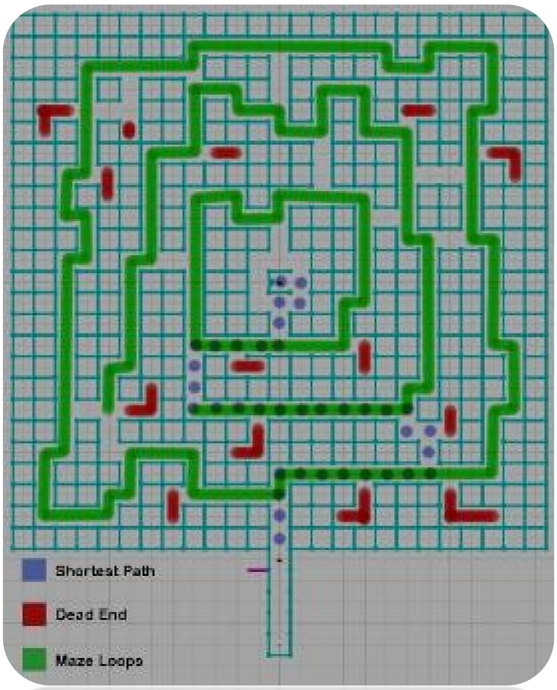
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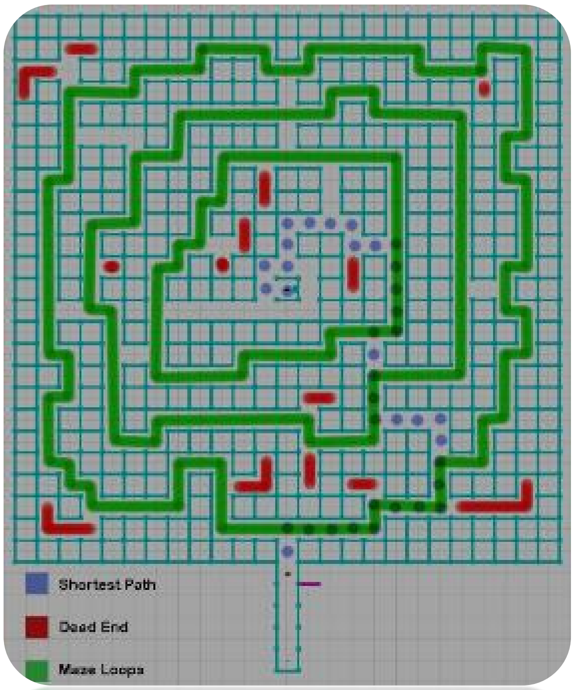
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