How effective is Virtual Reality as a research tool for simulating gambling environments in psychological studies?

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Author,
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Statement of Originality

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Abstract

The work presented in this thesis aims to design, develop and investigate the effectiveness of a Virtual Reality (VR) tool for conducting research in gambling behaviour. The majority of existing gambling studies are conducted in laboratories, rather than *in vivo*, raising questions over the generalisability of results [1]. VR is well established as an effective tool for exposure therapy, often motivated by an ability to create ecologically valid conditions whilst retaining experimental control, which is difficult to do *in vivo*. Whilst VR has also been used in some gambling studies, no work has considered how VR environments should be designed to best create ecological validity, and the differences in experience between laboratory and VR conditions. This thesis presents the process of designing and developing a VR tool, featuring a gambling task and VR environment to create an experience of gambling in a betting shop. A prototype artefact was tested within a pilot study to identify and fix bugs prior to starting user studies. Approached from the perspective of immersion, arousal and user experience; a within-subjects study (N = 48) was conducted. During this, participants were tasked with playing through the gambling task on a touch-screen tablet in a laboratory, before repeating the same task on a Virtual Gambling Machine (VGM) within the VR simulation of a betting shop. Subjective measures were applied to measure immersion, emotional involvement and workload. The results of user studies show that participants reported higher levels of arousal, in addition to higher levels of immersion in the gambling game when playing in VR. There was also a significant difference in self-reported physical task load in VR. These findings suggest that VR offers high levels of immersion which enable a user to better engage and focus on a research task, without a negative impact upon cognitive workload due to the VR equipment. Increased levels of arousal in the VR condition also mirror affects observed in existing work comparing *in vivo* conditions to laboratory-based methods [2], [3]. Based on these findings, we argue that VR should see wider use within gambling research, and propose that future work should compare VR with *in vivo* methods. This thesis also details the design and development steps required to create a tool which can effectively combine ecological validity and experimental control, demonstrating how key challenges were tackled and offering insight for future work. Additionally, the work presented in this thesis resulted in the creation of a VR environment which was designed and implemented to accommodate any gambling task. This VR tool offers psychology researchers the opportunity to create a game suited to their research needs and easily integrate it into a VR environment, offering ecological validity for experiments with little additional effort. This integration system can be ported into any VR environment created within the Unity engine to help suit the needs of specific research.

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Chapter 1

Introduction

Gambling represents a significant sub-sector of the UK leisure industry. The UK Gambling Commission estimates that 63% of adults engage in some form of gambling activity each year [4]. However, a significant number of gamblers suffer the effects of addiction and associated negative consequences: in 2017, the commission estimated 300,000 "problem gamblers" in the UK, with more than 500,000 individuals at moderate risk [4], [5].

Such statistics motivate significant amounts of researched conducted into the psychology of gambling, with the objective of understanding and mitigating factors that contribute towards problematic behaviour. This includes, for example, understanding player responses to game features [6], environmental factors [7], and the effectiveness of intervention techniques [8].

The majority of experimental research within gambling is conducted in laboratory environments, rather than *in vivo*, resulting in criticisms over how well the results generalise to real-world contexts [1]. Laboratory-based studies are criticised for being unable to provide ecological validity, unlike studies conducted *in vivo* which offer this at the cost of experimental control. Consequently, efforts have been made to use virtual reality (VR) as a means to combine ecological validity with high levels of control, and this has frequently been leverages for psychological treatments such as exposure therapy (e.g. [9]–[12]). VR has also been used in a small amount of gambling research to evoke an urge to gamble, as a therapeutic tool (e.g. [13]–[15]). However, the use of VR as a platform for behavioural research warrants a closer consideration of user experience and response whilst engaged with the VR system. As with laboratory settings, researchers are required to make informed judgements about participant engagement, how results might generalise, and the design of simulations and experimental scenarios. No existing work has yet addressed this.

These concerns regarding participant engagement, generalisability, and the design of simulations and experimental scenarios form the overall challenge that this project aims to address. Thus, exploring whether VR might be used to provide more effective experimental environments for gambling research than that of a laboratory.

Gambling research presents challenges in terms of ecological validity, so this is approached from a user experience perspective. Thus, the results presented in this thesis are from a within subjects study (N=48) in which immersion, emotional response, and workload were evaluated for a touch-screen gambling game. The game was played both in a laboratory environment, and on a simulated Electronic Gambling Machine (EGM) in a VR betting shop. Results show self-reported increases in player immersion in the gambling game, while in the VR condition, along with increased feelings of arousal and dominance. Additionally, the results show an associated increase in self-reported physical taskload when using VR. No previous work has undertaken a comparable analysis.

Based on the results, we argue that VR should see wider use in gambling research, providing a greater sense of player engagement as a direct consequence of higher reported immersion. Participants are more engaged with the gambling task, removing themselves from any experimental context and perhaps enabling more authentic behavioural responses to gambling stimuli. Furthermore, the results show that utilising VR does not impose higher cognitive workload on the participant, only requiring greater physical effort which is likely representative of *in vivo* studies. Further work within groups of regular and problem gamblers would be advantageous to fully understand the wider implications of these findings and better understand the limitations of VR as an experimental tool. Additionally, future work could aim to gain a better understanding of how VR-based experiments might compare to *in vivo* studies by comparing these two methods.

The remainder of this thesis is structured as follows:

Section 2 presents a comprehensive discussion of existing literature related to the research topic. This includes the importance of creating a VR experience which is coherent with real-world experiences, the measurements used in this study relevance to experimental research and presents existing psychology work that used VR. The information established in section 2 informs design decisions related to both the user study and VR artefact.

Section 3 re-iterates the motivations and challenges related to this study and establishes a clear list of research questions and hypotheses, forming the study overview.

Section 4 provides a detailed overview of the design and development process for creating the overall artefact, consisting of a gambling game and VR environment. This section is informed by section 2 and aims to detail the steps required to create a VR tool which can be used to measure gambling behaviour. Specifically, the challenge of creating a coherent user experience whilst maintaining experimental control for research purposes.

Section 5 forms the study methodology, detailing the quantitative measures used and how they were administered during the study. This builds upon much of the information established in sections 2.2.1, 2.2.3 and 2.4. Section 5 also presents information regarding the study sample, process, additional measures (qualitative), and information that was collected regarding participants.

Section 6 presents the results of the study and a discussion about what implications those results might have. Conclusions regarding the established research questions and hypotheses are addressed in this section and qualitative data is presented to support this. Additionally, limitations of the project are discussed in this section, including the study sample and measures used.

Section 7 concludes the thesis, summarising key points from section 6 and suggesting potential future work that might build upon the findings of this project.

Chapter 2

Related Work

2.1 Presence

Virtual reality (VR) simulations are characterised by a strong sense of *presence* experienced by users, a term which is often described as a sense of "being there"; that is, of being present in another physical space. Witmer and Singer [16] provide a more comprehensive definition, explaining that presence is a psychological state of *"being there mediated by an environment that engages our senses, captures our attention, and fosters out involvement"*. This definition not only describes the experienced sensation of presence, but also factors which Witmer and Singer found to contribute to the sense of presence. The concept itself originates from work by Minsky in 1980 [17] which coined the term *telepresence*, describing how a human operator may feel whilst interacting with a teleoperator system. These teleoperator systems enabled its user to control a remote machine using their own limbs and to also see through the "eyes" of the controlled machine. This idea was transplanted to VR during the 1990s, whereby a participant using VR technology had a sense of being within a virtual environment [18]. Since then, the phenomenon has been extensively investigated and categorised by researchers, for example Witmer and Singer [16], and Slater and Wilbur [19]. Much of the existing work aims to develop a better understanding of exactly what presence is and how it is influenced. Skarbez et al. [20] recently presented a review of research related to presence and similar concepts. The review collates and discusses a significant amount of research surrounding presence and forms the basis for defining presence throughout this chapter.

Skarbez et al. [20] describes that a potential shortcoming of presence, specifically as a generalised measure, is that it does not account for how realistic the presented scenario is. However, some scenarios may require as accurate a representation of a real-world counterpart as possible. This is particularly apparent in applications which have an emphasis on training the participant, such as surgical and military simulations, or perhaps even applications which focus on the treatment of addictions and phobias. The most relevant measure of realism for virtual environments is *fidelity*, defined by Alexander et al. [21] as, *"the extent to which the virtual environment emulates the real world"*. One sub-category of fidelity is *physical fidelity*, which covers a number of different dimensions including visual and auditory. Visual stimuli are present in most VR applications, whilst auditory stimuli may not always be present. Despite this, visuals are the more challenging of the two stimuli to effectively and realistically simulate within virtual environments. Visuals with high levels of realism are impossible to achieve due to limitations in technology, as VR equipment requires a substantial amount of computation power to run without the additional processed associated with visual models and graphics. Additionally, with regards to replicating humans and their behaviour, high levels of realism can result in an unsettling feeling known as the *uncanny valley*. This feeling describes where too high a degree of human realism evokes an un-pleasant impression in the viewer [22]. Despite the challenges and complications associated with creating realistic environments, Skarbez et al. explains that fidelity is logically orthogonal to immersion. Meaning that it is possible to create a high level of immersion in unrealistic scenarios, as well as being possible to create high fidelity in low-immersion media.

Slater [23] addresses confusion linked to presence as a construct, proposing a theory that presence is composed of two components termed *place illusion* (PI) and *plausibility illusion* (Psi). He defines PI as, *"the ... illusion of being in a place in spite of the sure knowledge that you are not there"*, corresponding to the conceptualisation of spatial presence and a sense of "being there". As aforementioned, this concept of spatial presence was first observed by Minsky [17] in 1980, referring to phenomena which was present during the operation of a teleoperator machine. As Minsky's original term *telepresence* was applied to VR technology [18], it is reasonable to accept Slater's definition of place illusion as a component of presence. Furthermore, the term *place illusion* emphasises referring specifically to a strong illusion of being in a place, and not other meanings that have been attributed to presence [23]. This emphasis further specialises the term for use when describing spatial presence for virtual environments. Alternatively, Psi is defined as, *"the illusion that what is apparently happening is really happening (even though you know for sure that it is not"*. Slater provides a comprehensive example from a previous study [24], which better distinguishes the two components:

> *"Consider in a virtual reality there is the appearance of a woman standing in front of you. Perceptually there is something there ... as you shift your head from side to side, her image in your visual field moves as it would in reality. This is PI. Now she smiles at you and asks you a question, and you automatically find yourself smiling back and responding to her question, even though you know no one is there." [23]*

The process of the virtual woman smiling, and a participant's willingness to respond would indicate that the participant is under the illusion that what is happening is really happening. This example highlights Psi as a description of a cognitive process as opposed to PI which refers to a perception of spatial presence. A potential flaw with this scenario is the possibility that the participant simply responded out of a willingness to complete a set task, as opposed to believing that the scenario was real. Nevertheless, by introducing Psi making it comparable to PI, Slater helps to recognise fidelity and correct behaviour as important components of any virtual experience.

In the same article, Slater states that *"immersion provides the boundaries within which [place illusion] can occur"* [23], implying that immersive systems, such as VR, enable PI. Skarbez presents an argument against this statement, explaining that there must be an objective characteristic for a virtual scenario in order to give rise to PI [25]. He proceeds to define *coherence* as a set of reasonable circumstances which can be demonstrated by a scenario, explaining that a reasonable circumstance is a state of affairs in a virtual scenario what is self-evident given prior knowledge [25]. For a virtual environment to meet this definition, it does not need to strictly represent the real world but instead that of a scenario that is provided. Consequently, a coherent environment is considered high-fidelity provided that its logical and behaviour components are consistent with that of the context provided. Skarbez provides the following example to better explain coherence:

> *If one had been led to believe that he or she is going to experience a virtual fantasy world, then the appearance of a character flying hundreds of feet in the air would be coherent behaviour. On the other hand, if one had been led to believe that he or she is going to experience a realistic training scenario, the very same behaviour would be incoherent[.]" [20]*

This differs from research conducted by Gilbert [26] which defines *authenticity*, as it does not discriminate between virtual environments that attempt to replicate real world scenarios and those which are oriented towards fantasy scenarios. Authenticity instead refers specifically to a user's expectations of a virtual environment given their prior experiences in the real world. Consequently, this definition is more applicable to VR applications with an emphasis on replicating real scenarios and environments. It does not blur the concept of realism by allowing for contexts to be created and applied to a virtual environment, instead forcing a real-world context. Skarbez attempts to argue that both authenticity and coherence are different terms for the same construct [20], but provides no reasonable explanation as to why. Therefore, for the purposes of this project, the two terms will be treated independently. Authenticity is therefore more representative of the type of experience this project aims to create, as it is focused on producing an environment which emulates a real-world setting and scenario as accurately as possible.

Embodiment is a major component of presence discussed in existing research. Within computing literature, embodiment refers to the representation of a user, as an avatar, within a mediated or virtual environment. This is loosely defined by Gabbard as *"representing the user within a VR"* [27], and more comprehensively explained by Benford et al. as *"the provision of users with appropriate body images to represent them to others (and also to themselves) in collaborative situations"* [28]. Both of these definitions imply that there is a requirement for the player character to be visually represented within the virtual environment in order for the user to feel embodied. It is therefore clear that embodiment, under its definition within computing literature, requires visual stimuli which represents the user. This differs from definitions given in psychology and philosophy literature, whereby Blanke and Metzinger state that embodiment includes, *"the subjective experience of using and 'having' a body"* [29]. De Vignemont also explains that, *"E is embodied if and only if some properties of E are processed in the same way as the properties of one's body"* [30]. These definitions emphasise the experience of controlling a virtual body through movement, and seeing that movement replicated by the virtual body as accurately as possible. This definition is more in-accordance with Slater's research [23] which states that the sensorimotor contingencies (SCs) present within immersive technologies, such as VR, assist in creating an illusion of presence. SCs refer to the actions that individuals know to carry out in order to perceive, such as moving their head and eyes to change the direction in which they are looking [23]. VR provides a means for approximating these SCs within a virtual environment, creating accurate movement and visual perception. Fundamentally, embodiment is considered to be a combination of the two definitions, whereby a representation of the user as an avatar must be present within a virtual simulation and this representation must also react as accurately as possible to user movement, including that of the head-mounted display (HMD) and any other controller devices.

This section discussed conceptualised definitions of presence and its components. The recent literature does not contradict one another, instead building upon concepts to form a concrete framework from which presence can be understood, measured and discussed.

2.2 Immersion

There is sometimes confusion between the terms *presence* and *immersion*. This is because the definition of *immersion* can differ depending on contexts. In the context of VR, the term *"immersive"* is used to refer to objective characteristic of VR systems [31], such as the resolution of a HMD or fidelity of its tracking system, whilst presence refers to the experience of the user, mediated by how immersive the system is. In the broader context of games, immersion takes on a different meaning. However, Jennett et al. explains that whilst there seems to be a broad understanding of the term within the gaming community, it is unclear as to what exactly the word means and what causes it [32].

Brown and Cairns [33] made an effort to further understand immersion in games, by conducting a study in which seven "gamers" were asked to talk about their experiences playing computer games. The results of this study formed a grounded theory that immersion is linked to involvement, and is directly limited by several barriers stemming from a combination of human, computer and contextual factors. In turn, these barriers were used to deduce three distinct levels of immersion. The first is "engagement", reached by overcoming the game preference barrier which required the investment of time, effort and attention into learning how to play the game and understanding its control scheme. The second level is "engrossment" which is reached by overcoming the game construction barrier. At this level, the player is no longer consciously deciding which controls to use, and their emotions are being directly affected by the game. Study participants describe this as, *"[a] zen-like state where your hands just seem to know what to do, and your mind just seem to carry on with the story"* [33]. After overcoming the barrier of empathy and atmosphere the player is able to enter the highest level of immersion, dubbed "total immersion". During Brown and Cairns' study, participants described this as feeling like the game is all that mattered, as they felt cut off from reality and began experiencing a sense of presence [33]. Total immersion required the highest level of attention and was the rarest of the three experiences, whereas engagement and engrossment were more likely to occur [32].

In another study, Haywood and Cairns took a qualitative approach to considering the engagement of children when interacting with a museum exhibit [34]. From this study, Haywood and Cairns discovered some key features of engagement: participation, narrative, and co-presence of others. Both participation and narrative suggest that individuals can experience immersion once there is a basic progressive structure which allows them to apply their own ideas to better understand an interactive system [32].

The results of this research suggest that *immersion* can be defined by attributing it to a set of descriptive features [32]. Brown and Cairns mention that as players become more immersed, they lose track of time as a consequence of focusing more upon the game and becoming more involved [33]. Furthermore, Brown and Cairns reported that players begin to lack self-awareness and are less aware of their surroundings as they become more immersed [33]. Finally, both Brown and Cairns [33] and Haywood and Cairns [34] seem to closely attribute immersion with involvement, often using the words interchangeably throughout their reports. To summarise, these findings suggest that the features of immersion are as follows: lack of awareness of time, loss of awareness of the real world, involvement and a sense of being in the task environment [32]. Witmer and Singer define immersion as *"a psychological state characterised by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experience"* [16]. This definition is consistent with both the context of VR and games, each of which offer a sense of presence once immersed. Therefore, whilst defining immersion is dependant on context, it is directly associated with a sense of presence regardless of context.

It is understood that the objective characteristics of VR make it an inherently immersive system by definition, however, it is interesting to consider how this effects sensations of immersion for games played through the system. In this project, immersion is compared when playing a game within both a virtual environment, and on a touchscreen tablet. The level of immersion in each scenario will be measured using the immersion experiences questionnaire (IEQ) presented in work by Jennett et al. [32]. Presence will not be measured. However, research has repeatedly shown that a sense of presence is experienced under immersive conditions, allowing for an understanding that VR technology enables a user to feel present within a virtual environment.

2.2.1 Immersive Experience Questionnaire (IEQ)

Jennett et al. [32] build upon existing work for immersion in games, to create the Immersive Experience Questionnaire (IEQ). Existing research findings related to areas of flow, cognitive absorption and presence, were collected and utilised by Jennett et al. when developing the IEQ. Whereby flow is described as the process of optimal experience, *"a state in which individuals are so involved in an activity that nothing else seems to matter"* [35], and cognitive absorption is defined as a state of being deeply involved with software [36]. More specifically, Jennett et al. begin by including Agarwal and Karahana's five dimensions of cognitive absorption: temporal dissociation, attention focus, heightened enjoyment, control and curiosity [36]. However, these are adapted to relate more specifically to a particular experience of a given task rather than the general experience of using software [32]. Jennett et al. also derive questions from Brown and Cairns [33], specifically emotional involvement which is associated with the "engrossment" level of immersion. This resulted in a total of 16 pairs of related questions being present in the original version of the IEQ. Jennett et al. then ran a series of 3 experiments, where the second experiment led to five main factors being realised: cognitive involvement, real world disassociation, emotional involvement, challenge, and control. These factors directly relate to a user's sense of engagement and involvement during game play and are used during the analysis of the IEQ. Overall, Jennett et al. provided evidence that immersion can be measured subjectively, through the use of questionnaires, as well as objectively. Furthermore, the IEQ is provided as a means for measuring immersion which was refined to consist of 31 questions related to each of the five main factors [32].

The IEQ will be used in this project as a means to subjectively measure immersion across the two conditions, asking participants to report upon their experiences in each. Jennett et al. acknowledge that questionnaires can be problematic because they rely upon participant' subjective opinions [32], but explains that this problem will be overcome by searching for objective measures to support subjective measures. The first experiment presented by Jennett et al. confirms that this issue was indeed tackled during the development of the IEQ. Subjective immersion ratings, collected through the questionnaire, were compared with objective measures of immersion. Firstly, results suggest that participants who reported a higher sense of immersion took longer to complete a tanagram task after playing, implying a decreased ability to re-engage with the "real world" [32]. This supports the idea of a real world disassociation, creating a transitional period between being coming out of immersion in a game world, and returning to the real world. Secondly, Jennett et al. hypothesised that subjective self-reported immersion ratings would correlate with changes in eye movements, and that this was somewhat supported [32]. The third experiment found that, whilst pace of interaction was not significantly consistent with immersion scores, participants in an increasing pace condition experienced the highest level of anxiety and negative affect [32]. This supports Brown and Cairns [33] who suggested that emotional involvement is a key factor of immersion. Overall, Jennett et al. have covered a range of issues associated with subjective measures of immersion, demonstrating that IEQ results can be representative of those obtained through objective measures.

2.2.2 Presence and Emotional Response

Emotional response is an important factor in understanding gambling behaviour, and is often investigated by researchers (e.g. [37]–[39]). We explore this in our own study, and it is therefore useful to consider how VR mediates emotional responses in general.

Riva et al. [40] investigated the ability of VR scenes to invoke emotions, specifically anxiety and relaxation. In their study, sixty-one participants were exposed to three virtual environments in a randomised order, each intended to elicit different emotional responses. Detail is not provided about the exact composition of these virtual environments, however, Riva et al. explain that a shared layout was used and VR environments only differed in the aural and visual experience [40]. The study used three questionnaires to measure mood before and after each VR experience, specifically *Visual Analogue Scale (VAS)* [41], *Positive and Negative Affect Schedule (PANAS)* [42] and *State Trait Anxiety Inventory (STAI)* [43]. Two additional questionnaires were used to measure presence, specifically the *UCL Presence Questionnaire* [44] and the *Television Company Sense of Presence Inventory (ITC-SOPI)* [45]. No objective measures were used in the study. However, each of these questionnaires have been applied frequently throughout existing research. Riva et al. acknowledge this caveat, mentioning that the use of psychological indexes may help to obtain a more complete picture of emotional response [40]. Nevertheless, Riva et al. report an inter-relationship between presence and strength of emotional response, expressing that both the anxious and relaxing environments were effective in eliciting an emotional response which was coherent with their contents [40]. This suggests that VR is an effective medium for inducing mood and emotion. Similar observations were found by Brown and Cairns [33], when measuring immersion. They reported that participants became more immersed as their emotional involvement in a task increased. This could suggest a link between the results the Riva et al. study and general immersion within the task, under the definition provided by Jennett et al. [32].

A number of studies have also noted increased arousal when performing tasks performed in VR, using a HMD, as opposed to 2D screen-based interfaces. One such example of this is a study presented by Estupiñán et al. [46], whereby they aimed to investigate whether VR could be used to increase arousal and valence. Estupiñán et al. present this work as a pilot study, whereby participants were asked to observe an image for four seconds and were promptly asked to answer questions intended to measure valence and arousal concerning the image [46]. The questions themselves were based on works by Scherer et al. [47], and participants answered by click along a scale between 0 and 100, represented by a simple white bar on screen. The sample size for this study is small, inclusive of only ten participants, which creates concerns regarding the validity of the results. Nevertheless, Estupiñán et al. report that participants experienced a higher level of arousal in VR when compared to using a regular computer screen [46]. These results are consistent with findings from a study by Kim et al. [48] which used a more substantial sample size of fifty-five participants. In this study, Kim et al. [48] apply a modified three-dimensional version the Stroop task [49] to three representative virtual environment systems. These systems were a desktop PC, desktop PC with HMD, and a 6-wall virtual environment known as a Cave Automatic Virtual Environment (CAVE). Participants were instructed to locate two word cards within the virtual environment (green and blue word cards) whilst ignoring the colour of the word itself (i.e. a word spelled "RED" but coloured blue) [48]. By using this task, Kim et al. hoped to measure the effects of using a virtual environment on emotional arousal and task performance. The findings of this study report an increase in self-reported emotional arousal in both the CAVE and HMD conditions. This effect is observed regardless of task stress.

The results of both studies by Estupiñán et al. [46] and Kim et al. [48] suggest that VR systems evoke a greater emotional response, specifically arousal, when compared with 2D counterparts of the same scenario. When attributed observations by Riva et al. [40], which show a clear relationship between presence and a strong emotional response, we can infer that a high measured level of arousal is indicative of a high level of presence.

2.2.3 Self-Assessment Manikin

Bradley et al. [50] reports upon the Self-Assessment Manikin (SAM), a non-verbal, pictorial assessment technique that measures three emotional factors: pleasure, arousal and dominance. The instrument was originally devised as a combination of work by Lang [51], and Hodes et al. [52], and builds upon the Semantic Differential Scale (SDM) [53], a widely used instrument consisting of 18 bipolar adjective pairs rated along a 9-point scale. These paired adjectives are used to generate scores for pleasure, arousal and dominance. Bradley et al. explains that despite being informative, it is cumbersome to measure each of the 18 different ratings present on SDM [50]. Specifically, Bradley et al. explain that SDM requires a heavy investment of time and effort, and consequently results in a large database of statistics which require a high level of expertise to resolve [50]. The verbal rating system is also critiqued for being difficult to apply in non-English speaking cultures, unless translation and validation has been conducted, and also challenging to apply to populations who are not linguistically sophisticated [50]. In contrast, SAM uses only three measures as represented by pictorial scales, which each relate directly back to pleasure, arousal or dominance respectively.

In a study presented by Bradley et al. [50], seventy-eight participants were presented with images using a slide projector and asked to provide ratings according to the "emotional state" instructions used by Mehrabian and Russel [53]. Specifically, participants were instructed that twenty-one slides would be shown in total, each visible for 6 seconds, and that they were expected to report their ratings within a 45-second interval between each slide [50]. The collected ratings were then compared with those from a similar study by Greenwald et al. [54], instead reporting their ratings using SAM. Greenwald et al. also used 6-second intervals within which to show each slide. However, participants were only given a 15-second period to complete the SAM worksheet between slides and 60 pictures were shown instead of 21 [50]. During the study conducted by Greenwald et al. [54], participants were also provided with instructions which included a list of words from SDM to help identify the anchors of each dimension of emotion [50]. Upon comparing the results of these experiments, Bradley et al. found that dimensions of both pleasure and arousal were almost indistinguishable between both SDM and SAM [50]. Dominance was found to be less agreeable, showing insignificant correlation between the two experiments. However, Bradley et al. reports that, *"pairs showing the best agreement with dominance scores were the same for each instrument"* [50]. Upon further investigation, there is found to be a positive correlation between pleasure and dominance using SAM, where pleasant images are met with higher levels of dominance and unpleasant images have the opposite effect [50].

To summarise, these results show that SAM enables participants to effectively report each of the three factors of emotion, defined as pleasure, arousal and dominance. SAM is significantly simpler to complete and analyse than the SDM, presenting pictorial scales which can be correlated back to each of the three emotional factors. SAM is also far more time efficient to complete, allowing for immediate data collection after the completion of an experimental condition. This project will use SAM to measure emotional response in both the VR and 2D conditions, an important factor in understanding gambling behaviour.

2.3 VR in Psychology Research

VR technologies have been explored extensively by researchers in the fields of psychology and psychiatry. The majority of this work is concerned with therapeutic uses, such as exposure therapy and other applications focused on treating psychological disorders. This approach is called VR exposure therapy (VRET), which leverages a user's sense of presence to create platforms aimed at replacing *in vivo* methods.

The potential for VRET to replace *in vivo* measures has been recognised for some time. An early example of this can be found in a case report by Rothbaum et al. [55] dating back to 1996. Rothbaum et al. examined the efficacy of VRET to treat a fear of flying. The subject for the study was a 42-year-old with a debilitating fear and avoidance of flying, who met DSM-IV [56] criteria for a specific phobia. This individual was exposed to a number of sessions in VR, lasting 35-45 minutes each. In the scenario, the participant wore a HMD which visualised an environment in which they sat in an aircraft during take-off, flying, and landing, in both stormy and calm weather conditions [55]. The reported results of this treatment are astonishing. The participant, who had avoided flying since two years prior to starting the treatment, was able to complete a round-trip cross-country flight with minimal anxiety following the treatment [55]. Rothbaum et al. does however stress that it is unclear as to whether VR can be specifically credited for these results, explaining that this same treatment is available *in vivo* through exposure to actual aircrafts accompanied by a therapist [55]. However, Rothbaum et al. also mention that VR could be a feasible alternative in the future; subject to proving it as an effective treatment for more disorders, and also the equipment becoming more readily available.

More recently, Garcia-Palacios et al. [57] showed that VR was effective in treating arachnophobia. Garcia-Palacios et al. state some potential advantages of using VR over *in vivo* methods. Firstly, VR provides a high level of control over the environment present within the simulation, allowing for scenarios which may be impossible to replicate safely within *in vivo* experiments and treatment. Garcia-Palacios et al. state that *"VR gives the patient and therapist the ability to control the fear object"*. The provided example talks of how virtual spiders will obey *"commands"*, can be oriented within the virtual environment and can be touched without danger. This control over the feared object, in this case a spider, allows patients to safety control fears which are not easily accessible [57].

Logistical and financial advantages can also be attributed to VRET [57]. Take for example the previous work by Rothbaum et al., a process which exposed the subject individual to an experience of flying within an aircraft [55]. Therapists have previously reported numerous logistical problems and high expenses when attempting to create this sort of experience *in vivo*, such as purchasing tickets and renting a commercial jet for the purpose of privacy during treatment [58]. The logistics and costs involved in such a process are simply not present in VRET, replaced by the process of creating an environment which can be reused without incurring additional costs. Garcia et al. suggest confidentiality as another potentially problematic issue for *in vivo* treatment in specific situations [57]. Often participants may be reluctant to start treatment due to a lack of confidentiality. This is apparent in circumstances where the participant are embarrassed about their condition, which could be attributed to the treatment of specific addictions and phobias. VR facilitates confidentiality, allowing the patient and the therapist to control exactly who is present during the process, and who can see the participant undergoing treatment.

Some other examples of VRET being applied include the treatment of acrophobia [59], fear of flying [60], social anxiety disorder [9], and post-traumatic stress disorder [10]. The majority of this research took place during a time where VR was relatively expensive due to the additional equipment and software required [57]. However, the price of VR systems were dropping quickly with conventional desktop PC systems becoming powerful enough to handle the hardware and software demands [61]. Thus, modern VR equipment is more readily available to not only smaller businesses and institutions, but also the general public with the release of devices such as the *Oculus Rift*, *HTC VIVE*, and the least expensive, *Google Cardboard*.

Much of the research conducted before 2012 suggests that, whilst VRET produces similar results to other techniques, the observed effect size of these results are often smaller when compared to conventional cognitive behaviour therapy (CBT) [62]. However, a more recent meta-analysis, conducted by Valmaggia et al. [63], analysed 24 randomised controlled studies published since 2012, across a range of conditions. The findings suggest that published results for VRET are generally similar to conventional CBT and *in vivo* exposure [63]. However, Valmaggia et al. explain that the available evidence varied depending on the disorder which was under review, but confirm that multiple sessions of VRET can be valuable when treating certain conditions [63]. *Ecological validity* may explain why VRET is reportedly only valuable to the treatment of those specific conditions, a term derived from, *"the precise presentation and control of dynamic perceptual stimuli"* [63]. It should be stressed however, that "control" in this context refers to how an environment is controlled and behaves dynamically to influence how it is perceived when compared to reality. Despite appearing frequently in discussions of VRET applications, there is relatively little detailed consideration of how the design of environments and experiences moderate successful treatment, beyond observations that VR facilitates levels of control and personalisation which are not possible *in vivo*.

Botella et al. [11] emphasise the experience of emotions, specifically anxiety, as a key requisite of effective exposure therapy, and continue to explain that whilst some studies show significant correlations between presence and emotions [64], [65], many do not [59], [66], [67], or even find negative correlations [68], [69]. However, a meta-analysis performed by Ling et al. [70], which identified 33 papers with a total of 1196 participants, confirmed a positive relationship between presence and anxiety. Despite having a positive correlation, Botella et al. [11] indicate that more work is needed to better understand how requisite emotions of exposure therapy, such as anxiety and fear, interact with presence, and vice versa [11]. A greater understanding will enable designers to better manipulate the effects of VRET, enhancing its effectiveness for treating conditions.

To summarise, the validity of VR simulations when used in therapy is given as self-evident due to the vastly successful outcomes for treating patients. It is however clear that the use of VR for exposure therapy is rapidly becoming a more feasible idea. Thus, further research into the areas discussed in this section, particularly those pertaining to presence, will greatly enhance the effectiveness and validity of VRET in the future without simply making assumptions based on results.

2.3.1 A Platform for Experimental Research

A smaller body of work has also considered VR as a tool for experimental psychology, but is similarly built upon concepts of ecological validity, experimental control, and the ability to construct contexts which would be challenging to produce in real-life. However, VR solutions have been criticised by a number of researchers for how well their results might generalise to real-life, presenting an open question which motivates this project.

Gaggioli [71] discusses how VR may be applied to experimental themes in cognitive psychology, such as perception, attention and cognitive performance. Gaggioli explains that VR presents an opportunity to reach a deeper understanding of some perceptual phenomena, which may not otherwise be observed, as virtual stimuli can be tailored to the needs of each experimental task [71]. Furthermore, Gaggoli suggests that VR is particularly well suited to investigate *selective attention*, which describes the ability to focus behaviour or cognition when presented with otherwise distracting or competing stimuli [71]. Lastly, Gaggioli discusses how it is not yet clear why graphical representations attributed to VR should be more effective than its counterparts [71]. For instance, what makes moving, three-dimensional, representations within VR more effective than static, two-dimensional, stimuli? An assumption is made that by allowing the user to "steer" the interaction, VR will develop better mental models of abstract processes [71]. Gaggioli provides a more comprehensive discussion of each of these experimental themes [71], but the assumptions made indicate that VR represents a promising tool for experimental research. However, there is a lack of systematic research regarding methodological, technical and human factors [71]. Additional research is required in these three areas to fully understand how VR can contribute towards scientific psychology as a platform for experimental research.

Despite Gaggioli's conclusion, researchers continue to present numerous advantageous features of VR technology which could positively influence experimental research. Throughout existing research, two advantages are frequently acknowledged, those being ecological validity and control. Here, "control" refers to experimental control, the regulation of variables within an experiment. Control, as an advantage of VR technology, will be referred to as "experimental control" throughout the remainder of this section.

Wilson and Soranzo [72] discuss the idea that studies which aim to assess complex psychological constructs have, out of necessity, simplified tasks to be simple "point and click" exercises. Many existing experiments do not make use of a medium upon which they can accurately represent real world scenarios without sacrificing the level of experimental control that is provided by simpler tasks. Menshikova Galina et al. [73] suggest that VR offers a greater level of control over stimulus presentation and ecological validity as a consequence of its common features, such as stereoscopic depth which facilitates the illusion of seeing objects within a virtual space [74]. Other researchers also note the advantages of experimental control and ecological validity, but also noted the importance of plausibility illusion (Psi) [23] in maintaining participants' sense of presence. Pan and Hamilton [75] explain that, when studying phenomena which relies upon the belief that another human is present, it may be valuable to tell participants that a virtual character us driven by another person, even in instances where it is not [75]. However, whilst the example given by Slater also makes reference to interacting with a virtual character [23], he defines Psi as *"the illusion that what is apparently happening is really happening (even though you know for sure that it is not"* [23]. This definition does not indicate a requirement for social interaction, instead simply expressing that the events of a virtual world are perceived as really happening. It is therefore reasonable to suggest that Psi is not only an important factor in social virtual environments, but in all that involve events taking place which could be perceived as "real". Psi is not immediately present when utilising VR technology, it must instead be accounted for in the design of a virtual environment and scenario.

In accordance with Psi, the gambling task itself must also be accurately representative of what would be expected in similar real-world context. Failing to create a task, or game, that behaves as would be expected in the real-world will result in an incoherent experience, failing to achieve plausibility despite the accuracy of the VR environment. It will therefore be important to create a clear list of requirements when designing the gambling task within this project, to create plausibility. These requirements should be focused on the user experience, creating realistic game-play which accurately imitates the chosen gambling game. As these requirements are specific to the chosen game, these will be covered within the design section of this thesis, starting at section 4.1.

In summary, despite a relatively small amount of research being conducted on the topic, existing literature suggests that VR can offer numerous advantages to experimental research. The technology may be capable of bridging the gap between experimental control and ecological validity, allowing researchers to conduct experiments which retain accuracy and validity whilst providing an accurate representation of real-world scenarios. To this end, VR provides an opportunity to better understand a variety of topics, including behavioural, by providing a naturalistic environment which participants' may be encourage to engage with as they would in similar real situations. Psi an important factor to consider when building virtual environments, both social and non-social. The events and interactions within an environment should be capable of creating an illusion of realism in order to improve the ecological validity of experimental research. This comprehension of how VR can be used as a tool for experimental research motivates the development of a VR research tool throughout this project.

2.3.2 VR in Gambling Research

A small amount of existing research has explored the use of VR in settings related to gambling. Research which does exist is typically related to exposure therapy, and representing settings in which patients might experience the urge to gamble. For example, Giroux et al. [76] investigated the use of a VR simulation to induce a desire, amongst regular players, to play *Video Lottery Terminal (VLT)* machines. The findings of this work found that using a VR simulation elevated the desire to engage with VLT's within subjects, but Giroux et al. were unable to detect the hypothesised modifications to desire and perceived self-efficacy.

Park et al. [13] ran a similar study, aimed at testing the feasibility of a VR casino environment for use in repeated *Cue Exposure Therapy (CET)* to treat gambling addiction. Conklin and Tiffany refer to CET as a repeated exposure to drug-related cues, aimed at reducing re-activity to those cues via. extinction [77]. However, Park et al. are applying this type of therapy to gambling habits, explaining that CET is, *"based on a notion that prolonged and repeated non-reinforced presentation of cues will result in a gradual diminution of the urge through Pavlovian extinction"* [13]. To this end, Park et al. accept CET as a more generalised paradigm as opposed to being directly linked to drug-related therapy. Park et al. explain that participants were recruited on the premise that do not gamble excessively [13]. This distinction is based on prior research, which suggests that recreational gamblers report levels of cue-elicited urges similar to those reported by pathological gamblers [78]. Participants were then exposed to a three-dimensional VR environment whereby visual stimuli was delivered via. three surrounding screens [13], similar to how CAVE systems are implemented. The authors reported that initial exposure created an elevated urge to gamble, which diminished over repeated exposures. These results are consistent with those of Loranger et al. [15], who showed that VR simulations of both a bar and casino could be used to invoke a desire to gamble among participants. The results of Loranger et al.'s study however, also showed that the response was stronger among regular gamblers when compared with non-gamblers. This contradicts assumptions made by Park et al., despite those assumptions being based on prior research [77]. However, as Park et al. did not use pathological gamblers in their study, it is difficult to determine the reason for this discrepancy.

Subsequent work by Bouchard et al. [14] shows that the stimuli present in both studies [13], [15] can effectively be integrated into Cognitive Behavioural Therapy (CBT). Choo describes CBT as, *"a group of psychotherapuetic techniques in which psychological distress and maladaptive behaviours are treated by changing cognitions and behaviours"* [79]. Bouchard et al. states that all founding literature related to CBT (e.g. [80]–[82]) places a strong emphasis on the important of mastering therapeutic tools within the comfort and safety of a therapist's office and gradually transferring all acquired knowledge to everyday situations [14]. Based on this knowledge, the authors set out to validate VR as a tool for CBT. Bouchard et al. explain that whilst VR had previously been used in combination with CBT, existing studies are based on the therapeutic rational of cue exposure as opposed to inducing emotions and cravings to practice CBT techniques [14]. The study used a mixed sample of 28 "frequent" players, and 36 "occasional" players, resulting in a total sample size of 64. Participants were invited to play four games for 7 minutes each: Scrabble, as a control condition; a real VLT, with each participant gambling $20; a virtual bar, containing VLTs; and a virtual casino [14], [81], [82]. The authors report that the results of this study indicated that VR was as effective as real VLTs with regards to its ability to induce a significant urge to gamble.

With regards to this project, the most relevant piece of existing literature is presented by Young et al. [83]. In this work, the authors combined a HMD with joystick and mouse controls to create a semi-immersive platform. The aim was to study the persistence of slot machine play in both non-gamblers and problem gamblers. Two experiments were conducted, the first of which visualised a virtual casino environment on a 40" screen with speakers, and asked participants to navigate around using joystick controls [83]. In the second study, participants were presented with a similar scenario with the exception of using a HMD to visualise the virtual environment. They were once again asked to navigate around the casino environment using the joystick controls [83]. Whilst the results of this study place emphasis on understanding the effect of winning on a desire to gamble, the method and procedure share many similarities with that of the work presented in this thesis. Specifically, the research compares both 2D and VR visualisations of a gambling environment across the two experiments. The VR scenario is intended to replicate the experience of using VLT machines in the real world. However, a key difference comes in the application of the 2D-based experiment, in which Young et al.'s [83] first experiment allows the user to explore a virtual environment through the medium of a screen and joystick controls. In this project, we instead attempt to directly replicate the experience of playing a VLT machine within both real world, through the means of a tablet device, and again within a virtual environment.

The same system used by Young et al. [83] has been used in a number of other studies with the intention of investigating chasing behaviour [84], and players' response to in-game pop-ups respectively [85]. None of these studies specifically analyse the effects of immersive VR technology when compared to a 2D scenario, which this project aims to investigate.

2.4 Measuring Workload

Whilst VR offers the potential to create experimental contexts with greater ecological validity, it is important to consider any potential disadvantages of using these systems. One potential disadvantage could be increased workload caused by using an unfamiliar system to interact with a research task, as opposed to interacting with a similar task in the real-world. Such phenomena has been reported in previous research, such as that by Knierim et al. [86] which analysed the perceived workload of typing on a real keyboard when compared with one in a virtual environment. The study used samples of both inexperienced and experienced typists, and recorded how many words per minute (WPM) were typed by each participant in both scenarios. Knierim et al. also made use of the NASA-TLX questionnaire which enabled participants to subjectively report upon their perceived workload during each task. The findings of the work show that inexperienced typists typed significantly slower in the virtual condition, averaging 37.581 WPM compared with 45.393 when using a real keyboard [86]. However, there was no significant difference in WPM for experienced typists across the two conditions, reporting 66.566 WPM in VR compared with 67.223 when using a real keyboard. This highlights an important issue with virtual reality simulations. Specifically, there is a noticeable increase in difficulty when completing a task in VR when compared with the same real-world task, although mastery of the task seems to cancel-out these negative effects. This is re-iterated in the perceived workload, recorded using the NASA-TLX, where inexperienced typists reported significantly higher workload for the VR condition [86]. Conclusively, the results of work by Knierim et al. suggest that experience when completing a task can mitigate any potential increased workload. However, it also highlights that such a disadvantage may exist when conducting experiments through the medium of VR.

A significant portion of gambling research is focused on observing participant behaviour, such as how problem gamblers react to specific cues (e.g. [13], [15]) and how environmental factors encourage an urge to gambling (e.g. [83]). Excessive workload could influence the results of such work, causing participants to behave differently due to unnecessary stress caused by VR, therefore impacting upon how well results generalise to real-world scenarios. In a paper which details the development of the NASA-TLX, Hart and Staveland [87] state that operators experiencing excessive workload may behave as if overloaded, and adopt strategies associated with high-workload situations. This could cause participants to avoid or rush tasks, experience psychological or physiological distress, or adopt a lower criterion for performance [87]. Each of these factors have the potential to create discrepancies in the results of any psychology study, and interfere with participant behaviour.

In summary, increased workload may be characteristic of using a VR system and could negatively influence the results of gambling research. Consequently, the work presented within this thesis will make use of the NASA-TLX questionnaire as a subjective measure of perceived workload for study participants. The NASA-TLX was developed by Hart and Staveland in 1988 [87] and re-evaluated by the authors in 2006 [88]. It has been used extensively throughout research across many fields, including those related to gambling (e.g. [89], [90]) and virtual reality (e.g. [86], [91]). The results of such studies have demonstrated that the results of NASA-TLX reflect the outcomes of objective measures, such as in the aforementioned study by Knierim et al. [86]. Furthermore, as the NASA-TLX is a subjective measure, it is well-suited to measuring user experience, which this project aims to focus on when evaluating VR as an experimental tool for gambling research.

Chapter 3

Study Overview

Existing work related to gambling behaviour typically conduct experiments within the confines of a laboratory, offering a significant advantage over experimental control when compared to other *in vivo* methods used in some studies. However, it is suggested that such studies may be limited in the extent to which the results can be generalised to real scenarios [1]. Whilst this may not be crucial in some instances, such as studies which test theory of methodological strategy [92], there is a question of validity when extrapolating laboratory findings and applying them to real settings. Conducting laboratory based experiments may therefore incur a lack of validity when applied to behavioural research, such as those concerned with gambling. However, in general, VR appears to offer both control and good ecological validity. This technology has been widely applied as a tool for exposure therapy [9], [10], [55], [57], [59], [60], and has also been shown to evoke a desire to gamble equivalent to that of real gambling environments [14]. It is therefore reasonable to consider whether VR can provide an effective experimental platform for gambling research. Furthermore, it would be interesting to see how the experiences of participants differ when using VR compared to laboratory based studies, and whether those experiences can be better related to those of real-world environments.

Within therapeutic research, VR has been credited as a potential solution to the logistical and financial limitations of *in vivo* therapy. However, there is little existing work which examines the advantages of VR for gambling research. Researchers are starting to explore VR as a tool for gambling research (e.g.

[83]–[85]), however, no existing work has yet directly engaged with the questions of participant experience and relating those experiences to reality.

Gainsbury and Blaszczynski [1] present a summary of existing comparisons between laboratory and *in vivo* studies. The work presented seems to suggest that levels of arousal, a sensation which has strong links to persistent gambling, are lower in laboratory experiments when compared to those ran within a real-world setting [2]. Diskin et al. reports similar results, explaining that whilst arousal among Electronic Gambling Machine (EGM) players was elevated in the laboratory, the effects were amplified in a real-world setting [3]. However, comparisons such as these are rare, and often limited by small sample sizes and other potential confounding factors such as inconsistencies with financial gains through gambling in the laboratory setting.

Within this study, these questions are approached from the perspective of user experience such as levels of immersion, arousal and workload when comparing a VR scenario with that another conducted in a laboratory setting. Participants are drawn from the general population based on the prerequisite that they have previously engaged with some form of gambling activity. No discrimination is given towards the extent of gambling experience, resulting in various levels of gambling experience and knowledge among participants. The study specifically focuses on the following research questions:

> **RQ1:** Do users experience higher levels of immersion and engagement with a gambling game while playing in a VR representation of a real-world gambling environment, as compared with a laboratory-based condition?
> **RQ2:** Do users experience higher levels of arousal while playing the game in a VR environment, as compared with the laboratory condition?
> **RQ3:** Is there any difference in task workload for players while playing a gambling game in VR, as compared with a laboratory condition?

The laboratory condition, consisting of the participant playing Five Card Draw on a touchscreen tablet, is compared with playing the same game in representation of a betting shop environment within VR. The research presented in this report is approached deductively, in which we aim to answer these three research questions, and construct the following hypotheses:

> ***H1$_A$:*** *Participants' levels of immersion and engagement in the FCD game while playing the VR environment will be higher that than experienced while playing on the touchscreen tablet.*
> ***H2$_A$:*** *Participant's level of arousal will be higher while playing in the VR environment than while playing on the touchscreen tablet.*
> ***H3$_A$:*** *Participants' will experience higher levels of task load while playing the VR version of the game.*

H1$_A$ and H2$_A$ are motivated by work concerning VR when compared to laboratory conditions. Specifically the works compared by Gainsbury and Blaszczynski [1], which suggests that VR provides a higher level of ecological validity (e.g. [71], [75], [93]) and additional work which highlights the importance of ecological validity in generating presence [23]. It is hypothesised that a the higher sense of being present within a betting shop will result in higher levels of immersion/engagement in the simulated FCD game, and higher levels of arousal which can be attributed to *in vivo* studies [2], [3]. H3$_A$ is motivated by an observation that using the HMD and hand controllers of the HTC VIVE may require more physical and cognitive effort than using a real-world touchscreen interface.

Chapter 4

Design and Implementation

4.1 Gambling Activity

To determine the effectiveness of VR as a tool for gambling research, an appropriate gambling activity first needed to be chosen to encourage natural gambling behaviours. The chosen game would need to satisfy certain requirements and additionally, facilitate other features such as rigging and logging which would allow for suitable study data collection.

The first requirement is simplicity – The game and its rules must be understood by individuals with varying levels of experience, including those who have previously gambled but have no prior experience with the game specifically used in the study. However, existing research in games design demonstrated the importance of balancing difficulty when creating tasks for a user to complete. Thin et al. explain that *Flow state*, described as the sensation of being fully immersed in a video game [94], only occurs when a task is within an individual's ability to perform whilst remaining challenging enough to not induce boredom [95]. Immersion, in this context, refers to user engagement and is therefore a crucial consideration for the purposes of this project. Unfortunately, it is difficult present an appropriate and engaging challenge to all individuals within a large group of people, which is why many commercial video games allow the user to adjust the difficulty to suit them. Some work has attempted to address this issue through dynamic difficulty adjustment [96]. However, implementing such a system is not within the scope of this project, and would be unsuitable for experiments with such a short duration. Therefore, for the purposes of this project, the gambling task will cater to the expected skill level of less-experienced gamblers as this is the chosen study sample. The chosen game must be relatively simple, featuring some decision-making elements to avoid boredom.

The second requirement is to create a high-risk/high-reward scenario which accurately represents the type of game-play found in most gambling activities. For instance, a report published by the UK Gambling Commission in 2017 states that many Fixed-Odds Betting Terminals (FOBTs) enabled bets of up to £100, creating a high-risk scenario by offering higher rewards of up to £500 [97]. These machines are highly accessible and can be found in high-street betting shops across the UK. This type of game-play is therefore highly representative of the scenario this project aims to simulate. Replicating it would enable a high sense of plausibility illusion (Psi) and thus presence, both of which are necessary when studying behaviour which relies upon a belief that what is happening is real [23], [75]. Therefore, this is an important factor in gambling research where laboratory-based studies are criticised for results which do not generalise due to a lack of ecological validity [1].

Finally, the outcomes of the chosen game will be controllable to create a tool that is well-suited for use in research experiments within the field of gambling. This requirement stems from the fundamentals of experiment design, which states that the difficulty of unambiguously interpreting research outcomes varies inversely with how much control the researcher can exercise over randomisation [98]. By providing the researcher with a fine degree of control over the outcomes of the game, the tool enables more accurate observations and conclusions to be made about participant behaviour. For example, in studies which aim to assess the behavioural impact of negative feedback (e.g. [99]), or near wins/losses (e.g. [100]). Of course, which variables are controlled and to what degree are specific to the aims of a gambling study. However, as this project aims to evaluate the effectiveness of VR for gambling research, it must investigate the ability to exercise high levels of experimental control, as seen in therapeutic applications (e.g. [57], [59]). Furthermore, this design requirement will demonstrate additional requirements beyond having a VR environment within which a game can be simulated. Specifically focused on necessary steps for creating a coherent experience which can facilitate high levels of experimental control. For instance, as gambling games appear to have "random" outcomes, what steps are required to maintain an illusion of randomness within a coherent environment whilst ensuring experimental control?

In summary, the 3 requirements determined for picking and implementing a gambling task are simplicity, high-risk/high-reward game-play, and experimental control.

4.2 Five Card Draw

'Five Card Draw' (FCD) was identified as being a game which satisfied the requirements and became the base for the implementation stage of the project. It is a simple variant of poker, requiring the player to build a hand which satisfies one of the various possible winning outcomes such as Straight, Flush, etc. It differs in the fact that it can be a single player game, foregoing the initial deal of 2 cards to players and dictating an outcome based purely on five cards, hence the name. Primarily played in online venues and on betting machines, FCD plays out similarly to a fruit machine. The player is allowed to bet a desired amount and is then presented with five initial cards. They are then then given the opportunity to hold any cards which might offer them an advantage when trying to get the best possible outcome. This encourages players to make informed decisions and devise a strategy which will offer the most substantial financial gain at the end of each play-through. Finally, the cards that were not held by the player are discarded and replaced with newly dealt cards, resulting in an outcome and evaluation of winnings. This process is repeated until the player either cashes out of runs out of credits to continue betting with. The final implemented solution of FCD can be seen in Figure 4.1.

Figure 4.1: Finished implementation of the FCD task.

FCD strikes a fine balance between offering enough complexity to require some decision making by the player, whilst also remaining simple enough that a completely new player could learn it quickly. In fact, it is reportedly a 'stepping stone' used by many people before moving onto more complex variants of poker, such as Texas Hold 'Em. Additionally, FCD offers very fast-paced game-play, only consisting of three different phases – deal, hold, and result. This is unlike other variants of poker which require several different stages of dealing and betting before resulting in a conclusion.

The official version of FCD allows the player to bet an amount ranging from a set minimum bet, up to either a set maximum or all-in. While this creates very high-risk situations, especially when the player bets significantly high, it is unfortunately unsuitable for the purposes of this project. We want to be able to control the outcome and number of hands played as much as possible, and if a user bets too high their play-through could conclude before meaningful data is acquired. Thus, the inherent high-risk nature of FCD needs to be suppressed for the purposes of research and betting will instead be more limited and additional supplementation will be provided to reproduce high-risk situations. This will preserve elements of high-risk game-play across the final product whilst maintaining control. For the purposes of this project, the in-game winnings for

FCD are returned as percentages of the initial bet and based loosely on mathematical poker probability. Figure 4.1 details the return amounts based on an initial bet of £1.

Winning Type	**Poker Probability (%)**	**Returns (£)**
One Pair	42.2569	1
Two Pair	4.74539	2
Three Of A Kind	2.1128	3
Straight	0.3925	4
Flush	0.1965	6
Full House	0.1441	9
Four Of A Kind	0.024	25
Straight Flush	0.00139	50
Royal Flush	0.000154	250

Table 4.1: Winnings model for the implemented version of FCD.

Another issue with FCD is that there is a significant number of possible outcomes that might stem from each initially dealt hand based on any decisions the player makes. Therefore, whilst the game itself offers simplicity to the player, the underlying mechanics of each play-through will be complicated to implement and thus, more prone to error. Special care will need to be taken to ensure that the final rigging system works correctly and bug-free to ensure that the results of the study are meaningful and to avoid participants becoming confused during game-play. Thus, this will be the most time-consuming part of the development process for the FCD game, with exhaustive testing required.

4.2.1 Rigging Outcomes

As previously mentioned, the results of each FCD play-through need to be controlled. Doing this allows for more accurate measurement of participant behaviour and responses to specific conditions, such as winning or losing. Further efforts will be made to ensure that the amount won or lost at any given point is also controlled. Managing specific pay-outs for each hand provides the capability of measuring participant responses to win conditions with a greater or lesser yield.

It is however crucial that participants feel a degree of freedom when playing. If it is obvious that the game is rigged it will likely discourage them from continuing to play and have a negative impact upon the results of the study. Herein lies the greatest challenge for the rigging process, creating a system which provides similar win/loss patterns throughout each participants play-through, whilst maintaining the illusion that their decisions have an impact upon the game.

In summary, the design and development of a rigging solution faces two challenges:

1. Control game-play to maximise the meaningfulness of study results.
2. Make the participant believe that their decisions have an impact.

These challenges lead to the decision to combine two techniques for rigging the results of the game, splitting the overall system into two parts – Hand Rigging and Balance Rigging. These two parts would handle different aspects of the rigging process and be combined to produce an overall system which offers both control and believability.

4.2.1.1 Hand Rigging Design

This part of the rigging process focuses on controlling which cards will be dealt to the player both as an initial deal and as finalising cards to determine the outcome of the hand. The initial deal will be used to present opportunities for specific winning outcomes, enticing players to hold cards which provide better pay-outs for the Balance Rigging process. The finalising deal will be controlled to guarantee the most desirable result for the Balance Rigging process. The most challenging aspect of rigging each hand is managing the players freedom to choose whichever cards they want to hold, meaning they might not be so easily convinced by the initial deal and could instead choose to go for an entirely different type of winning outcome. For example, if the initial deal aims to push the player towards a pair, and they try for a straight, it might not be possible to complete a pair. This element of player freedom significantly increases the required complexity for the rigging system.

Hand Initialisation

Initially dealt hands are the product of a small database, which selects randomly from separated arrays based on the current state of the game. These hands are designed to push the player towards picking certain cards by presenting very clear opportunities towards certain winning conditions. For instance, if the player should require a straight to bring them back up to the current target balance, they may be presented with any variation of card values in a sequence (e.g. 6,7,8; or 4,5,6,7) to prompt them towards holding these cards.

Of course, the player may not necessarily choose to hold these specific cards, dependant on several factors. For instance, participants may not have sufficient understanding of poker winning conditions to identify the potentially winning cards. Also, participants may simply not notice the cards.

Consequently, a selection of available starting hands to match the situation of the game is not sufficient to create a game-play experience which can be fully rigged, but it is a start.

Hand Finalisation

To simplify the design process, the viability of a rigging solution is subject to two design considerations: practicality and versatility.

Practicality refers to how well the solution can control the outcome compared to the time complexity of implementing it. This consideration links back the third requirement established in section 4.1, but is also stated as a means to reduce the development time for the project. The process of finding the most practical solution will be detailed throughout this section and should provide useful insights regarding the computational and time requirements for creating a solution which enables high levels of experimental control.

Versatility once again links back to the third requirement established in section 4.1. However, this consideration is in place to tackle player freedom, which creates many issues related to controlling or "rigging" outcomes for this project. These issues are detailed in section 4.2.1.3, under *"Rigging Flow"* but can be summarised as player decisions creating uncontrollable outcomes within the context of poker hands. This is due to the specific requirements for specific winning hands to be created in poker. For example, what happens when the rigging system wants to form a "Straight", requiring 5 cards values in sequence, if the player has held two cards with the same value? The desired outcome is impossible. The game cannot control the decisions of the player, so it must be versatile and adapt to such situations to create next-best outcomes.

Listed below are several possible solutions to hand finalisation, listed in chronological order of consideration during the design process:

1. **Predefined Hands** - The use of simple predefined hands within a database, whereby the most appropriate hand is selected and completed.
2. **Template System** - Storing ASCII based templates rather than hands which can be used to construct a wide variety of hands without explicit definitions of card values.
3. **Function Based** - Determining the best hand at run-time, through program functions without utilising any predefined data.

The function-based approach best satisfied the aforementioned considerations. The use of functions provides a level of dynamicity which is unparalleled when compared to the other two solutions. Additionally, the process of programming these functions is more time efficient than database entry, as a database of possible outcomes would be extremely large. When broken down, the function based solution provides the following advantages:

Firstly, there is no requirement for arduous database entry, a process which would have taken up a substantial amount of time to complete. Whilst there is a substantial improvement to run-time performance when using stored or precomputed data, the time requirement to record all possible winning hands would have been far too great. Additionally, the database would need to be expanded with each new initial hand possibility added, meaning that the solution would be difficult to expand and improve.

Secondly, not relying on precomputed data eliminates the limitations associated with such a solution. For instance, initially dealt hands can be entirely random if desired as possible winning outcomes are determined a run-time. This provides thousands of potential initial deals as opposed to having a limited number of deals and outcomes. This has a significant impact on game play over a long period of time, eliminating the risk of players realising that they are repeatedly seeing the same sets of initial cards. Furthermore, the system does not require manual effort to expand as all future initial deals will be accounted for.

This solution builds upon the practicality and versatility benefits of the template-based solution. The ability to construct outcomes at run-time and adapt based on what is required as a specific point during a game-play provides unlimited capabilities, whilst the lack of a database makes the solution more practical to implement. Additionally, moving away from string-based templates removes the need to use string operations, which are detrimental to run-time performance [101]. There are however several potential disadvantages to this solution:

Firstly, the time required for implementation is far more difficult to determine than database entry time requirements. This solution did indeed take a substantial amount of time to implement. However, the trade-off for time taken to implement over the versatility that the solution provides was deemed to be more worthwhile than spending a similar amount of time filling a database.

Secondly, debugging is far more difficult in code-based solutions rather than those which rely on stored data. This is amplified by the fact that the overall Five Card Draw game relies on chance and random outcomes. To maintain believability, random elements needed to be implemented into the final rigging solution which made the process of debugging both time-consuming and tedious. This proved to be a serious problem during the implementation process as bugs would repeatedly pop up throughout testing which needed to be fixed before studies could take place. A significant portion of development time was therefore spent fixing these bugs after the initial implementation was complete.

4.2.1.2 Balance Rigging Design

In addition to the aforementioned rigging of hand values, the players overall credit balance must also be controlled throughout the duration of their game-play. One reason for this is to demonstrate one the potential advantages to using a VR simulation for psychology research. Providing control over the outcomes of a particular scenario is vital when measuring the effects of specific feedback or stimuli when performing psychological studies. Thus, implementing such a solution provides the potential for using the VR application in future work, specifically looking at gambling behaviour. A second reason is to provide a reason for participants to respond to specific situations during the game-play, such as winning a large sum of money or losing for an extended period of time. Enabling such responses to take place might contribute towards a better understanding of how immersed a participant feels, based on how intense or reserved their emotional responses are. Whilst the situations could take place during completely random game-play, it is more suitable for the purposes of the study to control their frequency and magnitude.

An implemented solution for balance rigging will satisfy the following criteria:

- Allow specification of balance targets throughout the game-play, expressing points in time where the player should win or lose a specific amount.
- Provide a method by which the balance targets can be met throughout the game-play.
- Provide some room for deviance to ensure that an illusion of control is preserved during multiple sessions.

A combination of several different components will be used to achieve these criteria. Firstly, a series of target balances will be given as a curve to dictate a players balance throughout each play-through. This would be high fidelity, providing very fine control of the players balance during each played hand as opposed to simply specifying start, mid and end point values. By doing it this way, the researcher is capable of tuning the game to suit their needs. For instance, if a researcher wanted to look at how participants respond to long periods of losing followed by a sudden high win, they would be able to do so. The balance curve is explained in detail throughout this section and later in section 4.2.1.3.

Secondly, the curve will be used to provide the hand rigging system with information which helps determine the most appropriate hand to deal and also to select the most appropriate "finishing" cards for each hand. The balance curve informs the most optimal hand based on how close the resultant balance is, rather than specifically trying to stay closest to the target balance whilst remaining below the threshold. This provides some room for deviation from the curve, but can easily be recovered by stringing together a sequence of small losses or wins. An example of how this will work is that the balance curve could suggest that a Flush is most appropriate in the given situation based on the players current balance and the target balance for the next hand. Thus, this information will be used by the hand rigging system to provide cards which try to both encourage and complete a Flush hand.

Lastly, to ensure that the player does not become wise to the rigging process, a system will be put in place to allow for minor deviations in balance over multiple game plays. In other words, the balance curve might suggest a slightly less valuable winning hand to the most optimal. By providing a smaller win the system will have to compensate over future hands, perhaps turning one large win into several successive smaller wins. However, it is clear that adding randomness for the purpose of deceiving the player comes at the cost of precision and control. As a consequence, the volatility of each randomisation will need to be adjustable to suit the needs of each play-through - Ranging from no randomness to almost entirely random results.

However, the volatility of FCD helped in creating a less predictable experience when engaging with the Hi-Lo task, discussed in Section 4.2.2. Without this, the winnings earned within FCD would always be precisely what is required to keep the user on the balance curve. This causes the Hi-Lo mini-game to register that doubling the winnings would put them above the curve, resulting in a losing outcome every time. For instance, if a player is £5 below the balance curve, and they win £4 in their FCD hand. Doubling-up would mean they reach a balance

£3 higher than the intended, whereas they would remain closer to the curve by not gambling in Hi-Lo. Therefore, Hi-Lo would not allow the player to win, and this would always be the case when earning the maximum for FCD as opposed to the randomised winnings achieved through volatility.

Perhaps the most significant advantage of using a balance curve rather than predefined sequences of hands is that it is adaptive. Whilst encouraging the player to hold specific cards is definitely a possibility, it's far from guaranteed that a player will hold those cards and get the desired result as per the game flow. People will always look at each hand differently based on several factors, such as their experience, thus providing a sequence of cards which hint at an easy 'straight' or 'flush' might not be immediately obvious to some or they may choose to go for safer options. By using the balance curve, the game is able to adapt to such situations, compensating for large unexpected wins by completely denying another win for an extended period of time. Alternatively, the system could provide more winning opportunities to compensate for unplanned extended periods of losing.

4.2.1.3 Rigging Implementation

Process

The system for rigging outcomes throughout game-play of Five Card Draw was written in C-Sharp, independent of the Unity Game Engine. This greatly reduced the development time and complexity, but meant that many of Unity's functional elements were not available. For example, the debugging process was simplified by the lack of a graphical interface, which was replaced by a Console window. This removed the need to implement interactive graphical elements, instead simply using keyboard input to test rigging functions. Additionally, the compilation time was significantly reduced in comparison to a full Unity project as no additional libraries are included for the compiler to handle. These factors enabled rapid prototyping and debugging to take place throughout development of the rigging system, by means of simplifying interaction and code execution, resulting in a much shorter development time.

A working implementation of the rigging system was later imported into Unity by simply moving the C-Sharp files into the project directory and located within an individual folder. This way, the system remained independent from Unity scripts and could be easily changed in the future, if necessary.

Data

Within Five Card Draw, each belongs to a suit and retains a numeric value. This fact poses a question - how can these cards be best represented within a rigging system for the Five Card Draw computer game? Visually, each card has two properties, suit and value, both of which are used to determine what kind of winning condition a hand will satisfy. For instance, the suit is used when determining a Flush, such as the standard Flush, Straight Flush and Royal Flush. However, the value of the card is the only property associated with all other types of winning conditions, whereby the suit holds no power. This means that both the suit and value of each card needs to be implemented within the rigging system to satisfy all winning possibilities.

The solution to this issue was to recognise that a deck of cards contains only 52 suited cards, with 13 in each suit. Furthermore, Poker suits are can be placed into order as Clubs, Diamonds, Hearts and Spades, where Clubs are least valuable and Spades are most. This means that cards can be represented as an index between 0 and 51, resulting in a total of 52 unique indices. With these indices, simple maths can be used to deduce specific information about each card. For example, the suit (s) of a card can be determined by dividing its index (i) by 13 and letting integer truncation take care of the rest:

$$s = i/13.$$

Additionally, the value (v) of a card can be found by performing a modulo operation, where the dividend is the index (i) and the divisor is once again 13:

$$v = i \bmod 13.$$

Structure

The rigging system is comprised of functions and data structures which enable the outcomes of Five Card Draw to be fixed as desired. Classes are used to categorise the functions and data types, which are implemented as static members. In this way, each class serves as a form of namespace, whilst preserving the ability to contain private member variables and functions. Using a class, as opposed to an actual namespace, allows the surface of the rigging system to be simplified, providing public functions which often prepare data for use in the more complex, private functions.

The *FCD_RiggingTools* namespace is a great example of this structure. The scope of this namespace contains two crucial data structures called *ValueOccurence* and *ValueOccurenceList*. Additionally, the scope contains two static classes. The first is *Globals*, which holds several constant variables such as file paths, bet amounts and the balance curve. The second is *Extensions*, intended for organising useful functions which are used throughout the solution.

A second example is *FCD_RiggingSystem*, one of the largest collections of code within the system. The scope for this class contains many different static functions, both private and public, which execute operations related to completing a winning hand.

Example Functions

The *FCD_RiggingSystem* class holds the majority of complex operations within the entire rigging solution. When writing this class, it became evident that there were only four unique rigging behaviours within FCD, as opposed to there being one for each type of winning hand. These behaviours are pairs, straights, flushes and losses. All other winning conditions such as Full House, Four of a Kind, Straight Flush and Royal Flush can be derived from these four behaviours. Consequently, whilst there are public members for each winning condition, there are only a handful of private members which execute complex behaviour.

An example of these functions performs rigging for pairs and sets, taking in a parameter for the total required count to make up the desired pair or set. For example, a Four of a Kind would set this parameter to "4", whilst a simple Face Pair would set it to "2". This parameter also supports allows for multiple values, as it is an array, meaning that additional sets or pairs can be added in a single pass. For example, a Two Pair can be produced by passing through "2, 2", or a Full House by passing "3, 2". This parameter is then used within the actual execution, whereby it is checked against the number of occurrences for each card within the original hand. If there is a requirement for an additional card to be added to make the set or pair, this is done by drawing the simplified card value from a simulated deck. A simplified value means that a "2" which can be 0, 13, 26 or 39 within the indexing system for card values, will simply be a 0 with no given suit. By drawing from this simulated deck we avoid duplicate cards and an error will be given if all cards with that specific value have already been drawn. This check for duplicates in pairs and sets is almost redundant within the FCD solution as the deck resets after each hand, but it is useful within applications where this may not be the case. These steps are repeated for any additional sets or pairs as previously stated, before a final array of newly added card values is returned.

Balance Curve

A context is required to determine how rigging should take place, as without this there is no way of knowing which outcome is most ideal for the rigging process. Thus, the rigging system must provide a target balance which the rigging system can adhere to during game-play. This can be achieved by either providing a single target balance which the game tries to adhere to, or by providing an array of targets to be used throughout a play-through. The option of adding a single target is most simple to implement but will likely result in flat game-play which fails to captivate the player, resulting in boredom. This is because there will be no significant wins or losses present during the game-play, instead causing the players current balance to teeter between values within a range of only a few pounds. Instead, the concept of adding an array of target values, whereby the current target shifts during game-play, is far more ideal. This option would provide a means to manipulate where events of high wins or long losing streaks occur throughout a play-through. Additionally, the fidelity of this solution can be increased to provide more fine control of these events.

This results in the requirement of a 'balance curve' within the rigging system. So called a curve as it is possible to visualise the array of target balances as a curve on a graph, as seen in Figure 4.2. This curve is used in conjunction with an index which points to a specific value within the array at different intervals of game-play. This dynamic balance target facilitates the ability to maintain consistent wins or losses throughout the game-play whilst also enabling high-impact, substantial wins to take place.

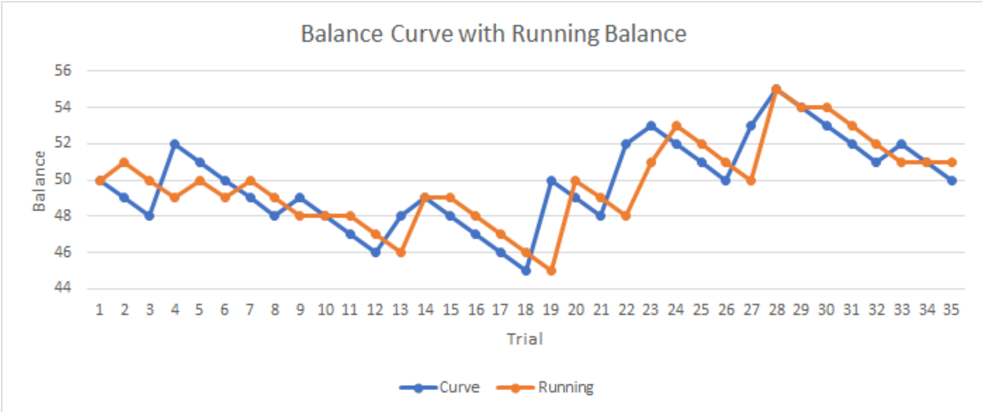

Figure 4.2: Example running balance compared with the implemented balance curve.

As would be expected, the core implementation of a balance curve will produce very consistent outcomes throughout any play-through, but this is also a problem. Having the game completely adhere to the curve could make the player more likely to identify a set pattern when playing the game multiple times. This becomes problematic for the study as each participant will be asked to play the game twice, once in VR and once on a tablet. If they identify a pattern during the second play-through then some results of the study may become invalid as they will likely respond negatively to the idea of playing a rigged game. Consequently, an element of volatility needs to be included in addition to the balance curve. This would cause the curve to be treated as more of a guideline without a need to specifically meet the balance criteria. This creates an illusion of randomness when playing the game several times whilst maintaining enough control to provide semi-consistent final outcomes.

Rigging Flow

The process of rigging a hand can be categorised as two separate phases on execution. The first phase aims to provide some form of initially dealt hand based on the current state of the game. This involves a comparison between the players current balance and their target balance for the current turn, using the balance curve. The result of this comparison is used to deduce whether the player is above or below the target and an appropriate initial hand of five cards is dealt based on this deduction. For example, a player will be dealt a hand that presents no winning opportunities if their balance is above the expected target. Conversely, a current balance which is below the target would result in a hand which encourages a specific winning outcome, whereby the chosen outcome will allow the player to meet the current target.

In contrast, the second phase takes place once the player has held their chosen cards from the initial deal and aims to complete the rigging process by producing the desired winning or losing outcome. This phase is a far more complex and exhaustive process than that of the first phase as it must tackle the issue of player freedom. Meaning that the player is capable of choosing any of the 5 initial cards to hold, including those which do not satisfy the desired rigging outcome. This is highly problematic because a player can hold enough "undesirable" cards to make the intended outcome impossible to achieve. Therefore, simply taking the original desired outcome and applying it to this process is not sufficient to create a working rigging system.

Consequently, this phase must perform exhaustive tests to ensure that the best possible outcome is achieved after the player has effected the game state. These tests need to account for two factors. Firstly, there can only ever be five cards in play at any one time, meaning that the number of newly added cards is limited by the number of cards the player has already held. This makes certain hands impossible to create, such as the 'straight' which requires exactly five cards to exist. The second factor is that certain cards are required as a prerequisite to complete a winning outcome. In this version of FCD, for instance, a simple pair must consist of only face cards meaning that numeric cards ranging from 2-10 cannot be used. This issue is a little simpler to tackle as, provided the player has held few enough cards, both face cards can be added to satisfy a winning face pair. However, this becomes problematic in situations where a 'full house' is optimal to correct the players balance against the balance curve. To create a 'full house', the player must not hold cards with more than two unique values, but player freedom dictates that they are entirely capable of doing so.

With these two factors in consideration, the second phase perform checks within several different functions, one for each possible winning outcome that exists within FCD, whereby the currently held cards are compared against various conditions. These checks result in a set of probabilities and information about whether or not an outcome can be achieved without exceeding the five card limit. Based on these probabilities, an outcome is selected which will allow the players current balance to normalise with the current target balance. There is some element of randomness at this stage whereby the final outcome is selected as one which will add an amount to the players balance which puts them exactly on the balance curve or slightly below. The Higher or Lower game is then used to make up the difference. This randomness provides a more unique experience during each play-through, meaning that a participant will have trouble detecting similarities between the two study conditions.

4.2.2 Hi-Lo Mini-game

One of the requirements for the projects gambling activity is to encourage high-risk and high-reward game-play, something that is prevalent in most gambling activities. As the implemented form of FCD fails to accomplish this due to fixed-size stakes, a higher or lower mini-game is added to accompany the FCD game-play.

This Hi-Lo mini-game allows participants to stake their winnings with the chance of doubling them. However, should the participant choose incorrectly within Hi-Lo, they will lose their winnings for the previous hand. This may create scenarios where a participant has won, for example, four-times their initial stake in FCD which they can double to eight-times or lose entirely. Alternatively, the player will have the option of returning to FCD with their initial winnings by simply choosing to collect rather than gamble. The fully implemented solution for Hi-Lo can be seen in Figure 4.3.

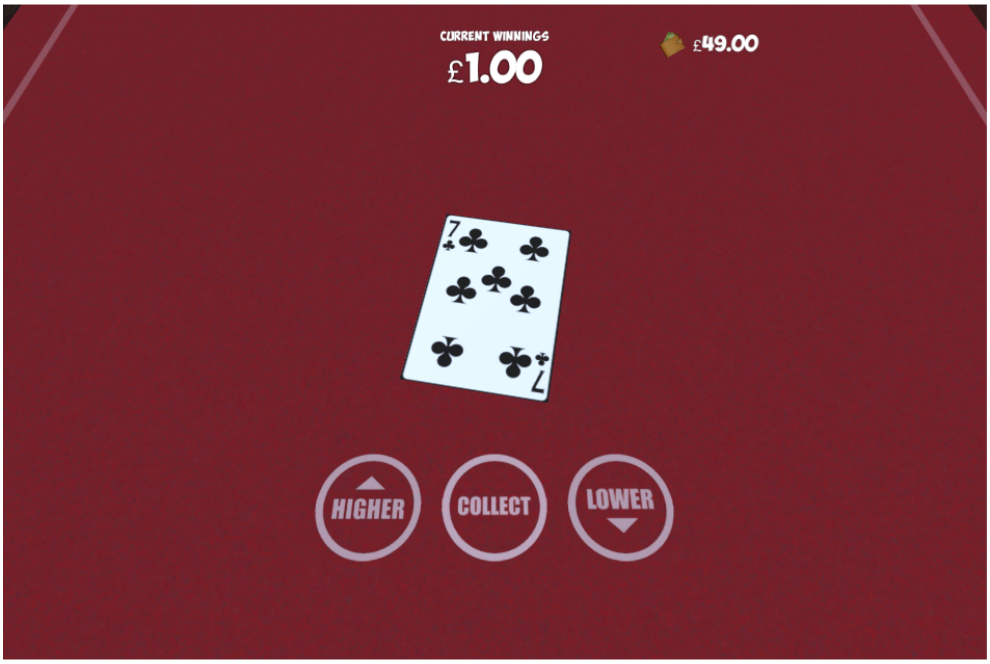

Figure 4.3: Finished implementation of the Hi-Lo mini-game.

4.2.2.1 Design and Implementation

The Hi-Lo mini-game is presented within the same world space as FCD after replacing the visual elements associated with the main game. This helps to maintain the connection between the main game and the Hi-Lo min-game, avoiding any confusion that may occur if the player were to disassociate the two tasks. These replacement visual elements are listed below:

- A card, taken from the FCD assets, forms the centrepiece for Hi-Lo. This will display a partially-random card value for which the user needs to guess higher or lower.
- A GUI text element for displaying the current winnings. This initialises as the winnings from the previous FCD hand.
- Two buttons for guessing whether the next value will be higher or lower than the current shown value.
- A third button for choosing to collect the winnings and return to FCD without gambling.

The initial card value is randomised, but not between the full range of possible card values. Firstly, the card will only ever belong to one suit, this avoids confusion regarding whether suits should be taken into consideration when deciding what the next card value will be. Secondly, the initial value will only ever be between six and ten, rather than being between two and ace. This is mainly done to help with the rigging process, by ensuring that the next card always has the possibility of being higher or lower. For example, if a two was given as the initial value, it is impossible for the next card to be a lower value and thus the result cannot be rigged for the player to lose if they choose higher. This particular range is chosen to maintain believability that the outcome is not entirely rigged. For example, if the initial card was a three and the player chose higher, a final value of two would raise suspicions as this losing outcome is incredibly unlikely in those circumstances.

The outcomes of Hi-Lo were rigged against the balance curve in a similar way to how FCD works. If the rewarded winning that will put the player further away from the current target, they will lose that instance of Hi-Lo. Alternatively, if doubling-up the winnings will allow the player to be closer to the curve, they will win. As mentioned above, this rigging process is assisted by the provided range of initial values, ensuring that it is always possible for the next card value to be higher or lower. In a sense, this makes the rigging process for Hi-Lo rather simple, as it only involves one decision making process against the initial card value to influence the outcome. Simply, the next card will always confirm the players choice of higher or lower if they are required to win, or be the opposite if they are required to lose.

4.3 Virtual Reality

During the study, participants were asked to play through the FCD game, both on a tablet and within a virtual environment. Two types of real-world gambling settings were considered for this environment - casino or betting shop. Two main factors were considered when deciding between these environments:

Firstly, based on statistics published by the Gambling Commission UK, there were a total of 8,406 betting shops operating within Great Britain between April 2017 and March 2018. This is significantly greater than the 152 Casinos operating within the same time period These statistics also show that betting shops contributed £3.2bn to the total figure of £14.4bn across all gambling activities between the period of April 2017 and March 2018. In contrast, casinos only supply £1.2bn of that figure, nearly three times less than betting shops This implies that betting shops are vastly more accessible and popular than casinos within the UK. Thus, participants may better associate with this setting.

Secondly, the environment must be constructed as life-like as possible within the time constraints of the project. Casinos are typically much larger than betting shops, often consisting of multiple floors and providing several different gambling activities which a customer can participate in. Conversely, a betting shop usually takes the form of a single open space featuring only two activities, sports betting and a selection of Video Lottery Terminals (VLTs). A betting shop is therefore significantly less complex to replicate than a casino as only a handful of simple assets are required to provide a visually realistic experience.

Based on these factors, the decision was made that the virtual environment would replicate a high-street betting shop.

4.3.1 Environment

4.3.1.1 Design

When approaching the environmental design, it was important to include stimuli for as many senses as possible whilst remaining true to the features of the original environment.

The most discernible of these features might be visual stimuli. Careful consideration will therefore be given to the visual elements included within the virtual environment, including the types of objects and the layout of the room.

However, it is improbable that an environment could be created which is visually indistinguishable from the real counterpart due to a lack of computational power and time limitations. The best way to tackle this issue is to use sufficiently complex geometry to create object models, use realistic textures, and to carefully consider the sizing of each object in comparison to the player. A visual representation of the virtual environment can be seen in Figure 4.4.

Figure 4.4: The fully built virtual environment used within the study.

Auditory stimuli is expected to play an important role in creating a realistic virtual environment, and will therefore be implemented strategically within the environment. Unlike with visual stimuli, realistic audio implementations are subject to only a few hardware and software challenges. Firstly, audio should emit from a source in 3D space, as it does within the real world. Secondly, the audio used should be related to the provided environmental context. Both of these factors contribute to creating a more coherent experience, which is important for giving rise to *place illusion* [25]. Finally, whilst audio can be advantageous, it may also distract from the set task [102]. This mainly occurs when the audio is too prominent in the environment, playing at a high volume, which makes it difficult to concentrate on anything else. It is therefore important to consider whether the audio is emitted at a balanced volume level, instead of being distracting.

Stimulating other senses, such as smell, may also contribute to a more coherent experience. However, this may require specialist equipment, which could make the study difficult to replicate in the future. Focusing on only audio and visual stimuli allows all components for creating a coherent experience to remain present within the artefact software, able to be presented using simply a HTC VIVE Pro, or a HTC VIVE and headphones.

4.3.1.2 Implementation

The first stage of the implementation process, for the environment, involved gathering a full idea of the real betting shop atmosphere and layout. Therefore, some time was spent inside several betting shops along the local high street to account for subtle differences across different companies. It was found that the shops consisted of three well defined areas. The first was a section dedicated to sports betting which often included televisions usually showing live horse racing. The second area was a customer service deck which was separated off behind a glass panel. The final area contained several VLTs, intended to be used whilst standing or sitting, whereby each machine often had several different types of game to choose from. This layout can be seen in Figure 4.5, however, different companies lay their shop out differently as seen in Figure 4.6.

Figure 4.5: Example of a betting shop layout (showing VLTs). [103]

Figure 4.6: Example of a betting shop layout (showing betting stations). [104]

However, the final virtual environment is set out to most accurately replicate one of the local betting shops that were visited. An annotated birds-eye view of the layout can be seen in Figure 4.7. All of the models in the scene were created specifically for the purposes of this project as it was difficult to find some models, such as VLTs, which were low-poly enough to be used in a virtual simulation. Again, using high-poly models would be ideal but computing power is already limited if a high frame rate is going to be achieved, especially when running a Head-Mounted Display (HMD).

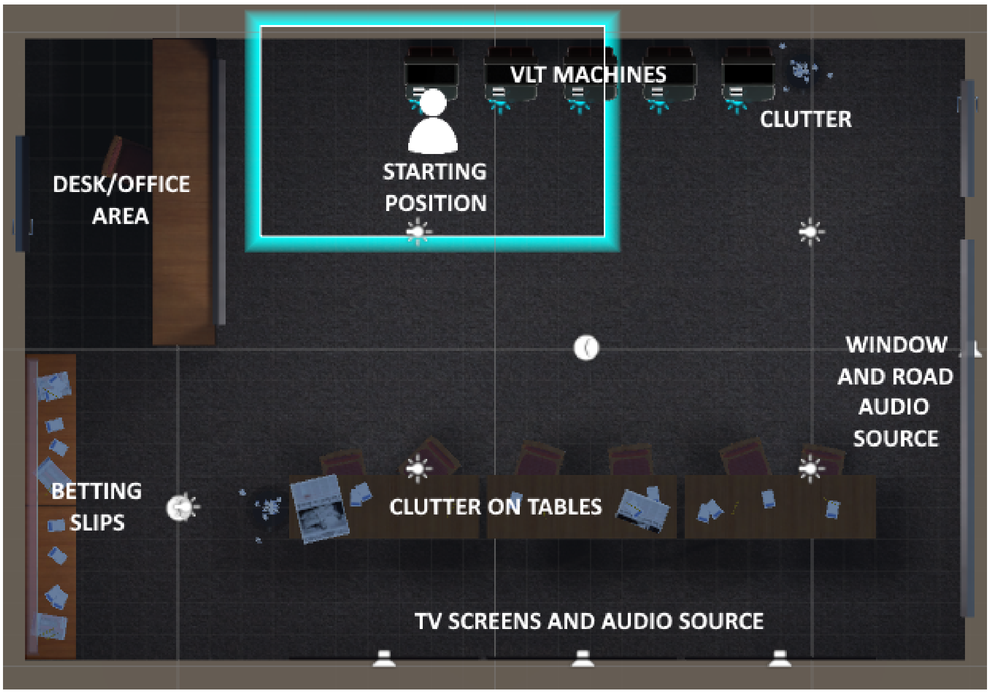

Figure 4.7: Annotated layout of the virtual betting shop environment.

The last major consideration was how to approach movement through a large space in VR, or whether to limit movement to the confines of a relatively small play space. Whilst there are several locomotive solutions for large virtual spaces, such as omni-directional treadmills and point and click style tele-porting, it was decided that the game would be best without any of these. Instead, the space within which the player could move around would be restricted to the play area as defined by the HTC VIVE light boxes in the real world. There are several reasons for this. Firstly, existing locomotive solutions either required additional equipment or actions to be conducted which would be unnatural, such as leaning-to and tele-porting with a controller. Secondly, adding movement beyond the defined play area did not add anything to the experience. Instead, allowing players to move freely around the entire room would open up too many opportunities to become distracted from the purposes of the study. The play space was then placed in such a way that the player would always spawn directly in front of the simulated VLT, as seen in 4.7.

4.3.2 Virtual Gambling Machines

For the purposes of the study, a solution would be required which can accurately emulate the behaviour of a real gambling machine within a virtual space. These Virtual Gambling Machines (VGMs) must be capable of loading a provided game and enabling interaction through a type of touch screen interface. Furthermore, this interaction must not hinder the performance of the overall product, to avoid high end-to-end latency, also known as visual lag, which can induce simulator sickness [105].

As an additional requirement, the solution to this problem must be implemented in such a way that it can be used repeatedly with different games in future studies. This poses perhaps the most challenging question - how do we allow interaction through a virtual touch-screen without having to explicitly define these interactions within the source code of a loaded game? Fortunately, Unity provides ways in which this interaction can be achieved.

These two requirements are established for the purposes of using VR artefact in future studies, particularly those within the field of gambling research. By enabling a VGM to function independently of the gambling game which has been loaded onto it, researchers are able to create their own gambling tasks and load them into the environment effortlessly. This is intended to remove the requirement to modify existing code within a gambling task, enabling a "hot-swap" functionality for gambling games.

Figure 4.8 shows the final product for the virtual gambling machine, being used to interact with the FCD game. The model was based on the designs shown in Figure 4.5

Figure 4.8: Final implemented solution for the gambling machine in VR.

4.3.2.1 Design

These requirements can be fulfilled using several different techniques within Unity. Asynchronous Scene Loading will be used to provide access to another scene within the project. This allows the FCD scene to be loaded without any change to which one is currently being used, remaining as the virtual reality scene. After this, game objects will be moved between the scenes to be included within the virtual space. This solution will have some additional overhead, such as confusion within Unity as to which Scene Camera is used as the main one, i.e. the one displayed on the headset. Additional care will therefore need to be taken to ensure that the solution works as intended.

Creating interaction between a touch screen, as a plane within three-dimensional space, and the FCD game will prove to be a challenge. However, a solution is to simply consider how interaction occurs within standard two-dimensional games in Unity. In these applications, Unity provides a means for registering interaction through a technique called ray-casting. This describes the process of checking object collisions using an invisible ray which is typically fired in any specified direction from a point in three-dimensional space. On a smart-phone game, this initial point is determined by where the user taps and its direction is given by the current orientation of the camera. This exact technique will be re-applied as a solution to the interactivity problem. Whereby the starting point is determined based on collisions between the VGM screen and the controller, and a direction is given by the current orientation of the previously loaded FCD camera within the game world.

However, it is not simply enough to utilise ray-casting, this must then trigger events on the loaded game. Furthermore, the implemented solution must fulfil the requirements established in section 4.3.2.1, focused on creating a re-usable solution for future research. Unity Events can be used to achieve this, which provides a way of calling back to a different function if another is triggered. An event can be triggered on a button or other interact-able game object via. ray-casting collisions, which then triggers the actual event or events which should execute on the loaded game, FCD in this instance.

4.3.2.2 Implementation

The implementation of VGMs can be broken down into two tasks - loading and interaction. Different features and techniques have been utilised in each to ensure that the requirements are fulfilled and the FCD game can be played on the virtual machine with little cost to performance.

A class named *BettingMachineBehaviour* forms the core of an VGM, connecting both the loading and interaction processes together to form a working solution. This class handles the initialisation of important components such as the two screens associated with an VGM, top and bottom, and also makes calls to a class titled *MinigameMngr* to begin loading the FCD game.

BettingMachineBehaviour contains three important variables. The first is a scene name variable which is used to search the Unity project for a *Scene* file which contains the provided string, this scene is then used in the loading process. The second is intended for a render material which allows a camera feed to be projected onto the surface of the screen object. The third variable is a *VirtualAudioListener*, a custom Unity script which allows game related audio to play through the machine rather than the hidden location of loaded FCD game assets.

Most of the complex behaviour associated with the VGM implementation is offloaded into separate classes for loading and interaction. However, all functionality related to how a controller collides and interacts with the screen plane is included within *BettingMachineBehaviour*. This includes gathering information about the precise point of collision on the screen and making calls to other classes to handle what should happen next. Additionally, a rumble effect is applied to the HTC VIVE controller at this stage to provide feedback that an interaction has occurred.

Loading

Loading another scene into the virtual environment as a "mini-game" is perhaps the biggest challenge associated with the implementation of VGMs. Unity fortunately provides a relatively straight-forward solution to this challenge in the form of loading scenes Asynchronously, which is performed by the *MinigameMngr* class and achieves a number of things. Firstly, by loading the scene in the background, or asynchronously, the main scene containing the virtual environment can continue to execute normally and with no discernible impact on performance. This means that scene loading and unloading can take place as it is required at run-time, where a much larger scene will just take longer to present itself on the VGM screens. The second thing that asynchronous scene loading does, is that it allows the second scene to run alongside the main scene once loaded. Whilst this may cause performance issues for larger games, it is perfectly acceptable for running the FCD game alongside the virtual reality environment.

After loading is complete, the *MinigameMngr* class will execute functions to better organise the newly added game objects within the virtual environment. Each game object is re-parented to a newly created game object to re-organise the editor hierarchy and also make it easier to find objects associated with FCD rather than the virtual environment. Furthermore, the scene camera for the game is located and has many of its properties changes including the aspect ratio and removing its main camera tag. Finally, the newly added scene objects are re-located and re-scaled if necessary, to ensure that they are hidden outside of the main camera view.

Finally, the audio associated with the mini-game is handled to ensure that the VGM object itself becomes the audio source as opposed to wherever the audio sources may have been within the loaded scene. This is done using the *VirtualAudioListener* class which searches for all active audio sources within the loaded scene before re-positioning and parenting them relative to the VGM root object.

These stages make up the entirety of loading a different game into the virtual environment.

This implementation impacts the re-usability of the VGM solution in a positive way, allowing a scene with any name to be loaded with all of its core game execution taking place alongside the main scene. All problematic game objects are managed based on their component type, rather than being specific to FCD, to ensure that the entire simulation performs as intended.

Interaction

After most of the initial collision detection is performed within *BettingMachineBehaviour*, the impact position is passed through to the *BM_Screen* class which then projects it onto the mini-game. It does this by performing an additional ray-cast using the FCD game camera in conjunction with the passed impact position as an origin point. This is identical to the standard ray-casting process and thus will output information based on which objects the ray collides with, returning the exact game objects in this case.

After gathering the game objects that were hit, a script called *EventHandle* is executed which simply makes a call back to an FCD function upon being triggered. This removes the requirement to add game-specific code in either the VGM or mini-game source code, instead providing a generic script to be executed on interaction. If this script did not exist, code on the VGM side would have to know class names to call specific functions, and code may need to be modified within the game source files to enable calls to be made.

However, this solution is not perfect in terms of re-usability and still suffers a few issues:

1. Functions within mini-game classes, such as classes used in FCD, require callback functions to be public.
2. The *EventHandle* still needs to be added manually to objects within the mini-game.
3. Collision models may need to be modified or added depending on the original solution for interacting with the mini-game, as the ray-cast is collision dependant.

Despite this, the solution remains versatile and though there is a potential for further optimisation regarding set up, it serves the purposes of FCD and other two-dimensional games sufficiently for this project and future studies.

Chapter 5

Research Methods

5.1 Experimental Design

5.1.1 Ethical Considerations

Ethical approval to run the study described in this section was obtained by the College of Science Research Ethics Committee (CoSREC) at the University of Lincoln (UID: CoSREC406). This approval was provided on the condition that the project and its studies meet a set of specific criteria, each of which are addressed within this section of the report.

5.1.1.1 Participant Information Sheet

Participants are provided with an information sheet which they are asked to read prior to taking part in the study. This sheet provides details about the purpose of the study, the typical study duration and the tasks which the participant will be expected to complete during the session. Furthermore, the sheet explains which types of data are collected during the study and the methods by which this data is be obtained, including questionnaires, interviews and recorded player metrics. This information is concluded with a short sentence which explains that the study is conducted in accordance with University of Lincoln ethical guidelines, and approved by the College of Science Ethics board.

The information sheet continues on to explain each participants rights concerning the study and their participation in it. Participants are told that they can withdraw at any time without prejudice and without being required to provide an explanation. Furthermore, participants have the right to request the destruction of their supplied or recorded data should they choose to withdraw from the study after completion. Reassurance is provided that in this event, all collected information about that participant will be destroyed as requested. Finally, the participant is told that they have the right to ask any questions about the study or their participation at any time before, during or after the study and that their queries will be met with as full an answer as possible.

The next section of the information sheet explains health and safety risks which may be present during the study. Participants are reassured that the study is being conducted in accordance with the *University of Lincoln School of Computer Science Health and Safety Guidelines*. These guidelines include appropriate risk-assessment for virtual reality equipment, which was applied to the study setup by a School Technician with appropriate Health and Safety training.

The next section expresses how the data collected from each participant will be handled after the study is concluded. Explaining that all collected data, including audio recordings, will only be seen or heard by members of the research team and will be stored anonymously. Participants are assured that any identifying personal information will be stored separately from all other collected data such as questionnaires, interviews and metrics. This information can also only be linked back to each participant through a unique participant ID. Regarding audio recordings, which will be collected during the interview process, the sheet explains that they will remain confidential and secure. These recordings are also transcribed as quickly as possible and the raw audio files are destroyed within 6 months of the study being concluded. Additionally, participants are told that quotes from audio files may be publicised at conferences and within academic literature but will remain anonymous. Any data gathered during the study will also only be used for analysis relating to this project.

Finally, participants are provided with details about how they can contact the research team once the study is concluded and that they will be contacted about the results of the study after data collection and analysis is complete.

5.1.1.2 Medical Screening Form

Participants are asked to complete a brief medical form. This form is used in conjunction with the *University of Lincoln School of Computer Science Health and Safety Guidelines* for VR, and asks the participant to disclose any medical information which may impede their ability to use the VR equipment or that might otherwise harm their person. The form consists of seven short questions and asks the participant to circle either 'yes' or 'no' depending on their individual answer to each question. These questions are as follows:

1. *Do you duffer from Epilepsy, or a similar condition which may be triggered by flashing lights or visual stimulus?*
2. *Do you suffer from any significant uncorrected problems with your vision, such as tunnel vision? (this excludes the requirement for glasses or contact lenses).*
3. *Are you pregnant?*
4. *Do you suffer from any conditions (e.g. related to mobility) which could cause you to be unduly injured by bumping into objects, or people, or by falling to the floor?*
5. *Do you suffer from Claustrophobia?*
6. *Do you suffer from any other condition which you think might affect your ability to use the VR?*
7. *Do you suffer, or have previously suffered, from a gambling addiction or other psychological problems linked to gambling?*

Questions 1, 2, 3, 4, 5 and 6 address medical conditions which would prevent a participant from using the VR equipment and completing the study.

Individuals who are highly sensitive to flashing images, such as those suffering with epilepsy or a similar condition, are at high risk of experiencing a seizure when using VR equipment. Therefore, individuals who circle yes on question 1 are excluded from the study at this stage.

Other visual conditions, which are uncorrected, are identified in question 2. This includes issues such as tunnel vision which describes the loss of peripheral vision with retention of central vision, causing a restricted and circular tunnel-like field of vision. Modern VR devices are specifically designed to provide as wide a field of view as possible to maintain the illusion of being present within the world. Thus, individuals who suffer from conditions such as tunnel vision will be unable to get the full experience and may become disoriented. They are therefore excluded from the study at this stage.

Additionally, whilst precautions are taken to ensure that the environment is safe, accidents can happen such as the participant falling or colliding with a real-world object. For this reason, pregnant women are excluded from the study to avoid serious injury to themselves or their baby.

Individuals with mobility conditions which may affect a participants ability to stand, maintain balance or explore the VR play space are also identified at this stage. Participants who affirm any such condition are excluded from the study at this stage as they may be more prone to accidents or unable to complete the task.

Whilst research has been conducted which uses VR to tackle issues with claustrophobia the virtual environment used in this study may not be appropriate for individuals who suffer the phobia. This is evidenced by the small 3D environment, restrictive play space and the fact that participants field of view will be entirely consistent of just a wall and virtual gambling machine for a large majority of time completing the task. For this reason, individuals who affirm suffering from claustrophobia are told they are not able to continue the study.

Question 6 asks participants to disclose any other medical conditions they may have which they feel could affect their ability to use the VR equipment and complete the study.

The final question is not linked to VR usage, but instead addresses any psychological conditions the individual may have which could put them at risk due to participating in a gambling activity. It is important that persons at risk of gambling addiction are not exposed to the gambling task used within this study. People who suffer from a gambling addiction may become aggressive during the study which could put themselves and the investigator at risk Furthermore, the gambling task may encourage vulnerable individuals to continue gambling after the conclusion of the study which could result in financial instability Individuals who have previously suffered from a gambling addiction and have since recovered may be driven towards a relapse Consequently, individuals who suffer, or have suffered, from a gambling addition or other psychological issue related to gambling are excluded from the study at this stage.

5.1.1.3 Participant Consent Form

At this stage, the participant is expected to have read the information sheet provided in addition to successfully completing the medical screening form, confirming that they do not suffer from any of the medical conditions mentioned. The participant then confirms these assumptions using a provided consent form before continuing the study. Participants must confirm that they agree with seven individual statements before they are allowed to continue with the study, as listed below:

1. *I have read, understood and answered the Medical Screening Form.*
2. *I have read and understood the Participation Information Sheet.*
3. *Any questions I have about the study at this point have been answered.*
4. *I understand that my participation if this study is voluntary.*
5. *I understand that I am free to withdraw at any point, including any time after the completion of the study today, without giving reason.*
6. *I understand that my data will be treated confidentially and held securely. Any publication resulting from this work will not include images of text which could identify me, without my express permission being sought.*
7. *I am 18 years of age, or older.*

These statements simply provide the participant with an opportunity to confirm that they have been presented with and understand both the participant information sheet and medical screening form. Additionally, the participant is asked to confirm that they have understood the main aspects of their participation and that their questions have been answered up to this point in the study.

Once the participant has agreed to these statements they are asked to provide their name, email, signature, and the current date, thereby agreeing to take part in the study and consenting to data collection, storage and use in the capacity explained within the information sheet. The personal information stored on this form is required, and represents an agreement between investigator and participant for the study to continue. Finally, a unique participant ID is provided, which forms the only link between consent from and collected data, and the participant is reassured that this form will be stored separately from other data. The study can now commence.

5.1.2 Measures

A mixed-methods approach was taken to data collection, utilising both qualitative and quantitative techniques. Quantitative data is collected using three questionnaires which have seen extensive use in existing VR and psychology research. These questionnaires provide information regarding immersion, workload and emotional response during the study for later analysis. Furthermore, certain metrics were recorded automatically by the Five Card Draw (FCD) game. These metrics could be used to deduce information about speed of play, decision making and also as sanity checks for task functionality. Qualitative data was collected in the form of a semi-structured interview. This interview allowed participants to elaborate on their experience and perhaps provide some useful information regarding their experience which was not covered in the questionnaires.

5.1.2.1 Quantitative Data Collection

Immersive Experience Questionnaire

The Immersive Experience Questionnaire (IEQ) provides a means for measuring immersion subjectively, in addition to existing objective methods such as measuring task completion time and eye movements which are not used in this study. The questionnaire was developed as part of a study which aimed to address issues around defining and measuring 'immersion' [32]. The paper describes the development of the IEQ questionnaire, whereby it was used in three studies and rigorously tweaked to produce a final result. The product of this paper forms the basis for collecting quantitative data about immersion in both study conditions for this project.

The IEQ features thirty-two questions, many of which tackle the same factor, and uses both negative and positive wording in order to control for wording effects throughout [32]. Participants are asked to rate how much they agree with the statement provided in each question using a 7-point scale, where 1 was 'not at all' and 7 was 'a lot'. During analysis, these questions are quantified into five main factors: cognitive involvement, world disassociation, emotional involvement, challenge, and control. Each question has a different impact upon it's associated main factor, whereby questions with negative wording deduct and those with positive wording adds to its associated final factor score.

Jennett et al. mentions that the questions used in IEQ relate to the particular experience of a given task [32]. Thus, IEQ is suited to this project as it facilitates data collection regarding the experience of playing FCD itself, rather than for VR systems which are understood to be an inherently immersive.

The questionnaire will be applied at the end of each study task. This will allow each participant to report information about their experience more accurately than if they were asked to complete two copies of IEQ, one for each task, at the end of the study session.

Self-Assessment Manikin

The Self-Assessment Manikin (SAM) [51], [52], was developed to simplify the existing Semantic Differential Scale (SDM), a set of eighteen bipolar adjective pairs each measured along a 9-point scale, published in 1974 [53]. These adjective pairs influence three main factors of emotion, both positively and negatively, and also contribute towards these factors to varying degrees. SAM proposes a means for simplifying these measures, instead representing each of the three factors in a non-verbal pictorial format [50], as shown in Figure 5.1.

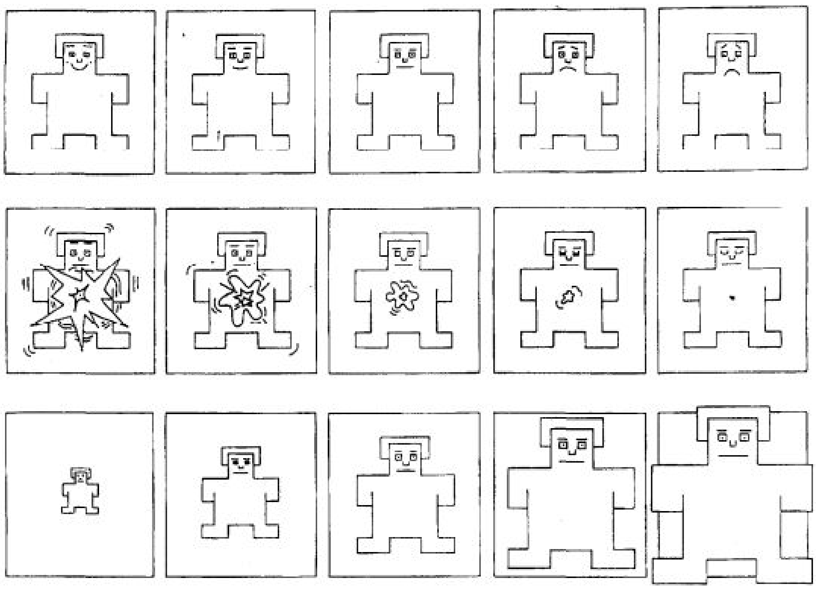

Figure 5.1: Bradley and Lang Self-Assessment Manikin [50]

As shown in Figure 5.1, SAM consists of three sub-scales which each represent one of three fundamental factors of emotion: Pleasure, Arousal and Dominance. The version used in our study differs slightly from the original 5-point scale, instead using a 9-point scale to facilitate a greater degree of accuracy. More specifically, the PXLab SAM format will be used in this study, as shown in Figure 5.2.

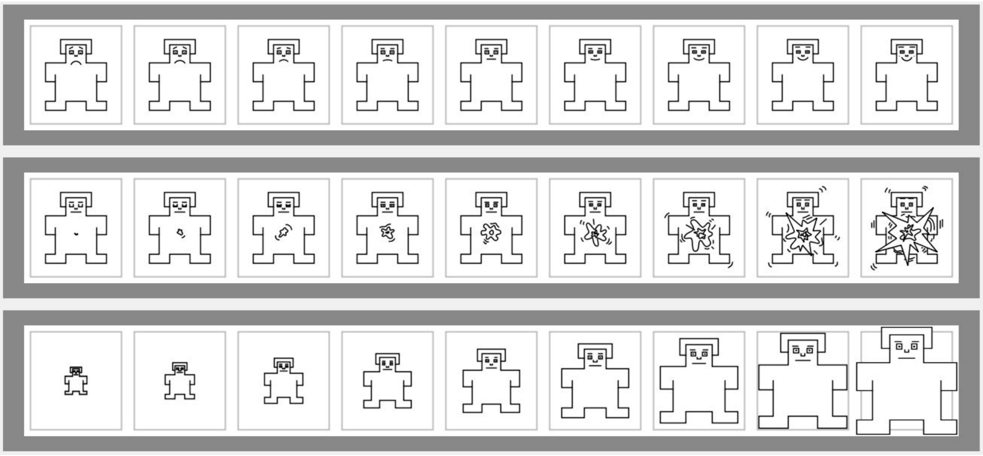

Figure 5.2: PXLab Self-Assessment manikin, using 9-point scale.

Participants will be asked to complete the SAM questionnaire with the assistance of a help sheet which provides more context about what each of the pictorial scales represent. This help sheet provides words which are associated with each main factor of emotion at both ends of the three sub-scales, as shown in Figure 5.3. The SAM questionnaire will be completed immediately after completing each of the two study tasks as with the aforementioned IEQ and NASA-TLX questionnaires.

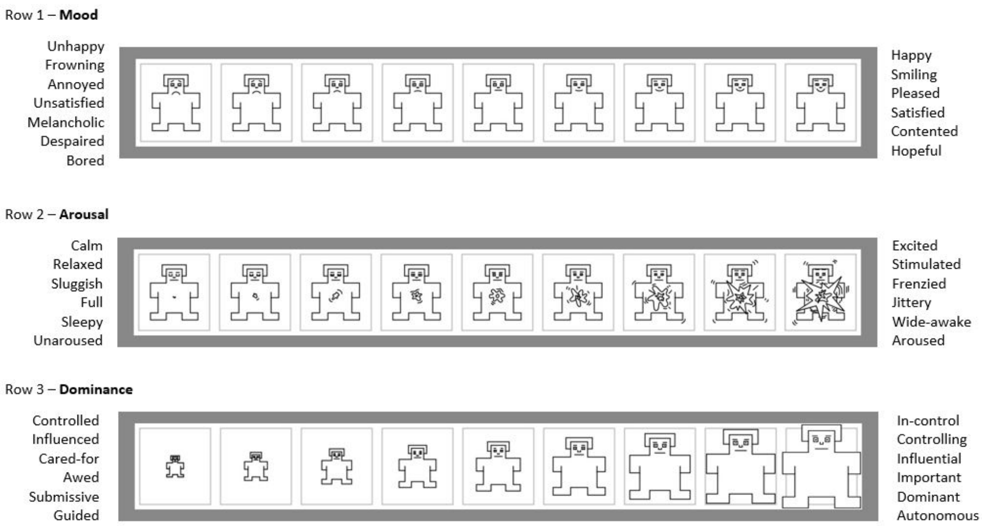

Figure 5.3: Self-Assessment Manikin help sheet, provided to study participants.

NASA Task Load Index

The NASA Task Load Index (NASA-TLX) provides as means to estimate the workload of a task during, or after its completion by an operator [88]. It was first reported by Hart and Staveland in 1988 and has since been used extensively not only as a measure of workload but also as a benchmark against with other measures, theories or models are judged [88]. Despite being created over 30 years ago, it has been rigorously evaluated and modified to keep it relevant to newer research applications. The most recent version of NASA-TLX forms the basis for measuring workload in study tasks for this project.

The NASA-TLX consists of six sub-scales: Mental, Physical, and Temporal demands, Frustration, Effort and Performance. Hart mentions that the combination of these dimensions are assumed to represent "workload" and proceeds to explain that these dimensions are the product of an extensive analysis of primary factors which do, and do not, define the subjective experience of workload for different individuals [88]. These sub-scales are broken down into six questions within the NASA-TLX questionnaire, each providing 21 gradients from "Very Low" to "Very High". The participant is asked to mark a point on the scale which represents how demanding they felt the task was, for each of the six sub-scales.

NASA-TLX will be applied in this project to measure the perceived workload of both the tablet and VR task within the study. Participants will be asked to complete the NASA-TLX questionnaire immediately after completing each of these tasks, as advised by Hart [88]. This will ensure that the results gathered from each task are an accurate representation of how the participant perceived workload for that specific task, as opposed to providing the questionnaire at the end of the study session.

5.1.2.2 Qualitative Data Collection

Post-Study Interview

Qualitative data will be collected using a voice recorded semi-structured interview, after both tasks have been completed. This will provide each participant with an opportunity to elaborate on their experience during the study and may justify the results of quantitative measures.

The interview questions are separated into categories which focus on three distinct elements of the study: the FCD game, the VR condition, and the tablet condition. Additionally, a final question provides an opportunity to elaborate on the overall experience and disclose any more information. Answers provided by participants will be followed up by additional questioning when required, to ensure that each participant divulges sufficient information related to their answers.

A script is provided to the study investigator with eleven separate questions, labelled according to their categorisation. This script is strict to ensure that bias does not influence the wording of each question and to improve repeat-ability. The exact interview process cannot be replicated as it is semi-structured, meaning that all follow-up questions will not be recorded on the interview script. However, by following the script and asking follow-up questions where necessary, the only potential difference in repeated interviews would be the level of detail given for each answer. Furthermore, bias is eliminated from main interview topics as the investigator must stick to the exact wording of the interview questions and does not diverge from simply asking for further information in follow-up questions.

Each question is carefully worded to avoid coercing participants into providing a specific answer by avoiding both positive and negative wording. Furthermore, the first question of each category always includes words which create association to the specific category such as 'Poker Game', 'VR' and 'non-VR'.

FCD Category

The first category of questions focuses on the FCD game experience in both conditions. The participant is told that these questions are linked to the FCD game only and their answers can include information about their experience of playing FCD in either task. The questions used in this category are listed below:

a: *Firstly, regarding the Poker Game, did you understand the rules when you started?*

b: *Do you think that your strategy for playing the game changed during the experience?*

c: *Do you feel that your behaviour changed while playing the game?*

The first two questions serve to assess how well each participant understood the rules and mechanics of the FCD game used in both conditions. It is important to establish this information as it may provide clarification as to why some participants had different experiences to others. For instance, a participant that did not initially understand the rules may have a harder time recognising card combinations and thus a higher cognitive workload might be expected in NASA-TLX results.

The third question asks participants to report whether or not they felt their behaviour changed whilst playing the game, whether this be between study conditions or simply as a consequence of in-game events. It may be interesting to correlate these answers against the Self-Assessment Manikin results to see if different emotions between conditions had a positive or negative impact on participant behaviour. Furthermore, participants may show different vocal and physical behaviour between 2D and VR conditions, this question provides each participant with an opportunity to report these differences.

Condition Categories

These categories allow participants to elaborate on their experience across both the VR and tablet conditions of the study. Before questions are asked, participants are told exactly which condition they are being asked about to ensure that no confusion takes place both between the previous set of questions and between the two conditions. The questions used in these categories are listed below:

a: *How did you feel while playing the (VR/non-VR) version of the game?*

b: *To what extent did you feel aware of your (real) surroundings?*

c: *In what ways to you think it was similar, and different, to a real gambling* machine?

VR condition only:

d: *Did you find the VR version easy to use?*

The questions asked regarding the VR condition are identical to those asked about the tablet condition to ensure that exactly the same information is collected about each condition. The answers provided by participants for question 'A' will be used as justification for SAM and NASA-TLX questionnaire results. Similarly, the answers provided to question 'B' may provide insight as to what aspects of each condition most contributed to immersion or a lack of.

Question 'C' asks for participants to directly comment on how similar or different each experience was to playing on a real gambling machine. In this instance, the participant recruitment conditions may become a problem as not all participants will be capable of answering this question. However, participants that are able to answer this question will provide useful insight regarding how accurately each condition simulates the real-world activity of using a gambling machine.

A final question is asked for the VR condition, which addresses how easy it is to use the developed VR environment during the task. These answers will be used to identify any common issues with interaction which may have a negative impact upon other measures. For instance, perhaps inconsistent feedback and completed actions when interacting with the FCD game could have negative consequences on immersion, workload and even emotion due to frustration and additional effort being required to interact with the task.

Final Question

After category-based questions have been answered, the participant is given an opportunity to elaborate upon their overall experience and provide any further information which might prove useful during analysis. This question is simply phrased *"is there anything else that you'd like to tell us about your experience?"*, and brings the interview to a close upon being provided with an answer.

5.1.3 Experimental Setup

Each study is conducted within a controlled environment to minimise external interference as much as possible, including sounds and visual elements which may interfere with the results of each condition. Specifically, the participant is to be accompanied only by the study investigator with no other persons present whilst the study takes place. Precautions are put in place to maintain this level of privacy such as sign-posting on room entrances which ask people not to enter or otherwise disturb the study in any way.

Environmental factors such as unintentional visual stimuli are mitigated as much as possible by using tall dividers to separate off the study area from the rest of the room, as shown in Figure 5.4. This limits visual distractions which may interfere with a participant's ability to concentrate on the set task, allowing study results to more accurately reflect the content of each condition more accurately. Auditory factors are more difficult to account for as participants will only be wearing headphones in the VR task whilst listening to the game volume out loud on the tablet. This is done to simulate being present with the device, using three-dimensional techniques to represent the position of audio in VR. Fortunately, the environment used in the study is very quiet and had no clear auditory distractions.

Figure 5.4: The study environment under use by the investigator.

5.1.3.1 VR Setup

The virtual reality task was completed by participants within the HTC VIVE play space. This space was marked out using white tape which accurately represented the bounding box within VR in order to provide clarity whilst not wearing the VR headset, as shown on the floor in Figure 5.4.

Regarding the VR equipment itself, each light-box stood at a short distance from one another, forming a play area which measured approximately 3m x 2m. The light-boxes were placed high enough to accompany tall participants taking part in the study, and tilted downwards by 30 degrees as advised on the HTC VIVE website [106]. The headset used was the HTC VIVE Pro, shown in Figure 5.5, the second-generation HTC VIVE model. This model included inbuilt headphones and has been credited with numerous advantages over its predecessor, including better weight distribution and a more intuitive strap reminiscent of the Deluxe Audio Strap upgrade for the original HTC VIVE [107]. Furthermore, the AMOLED display used in the HTC VIVE Pro is recognised as the greatest upgrade which allows the Pro model to run at 2880 x 1600 resolution, an 80% increase over the 2160 x 1200 resolution of the standard model [107]. These upgrades were deemed necessary for the purposes of the study as it allowed for a more comfortable user experience with a resolution that was more life-like and no longer suffered from the blurriness seen in the original model. This meant that hardware issues were less of a factor for participants deciding which condition is more realistic.

Figure 5.5: The HTC VIVE Pro headset [106]

The controllers and light-boxes belonged to a standard HTC VIVE kit. The reason for this is that the HTC VIVE Pro had not yet been released with the updated controllers or light-boxes at the time of running the study. However, using this older equipment did not prove at all troublesome as they provided sufficient accuracy when measuring and reporting player movement within the VR play-space.

A powerful desktop computer was used to run the VR equipment sufficiently enough to mitigate issues with frame-rate, which can induce simulator sickness if managed incorrectly. This desktop was provided by the University of Lincoln and was capable of running the VR display, an additional display for monitoring and all necessary software at a smooth and consistent rate throughout each study. The exact specifications for the desktop machine, alongside recommended minimum specifications provided by HTC VIVE [106], are shown in Table 5.1.

	Study PC	**Recommended (Pro)**
Processor	Intel Core i5-6400	Intel Core i5-4590 or AMD FX 8350, equivalent or better.
Graphics	NVIDIA GTX 970	NVIDIA GTX 1060 or AMD RX 480, equivalent or better.
Memory	16 GB RAM	4 GB RAM or more
Video output	Display Port 1.2	Display Port 1.2 or newer.
USB	USB 3.0	1x USB 3.0 port or newer.
Operating System	Windows 10	Windows 8.1 or later, Windows 10 (best).

Table 5.1: Study PC specifications compared with recommended specifications.

The graphics card used in the study was a NVIDIA GeForce GTX 970 which performs statistically worse than the recommended NVIDIA GeForce GTX 1060. Despite this, no performance issues were observed during extensive testing both during the development of the VR environment and during pilot studies. This is likely due to the relatively similar performance of the two cards as the 970 was one of the higher performing models of the 9-series cards, and the 1060 is the lesser performing 10-series card.

5.1.3.2 Tablet Setup

The tablet-based task asked participants to play through the FCD game on a touch-screen device. This allowed for similar interaction between both the tablet and VR conditions as both scenarios involved tapping a screen, or virtual screen, to progress through the FCD game.

The device itself is a Dell Inspiron 15 7000 laptop/tablet, shown in Figure 5.6. During task completion the device was folded back on itself, to enable tablet mode, and placed with the screen pointing directly upwards on the table depicted in the back of Figure 5.4. Participants will be specifically instructed not to move the device from its set position at any point during task completion.

Figure 5.6: The Dell Inspiron 15 7000 used in the study.

The Dell Inspiron 15 7000 runs Windows 10 as an operating system which was significantly better for the purposes of this project than running Android or iOS operating systems. This is because the FCD game is built and optimised for Windows platforms, the operating system upon which it was developed. Despite

Unity providing functionality for exporting to an android APK, it was safer to build for one operating system and to be sure that the game performed identically on each device used in the study.

Furthermore, the touch-screen device uses hardware which makes it more than capable of running the FCD game. This was investigated through extensively testing the game from start to finish on the device and ensuring that the performance remained consistent with the VR condition. All relevant specifications for the device have been listed in Table 5.2.

	Dell Inspiron 15 7000
Processor	Intel Core i7-8565U
Graphics	NVIDIA GeForce MX150
Memory	16 GB RAM
Display	15.6 inch
Operating System	Windows 10

Table 5.2: Dell Inspiron 15 7000 specifications.

5.1.3.3 Training

Prior to the study conditions, participants are instructed to engage with a short tutorial concerned with the rules and game-play of FCD and Hi-Lo within this project. The tutorial comes in the form of a PowerPoint presentation, including a mixture of images, screen-shots, game-play clips and text-based slides.

The first slides of the tutorial presentation provide images of example poker hands, as seen in Figure 5.7. These images are accompanied by short explanations of what establishes each hand, and the associated winnings that this study's implementation of FCD provides. This help to establish the rules FCD as a poker-like game.

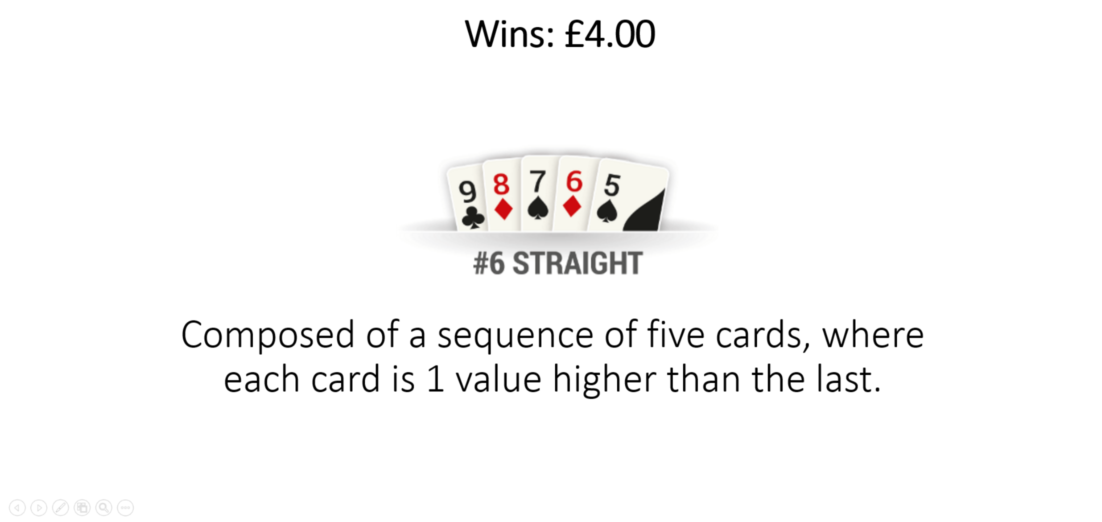

Figure 5.7: Training slide explaining a poker-hand ("straight") within FCD.

Following the rules, is a slide that address the layout of FCD, as seen in Figure 5.8. This familiarises the participant with the visual elements of the game. This is followed by a slide that briefly explains the implementation of aces, a subject that could cause confusion. The slide explains that aces are the highest card, rather than the lowest, and that a reminder of this fact is also present on screen during game-play.

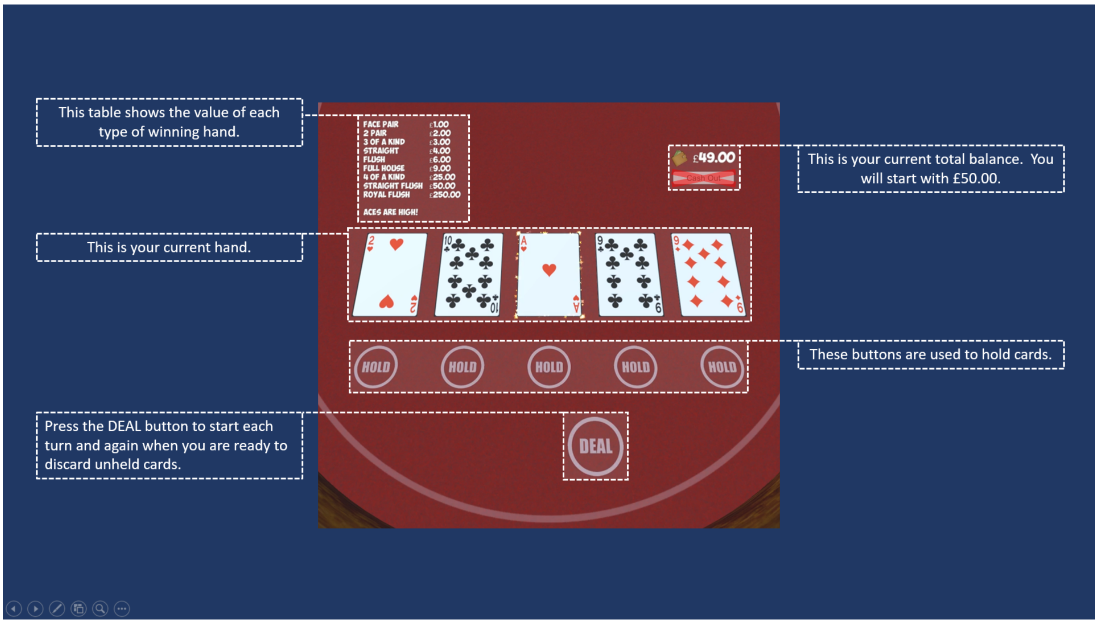

Figure 5.8: Training slide for the layout of FCD.

The final slides concerned with FCD are related to the game-play, and provide a series of short, annotated, visual clips which demonstrate the full process of receiving a hand, holding cards, and winning or losing in that particular hand. These are presented on their own slides, and are recapped by a final clip which combines all prior clips and annotated information, as seen in Figure 5.9.

Figure 5.9: Training slide containing an FCD game-play clip.

This process is repeated for the Hi-Lo mini-game, detailing both the layout and game-play. The rules are considered to be self-evident given the name of the game, but are however, provided in a final summary which details the objective of Hi-Lo, as seen in Figure 5.10.

Figure 5.10: Training slide which summarises Hi-Lo.

Amongst the final slides of the presentation is a full video showing the full process from starting a an FCD hand to gambling winnings in Hi-Lo, and a losing example hand is also provided. This is simply intended to recap game-play elements, whereas previous game-play is broken down into short clips to allow participants to progress through the training task at their own pace.

5.1.4 Pilot Study

A pilot study was conducted to examine whether the crucial components of the main study will be feasible. A small sample size of 3 participants was used to conduct the pilot study. Each participant was run through the full study procedure, filling in all proposed questionnaires and participating in a recorded interview. The results of the pilot were however, not included within the analysis of the main study. The pilot was used to validate the study procedure, artefact and measures.

The pilot study concluded that the main study was feasible. Only one potential issue was identified concerning the interview questions, whereby participants were often confused between questions regarding strategic and behavioural changes whilst playing FCD. It was therefore noted that additional explanation is required to distinguish these two during main study interviews. Aside from this, no further changes were made to the procedure or its measures. However, the pilot study revealed several bugs within both the VR simulation and the FCD game:

1. Haptic feedback was inconsistent when interacting with the virtual VLT screen.
2. FCD hands sometimes interpreted incorrectly by the rigging system, causing unintentional win and loss conditions.
3. One instance occurred where a hand was incorrectly rewarded as a "royal flush", causing the participant to accrue a substantial balance.

The haptic feedback issue was related to discrepancies in collisions between the virtual player hand and VLT screen. Collisions were inconsistent with the functionality used to interact with the game, using raycasting. This issue was fixed by allowing haptic pulses to be directly triggered by interaction with the game as opposed to a separate collision process.

The issue of FCD hands being incorrectly interpreted by the system was found to be caused by insufficient safeguards being present both prior and during the rigging process. Specifically, hands such as "face pairs" were still included whilst performing final probability checks despite a higher win, such as a a "two pair", already being accomplished by either holding or rigging processes. Safeguards were added to ensure that lower win conditions were discounted when calculating the final win condition.

After numerous attempts to replicate the "royal flush" incident, the cause of the final issue was identified as a null-condition interfering with parts of the rigging process. This caused the hand to be incorrectly interpreted and thus rewarded as a "royal flush" despite visually presenting a lower win condition. The source of the null-condition was located and remedied to solve this problem.

5.1.5 Participant Recruitment

Recruiting participants for this study is subject to several criteria to satisfy ethical requirements, and additionally to ensure that the demographic is well suited to the research parameters and thus capable of providing meaningful data.

5.1.5.1 Pre-Study Screening

All participants will be at least 18 years of age in order to comply with the minimum legal age of gambling in the UK. Whilst participants are not gambling their own money in the study, the task itself is associated with gambling. Additionally, participant performance in the study will impact their chances to win money in a post-study lottery, which is considered gambling.

Additional screening will analyse previous gambling experiences for each candidate. Individuals with no prior gambling experience will not be allowed to participate in the study. This is done for ethical purposes, ensuring that the study will not introduce participants to gambling. Any prior engagement in gambling is suitable for the purposes of the study, ranging from scratch cards to sports betting and casinos.

Medical information was also collected from participants to ensure that they were able to participate in VR without experiencing discomfort and to minimise the chances of an accident taking place. Participants were asked to fill in a medical form and disclose any visual, mobility or phobic issues which may impede their ability to complete the study task.

5.1.5.2 Study Sample

A total of 48 (32 male, 16 female) participants were recruited through convenience-sampling from the University of Lincoln campus and surrounding area. Ages ranged from 18 to 51 (M = 25.64; SD = 8.16). On the basis of self-reporting, 39 participants reported that they had used VR before, across several devices. Figure 5.11 shows the usage of each device, whereby some participants had used multiple devices.

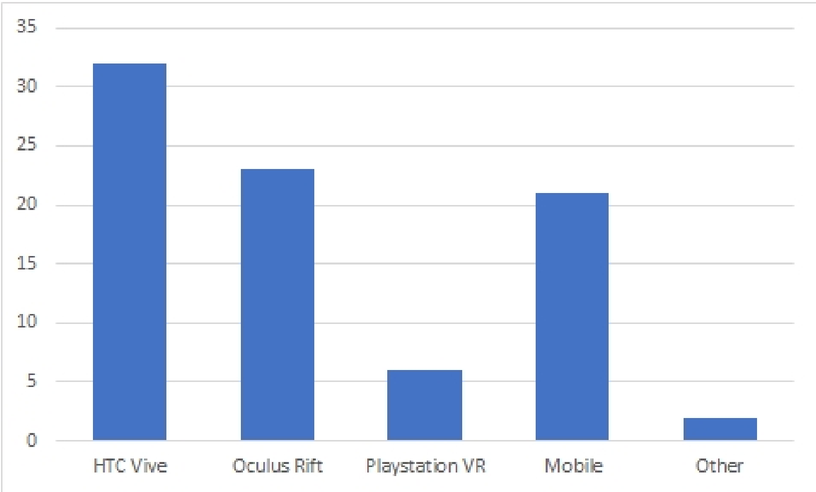

Figure 5.11: VR device usage for study participants.

Each participant was also asked to report the last time they had used a gambling machine, whereby 26 participants reported having used a gambling machine within the last year. The full breakdown of gambling machine use is shown in Figure 5.12.

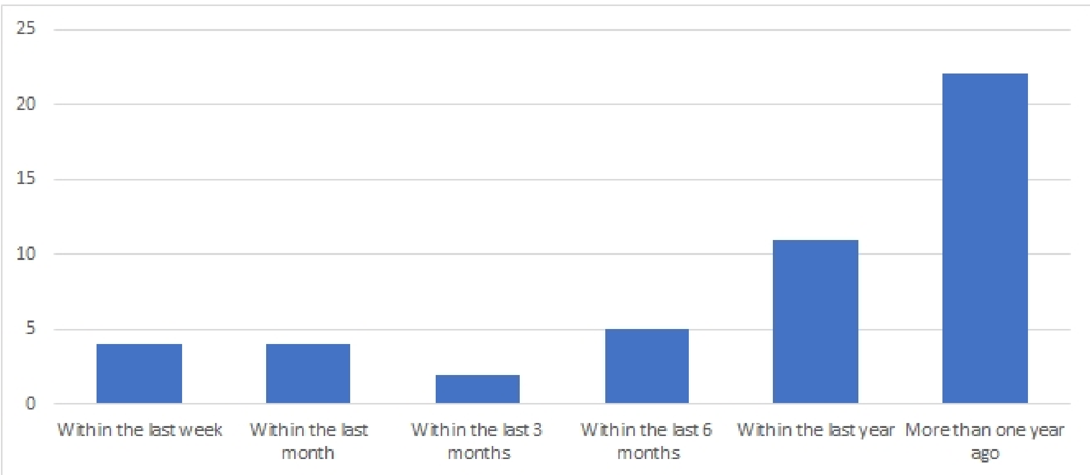

Figure 5.12: Time since last using a gambling machine for study participants.

During recruitment, an issue arose with regards to recruiting female participants who fit the specific criteria of having previous gambling experience. Many female individuals who were approached about taking part in the study would explain that they had no prior gambling experience. Thus, despite putting emphasis on recruiting female participants, time limitations meant that more male participants were used to ensure that a satisfactory sample size was reached. This discrepancy between the number of male and female gamblers is however also reflected in statistics. During 2017, the Gambling Commission UK reported that around 48 percent of males take part in gambling activities, whilst only 41 percent of females do so [4]. Whilst these statistics do not match up completely with the gender split in the study, of 66 percent male and 33 percent female, it does indicate that a gender split may be more representative of regular gamblers in the UK.

5.1.6 Study Procedure

5.1.6.1 Pre-Conditions

Participants are greeted upon arrival, and introduced to the study investigator. Participants are then instructed that the study uses the HTC VIVE, and asked to fill in the medical form, described in Section 5.1.1.2, to ensure that they are medically capable of taking part. If the participant answered affirmatively to any question on this form, they are rejected from the study at this stage.

Next, it was explained to the participant that they are required to provide informed consent to take part in any study at the University of Lincoln. Participants are then presented with the information sheet, described in Section 5.1.1.1, and encouraged to ask any questions they had whilst reading through it. Once the participant indicates they were ready to move on, they are provided with the consent form, described in Section 5.1.1.3, and asked to sign. If a participant refused to sign the consent form, they were rejected from the study at this stage. Upon successfully providing informed consent, the participant is assigned a unique identified, formed of randomised letters and numbers, which is used to label their data from here on.

The last form participants are asked to complete is for demographic information. This form asks the participant to disclose their gender, age, previous experience of VR (including specific devices), and the last time they had used a gambling machine. Once the participant has completed the form, the study proceeds.

Before engaging with the experimental conditions, FCD is briefly described to the participant and they are asked to complete the training described in Section 5.1.3.3. Once participants are done, they confirm with the investigator and are told one final bit of information which is not included in the training presentation. Specifically, the rules surrounding a Face Pair when compared to other pairs or sets. Participants are asked to confirm understanding and prompted with another opportunity to ask questions before moving on to the study conditions.

5.1.6.2 Experimental Conditions

There are two experimental conditions, one for playing FCD within VR, and the other for playing on a touch-screen tablet. These conditions were counterbalanced, meaning that if one participant started with VR, the next would start with the tablet. This process is repeated for all forty-eight participants.

Regardless of condition, participants are instructed that they would be playing FCD twice, being asked to complete the three questionnaires between each condition, as described in section 5.1.2.1. No prior details were given about any questionnaires except the SAM, as the pictorial scales were deemed to required further explanation. Explanations are given for each of the three sub factor pictorial scales, and participants are presented with the SAM help sheet. The participant is then asked to have a go at filling in a base-line SAM sheet using the help sheet to assist them.

Upon completing the SAM base-line, participants are informed that they will not be gambling with real money during the study. However, they are told that they will be automatically entered into a raffle to win a real cash prize, and that the number of raffle tickets they win is dependant on their task performance.

Participants are specifically told that the prize for each condition is 30 pounds and that the lottery will be drawn after concluding all studies. Before moving on, the participant is prompted for any questions regarding the lottery.

At this stage, the appropriate study condition is applied as per the counterbalancing. Both conditions follow a similar process, however, a few dialogues are specific to each. Therefore, they have been split under different headings below. It is important to understand that the order of the headings is not consistent with the order of the counterbalanced conditions.

In both versions of FCD within conditions, participants play through 35 trials/hands, regulated by the balance curve and rigging system. The participants are not informed of the exact number of trials, or the presence of rigging within the game.

After completing one of the two conditions, participants are immediately asked to complete the SAM, NASA-TLX and IEQ questionnaires, in that order, before either moving onto their second condition. Alternatively, if the participant has completed the second condition they proceed onto the interview process upon completing the questionnaires.

Tablet Condition

Participants are instructed that they will be playing FCD on a touch-screen tablet, that the task will usually take around 8 minutes to complete, and that it will be following up by questionnaires.

Participants are told that the tablet will be placed on the table in-front of them, with the game already loaded, and that the investigator will step back for the duration of the play-through. The participant is specifically instructed not to move the tablet off the table, and to simply play through the game until it is over.

Before allowing the participant to continue, they are prompted to ask any last-minute questions and informed that it is important that they and the investigator do not talk whilst they play.

Once any questions are answered, the tablet is placed on the table, and the investigator steps back out of sight to await the participant completing the experiment. Once completed, the paper-based raffle tickets are filled out and set aside for the end of the study.

VR Condition

Participants are instructed that they will be playing FCD on a virtual gambling machine, that the task will usually take around 8 minutes to complete, and that it will be following up by questionnaires.

Participants are run through a brief training exercise to allow them to familiarise themselves with the VR equipment, light-boxes and the play-space rectangle. The headset is explained first, detailing how it works and showing both the mechanism for tightening the strap, and adjusting focus for the lenses. Afterwards, the controllers and relevant controls are explained, only the trigger for this study. The investigator then gestures towards the light-boxes and the white tape used to mark the play space rectangle. After the participant has confirmed their understanding of all the features listed, the following safety points are covered:

1. "You will see a blue wire-frame wall when approaching the edge of the VR play space. It is important that you do not walk beyond this as you may collide with real-world objects.”
2. "If you find yourself becoming tangled in the headset cable, please stop what you are doing and take the time to untangle yourself.”
3. "We would not normally communicate during the study. However, if you are having difficulty, simply raise your hand or ask for help.”
4. "If I identify that an accident may occur, I will tap you on the shoulder. Please stop moving in this instance and await instructions.”
5. "If you begin to feel nauseous, please let me know and I will remove the headset.”

The participant is informed that the virtual environment containing the gambling machine will be loaded up, and instructed to play through FCD on the simulated gambling machine (SGM) until the game is over. However, participants are also encouraged to move freely and look around to get a feel for the environment.

Before allowing the participant to continue, they are prompted to ask any last-minute questions and informed that it is important that they and the investigator do not talk whilst they play. The participant is then handed the VR headset and the investigator moves out of the play-area. Once wearing the headset and handling the controllers, the participant plays through FCD on the SGM. Once the study is done, the paper-based raffle tickets are filled out and set aside for the end of the study.

5.1.6.3 Post-Conditions

Participants are informed that they will now be asked to take part in a short, recorded interview whereby they are asked the questions described throughout Section 5.1.2.2. Safe storage of audio recordings is specifically mentioned before continuing, and the participant is asked to confirm that they understand and are happy to continue. After confirmation, the interview begins.

Once the interview is concluded, the participant is thanked for their time and re-presented with the information sheet and their raffle tickets.

Once the participant has left the premises, all recorded data is scanned into electronic format and stored on a secure, file protected, PC. Paper based study data is stored within a filing cabinet, protected under lock and key. Special care is taken to ensure that all copies of consent forms are stored separately from recorded data, both online and offline. These precautions are taken to ensue that the participants identity remains confidential and is not otherwise compromised.

Chapter 6

Discussion

6.1 Immersion

	Tablet		**VR**		
Sub factor	**Mean**	**SD**	**Mean**	**SD**	**p-value**
Challenge	17.646	3.5580	17.917	3.7972	0.593
Control	22.625	5.4211	26.625	4.3644	<0.001
Real World Disassociation	25.583	8.1367	35.771	7.1407	<0.001
Emotional Involvement	24.188	6.4533	26.958	6.5881	0.003
Cognitive Involvement	45.625	7.1478	47.813	7.2160	0.026
Question 32	5.604	1.9758	7.917	14267	<0.001

Table 6.1: IEQ scores for both the Tablet and VR conditions.

> ***RQ1:*** *Do users experience higher levels of immersion and engagement with a gambling game while playing in a VR representation of a real-world gambling environment, as compared with a laboratory-based condition?*

The Immersive Experience Questionnaire (IEQ) [32] was used to measure whether participants experienced higher levels of immersion when playing Five Card Draw (FCD) within a laboratory setting, or VR betting shop environment. Whereby the laboratory-based was comprised of playing FCD on a touchscreen tablet. It was hypothesised that users would experience higher levels of immersion in the VR condition. This is motivated by work which highlights the importance of ecological validity when generating presence [23], and how this will result in higher levels of immersion/engagement with the FCD task.

Analysis of IEQ results suggests that participants experienced a statistically significant difference in subjectively measured sub factors for *control*, *real world disassociation*, *emotional involvement*, and *cognitive involvement*. Specifically, analysis showed that the mean scores for each of these sub factors were higher in the VR condition than the laboratory-based tablet condition.

Participants reported no statistically significant difference for the *challenge* sub factor. A potential reason for this is that the FCD task remained consistent for each condition. The experience was regulated by the underlying rigging system mechanics and balance curve which provided a consistent stream of wins and losses throughout both conditions. However, these results suggest that the type of interaction did not affect a participant's perceived sense of challenge for FCD.

Results for *real world disassociation* suggest that participants felt less present within the laboratory, a setting which is associated with experiments. This may allow a participant to engage with the task more naturally, without being concerned about whether they are performing as expected by the investigator, perhaps feeling less concerned about time taken or performance when completing the study task. This theory is consistent with NASA-TLX results for *temporal demand*, presented in Section 6.3, which was found to have no statically significant difference between conditions. As participants were not given a time frame within which to complete the task, the theory cannot be fully accepted without further investigation. However, several participants reported being more aware of the investigator being present during the tablet-based condition, for example:

> *"Whereas with the VR set, I knew you were there but you can't get a sense of where you are ... so you feel like you're stood in a pub with people around you, especially with the ear sets on. But on the tablet you've got a quiet room, but you can hear people breathing ... you're just aware more I think."*

> *"On [the] tablet ... you're quite aware that you're behind me ... [which] made it so you wanted to do better [because], if you're playing it by yourself, you're not being judged by your surroundings."*

Participants reported a higher sense of *control* for the VR condition. This could suggest that participants felt that they had more influence on the outcome of FCD in the VR condition. This is is supported by SAM results for *dominance*, presented in Section 6.2, which suggests that participants felt more dominant when playing the VR condition. However, it is difficult to understand why this may have been the case as both conditions were rigged to provide an extremely similar experience, in terms of winning and losing, throughout game-play. It could be argued that participants were not aware of this fact, however, they were able to notice that their winnings were almost identical across conditions, as a consequence of the balance curve. This might therefore suggest that participants were reporting their sense of control for interacting with FCD, rather than controlling outcomes. Participants may have reported a higher sense of control as a consequence of the sensorimotor contingencies (SCs) present within VR technology [23], which describe actions we know to carry out in order to perceive. Interacting with the virtual VLT machine may have felt more "natural" than tapping on the touchscreen tablet, as the physical movements used in VR are more associative with every-day life. However, participant answers provided for interview questions often suggested difficulty when using the VR controls, so this is unlikely the case. The most likely reason for a higher reported sense of control may have been due to the freedom participants were given in each condition. Participants were given no rules for the VR condition, simply instructed that they will be placed within a virtual environment and that they must play through the FCD game. However, participants were explicitly told not to move or adjust the position of the tablet in any way, and to only play through the game by tapping the screen until done. By restricting the way in which the participant can interact with the tablet, they may have consequently felt less control over the FCD task, upon which the game was presented. This was unintentional, but may be supported by participants feeling a lower sense of *dominance* in the tablet condition, as shown by the SAM results in Section 6.2. Further investigation would be required in the future to confirm whether or not this is the case. However, information provided during the interview process suggests this may be the case, for example:

> *"The idea of me having the controller in both hands made me want to use the two hands, whereas with the tablet, you said not to touch [it]."*

Subjectively reported scores for *cognitive involvement* show a statistically significant difference between both conditions. Specifically, participants reported higher scores for the VR condition as opposed to the tablet condition. Participants may have felt more relaxed when playing the tablet condition, which the results of NASA-TLX suggests is a more physically demanding than the VR condition, as reported in 6.3. This might encourage participants to play the game using a more nonchalant approach, causing them to be less interested in the task and consequently less cognitively involved. The answers provided during the participant interview support this, whereby participants frequently stated that they felt more relaxed while playing on the tablet. Participants also often associated the tablet condition with playing at home, on a mobile phone, rather than a real VLT machine. This association suggests that the laboratory condition might not be capable of producing the same results as would be observed by a participant using a VLT machine. A more realistic setup, using a bought or rented VLT machine may produce similar results under laboratory conditions but this could be expensive, and a lack of ecological validity would not produce similar results to *in vivo* measures. However, further work would need to be done to validate the VR artefact as a suitable alternative to *in vivo* studies by comparing the two scenarios. Quotes from participants concerning relaxation and association to mobile games are included below:

> *"Actually more relaxed then standing round ... the tablet version I could easily play at home, sitting on the sofa and then just watching Netflix in the background."*

> *"I preferred playing [the tablet] version of the game, it was more relaxed ... It's a more relaxed position to me, than being stood up for the VR."*

> *"I think if I was sort of on my couch, in my house with my feet up ... I'd be more inclined to burn hours into [the tablet]."*

> *"[The] tablet is ... more relaxed because you know you're not going to lose anything, it's just fake money."*

"I think I was a bit more, kind of relaxed in the tablet version. So, I wasn't as competitive ... I was more, like just playing, rather than actually thinking about it as much."

As a validated questionnaire, the results of IEQ are accepted as accurate measures of immersion, thereby providing evidence to support the proposed hypothesis. Work by Brown and Cairns [33] further supports this by linking high levels of immersion to engagement, suggesting that the results of IEQ are also indicative of participants being more engaged with the task. This conclusion is base on statistically significant results provided for control, emotional involvement, and real world disassociation sub factors. No statistically significant difference was found between conditions for challenge. This sub factor is therefore not indicative of higher immersion for either condition, and not relevant for the final conclusion.

To summarise, the results of IEQ, along with the accepted hypothesis, present a number of advantages for gambling research when compared with laboratory-based measures. Increased *cognitive involvement* for the VR condition suggests that additional steps would need to be taken in order to measure similar participant behaviours within the laboratory. Specifically, a setup would be required which more accurately represents a VLT and betting shop, resulting in a larger financial investment to potentially create an environment which is ecologically valid and encourages the participant to engage with the task as intended. In this particular study, participants associated the touch-screen tablet with a more relaxing experience, where they could nonchalantly complete the task. In contrast, the VR task was more engaging and produced a higher reported score for *real world disassociation*, suggesting that the participant felt less aware of the real-world when playing FCD through the medium of VR. Participants also reported feeling less aware of the investigators presence, potentially enabling them to display behaviours which are more associative with the task and less reserved as a consequence of not feeling criticised for their reactions. Furthermore, participants showed higher reported levels of *emotional involvement* for the VR task, suggesting that they may react more intensely to stimuli provided by the task, such as winning or losing conditions. These intense behaviours may provide an opportunity to measure larger effect sizes during gambling research, when compared to those shown during laboratory-based experiments. Finally, despite being more physically demanding, a participants perceived sense of challenge remains consistent for tasks regardless of being experienced in VR or within a laboratory.

Overall, the results of IEQ have shown that VR creates a more immersive experience for the experimental task, than that of a laboratory. It provides a number of potential advantages for gambling research as a result, without offering any disadvantages such as increased challenge. This provides an opportunity to use the VR platform within gambling research to confirm or disprove the advantages listed above.

6.2 Arousal

	Tablet		**VR**		
Sub factor	**Mean**	**SD**	**Mean**	**SD**	**p-value**
Mood	6.542	1.3040	6.979	1.5641	0.070
Arousal	5.125	1.9199	5.688	1.6394	0.036
Dominance	5.333	1.3579	5.771	1.3565	0.041

Table 6.2: SAM scores for both the Tablet and VR conditions.

RQ2: *Do users experience higher levels of arousal while playing the game in a VR environment, as compared with the laboratory condition?*

The Self-Assessment Manikin (SAM) was used to measure each participant's emotional response within both the laboratory-based tablet condition and the VR condition. It was hypothesised that users would experience higher levels of arousal in the VR condition.

Analysis of SAM results suggests that participants experienced a statistically significant difference in subjectively measured sub factors for *arousal*, and *dominance*. Specifically, analysis showed that the mean scores for each of these sub factors were higher in the VR condition than the laboratory-based tablet condition.

Results for the mood sub factor reported no statistically significant difference between the two conditions. This could indicates that using VR technology, associated with ecological validity, does not impact upon a participants perceived pleasure whilst engaging with the FCD task. Whilst this does not show a positive effect of using VR when compared to laboratory-based studies, it also suggests that there is no inconsistency with the measured effect between both conditions. No advantages or draw-backs were therefore observed as a result of analysing the mood sub factor.

Results showed a statistically significant difference for the *arousal* sub factor between conditions, showing higher reported scores for the VR condition. By using the terms provided on the SAM help sheet, the reported scores for *arousal* can be linked to other measures used in the study. For instance, the discussion provided for *cognitive involvement*, in Section 6.1. During this discussion, evidence was provided to show that participants felt more relaxed, a term which falls on the lower end of the pictorial scale for *arousal*. Furthermore, results of the NASA-TLX show higher levels of physical demand for the VR condition, as shown in Section 6.3. This supports the idea of a participant feeling "stimulated" rather than "calm" or "sluggish". Reportedly higher levels of arousal suggests that the VR condition is more characteristic of *in vivo* studies, which are often shown to elicit higher levels of arousal than laboratory-based studies [2], [3]. Whilst this does not prove that the VR condition would be equally as effective as a similar *in vivo* study, it does suggest that measured results during experimental studies may be similar in both. Therefore, the results of VR-based experimental studies may be better generalised to real-life scenarios, as with *in vivo*, when compared to often results from laboratory-based study, which are often criticised for their how well they generalise. More work would need to be conducted to investigate exact similarities and differences between results for VR-based studies and those conducted *in vivo*.

The reported statistically significant difference for *dominance* supports the reported score for the *control* sub factor of IEQ. Both of these results suggest that participants felt more control over the FCD task in the VR condition, which is understood to have potentially been caused by an experimental error, as discussed in Section 6.1.

In summary, whilst the results of SAM offered no disadvantages with regards to the mood a participant experienced, reported scores suggest that *arousal* was higher in the VR condition, supporting the proposed hypothesis. This may have implications on gambling research as this same phenomenon has been observed when comparing laboratory-based studies to those conducted *in vivo*, whereby *in vivo* studies show higher levels of arousal [2], [3]. This opens up the question of how well the results of a VR-based gambling study might reflect those of one ran *in vivo*, and whether VR can be used as an alternative which offers both experimental control and ecological validity.

6.3 Workload

	Tablet		**VR**		
Sub factor	**Mean**	**SD**	**Mean**	**SD**	**p-value**
Mental Demand	9.354	4.7522	10.563	5.1111	0.088
Physical Demand	3.521	3.1222	7.271	5.3225	<0.001
Temporal Demand	7.146	5.2022	7.250	4.9055	0.887
Performance	9.458	3.8645	9.729	4.1501	0.568
Effort	9.438	4.6030	9.417	4.2718	0.976
Frustration	9.438	5.0735	8.479	5.1281	0.249

Table 6.3: NASA-TLX scores for both the Tablet and VR conditions.

> ***RQ3:*** *Is there any difference in task workload for players while playing a gambling game in VR, as compared with a laboratory condition?*

The NASA Task Load Index (NASA-TLX) was used to measure each participant's emotional response within both the laboratory-based tablet condition and the VR condition. It was hypothesised that users would experience higher levels of workload for the VR condition.

Analysis of NASA-TLX results suggests that participants only experienced a statistically significant difference in the subjectively measured sub factor for *physical demand*. Specifically, analysis showed that the mean score for this sub factor was higher in the VR condition than the laboratory-based tablet condition.

All other sub factors reported no statistically significant difference across conditions. However, the likely explanation for this is consistent for several sub factors. Fundamentally, all questions within the NASA-TLX are phrased in such a way that they target the set task, with many of them using the word "task" when asking for participants to subjectively report workload. As the task for both the tablet-based and vr conditions was the same, to play through FCD until the game over screen was shown, it is reasonable to assume that participants would report a similar perceived workload for both conditions. For *temporal demand*, participants were not given a set time limit, within which they were required to complete the task, in either conditions. For *performance*, the winning and losing conditions were controlled identically throughout each play-through, resulting in final winnings which were almost identical in each condition. If winnings were used as a metric for success, it is therefore reasonable to assume that participants would report a similar level of performance for both conditions. The similar mean scores for *effort* is slightly unusual, as results had shown a significant difference for mean *physical demand*. Additionally, whilst mean *mental demand* showed no statistically significant difference, the mean score for VR was tending towards being higher for VR in this sample. As effort can be considered a combination of these factors, one would expect higher reported levels of effort required for the VR condition. However, this is likely not the case due to the wording of the question, specifically asking "how hard did you have to work to accomplish your level of performance?". It is likely that participants associated the performance and effort questions with one another, levelling out the reported level of effort as a consequence.

Mental demand is slightly more difficult to understand, as participants often made comments associated with taking time to learn the controls for VR. However, as learning only took a limited amount of time, it is likely that participants were able to understand the controls sufficiently throughout the remainder of the VR condition to report little difference in scores for *mental demand*. This may also explain the very minor difference in reported means for this sample, though this cannot be generalised to a larger sample.

The lack of a statistically significant difference for mean *frustration* scores across conditions is also likely caused by the fact that the game-play experience of the task, being FCD, remained consistent across both conditions. These findings also support reported scores for *challenge*, reported in Section 6.1. However, it might be interesting to separately measure certain terms for this sub factor in future studies. Specifically, it would be interesting to see if reported levels of insecurity provide evidence to support previous discussions concerned with the participant being less aware of the investigator, discussed in section 6.1. There may be a correlation between the results of such a test and feeling less "judged", as suggested by some participant interview answers.

The only statistically significant difference was measured for the *physical demand* sub factor, whereby the VR condition was reported to be more physically demanding. Whilst the question is worded specifically towards the "task", as with temporal and mental demand, the interaction required to complete the set task is different. Participants are still tapping on a screen within virtual space, however, they are stood up rather than being sat down. Quotes presented in section 6.1 whilst discussing cognitive involvement, support this. Specifically, participants frequently mention sitting as a more relaxing position, as opposed to standing in VR:

> *"Actually, more relaxed then standing round ... the tablet version I could easily play at home, sitting on the sofa and then just watching Netflix in the background."*

> *"I preferred playing [the tablet] version of the game, it was more relaxed ... It's a more relaxed position to me, than being stood up for the VR."*

> *"I preferred the tablet in front of me as opposed to having this whole headset on and being stood up and having to wave my arms around."*

Additionally, it could be argued that the actions required to tap the screen are also more physically demanding, and the last quote supports this. Whilst using the tablet, the participant can rest their elbows on the desk and tap nonchalantly, whereas they are required to suspend their arms and move back-and-forth horizontally to interact with the FCD game in VR. Consequently, it is clear to see why participants experienced a higher sense of physical demand in VR.

The results of NASA-TLX suggest that the perceived workload of the task, with exception to physical demand, does not change based on whether it in presented within VR or a laboratory. The higher sense of physical demand is likely to be similar to studies conducted *in vivo*, but the two should be compared in order to confirm or deny this.

6.4 Limitations

Several limitations become apparent when considering the work presented in this thesis. Firstly, the study sample used was recruited using convenience sampling from a population of students, many of whom had only some experience with gambling in the past. No problem gamblers were used in the study, meaning that the reported results cannot be directly compared with existing gambling research or generalised to gambling in real world contexts. However, the project was not focused on observing gambling behaviour and instead aimed to design and evaluate the effectiveness of a VR tool for replicating a real-world scenario when compared a laboratory-based method. The decision to use participants with some gambling experience was purely an ethical consideration and does not impact the validity of results related to the user experience including immersion, arousal and workload. The implications of these findings are discussed throughout sections 6.1, 6.2 and 6.3, and summarised in section 7.

Another limitation is linked to the findings presented in section 6.2, which states that higher levels of reported arousal in the VR condition support findings in existing research comparing studies conducted *in vivo* to those in a laboratory. It is important to consider the novelty aspect of VR when making this conclusion, as experiencing VR for the first time could influence reported levels of arousal for some participants. No qualitative data collected during interviews confirms whether this is a factor in the results of this study. However, participants were asked to provide information regarding their experience with VR prior to the study, as shown in section 5.1.5.2. Around 81% of participants reported having used VR in the past, with 66% of participants stating that they had used the HTC Vive specifically. Whilst this does not eliminate the possibility of a novelty factor, it suggests most participants would not experience such a phenomenon. However, future work should ensure that all participants had prior experience using VR.

Finally, the results of the study also suggest a potential caveat to using IEQ as a subjective measure of immersion, specifically for the purposes of this study. Previously, the IEQ has been used to measure immersion for specific tasks, and the questions are validated as a means to measure how immersed an individual is within a game, played within the real world. In this sense, the game is facilitated by the real world, creating two layers: game, and real-world. In this study, these layers are interrupted by a new layer of interaction, the *"virtual-layer"*. This creates a three-linked chain of layers, within which the game is no longer facilitated by the real world but instead facilitated within a virtual world. As a consequence, some sub factors of IEQ become more complicated. Additionally, questions linked to awareness of the real world are likely to produce answers which are instead linked to VR rather than the game or task, due to specific wording. As is understood, this project is the first to apply VR in this way. Thus, no existing validated measures account for the level of interaction present within our unique scenario, but IEQ was found to be the best available measure for task immersion. Does this invalidate the findings of this study? No, participants were still able to disassociate from the real world, which is important for immersion and engagement. It does not matter for the context in which IEQ was applied, which was to compare immersion between laboratory and VR studies. We argue that the findings still show increased immersion for the VR condition, providing an ecologically valid environment within which the user disconnects from the real world. VR simply facilitates the ability to disassociate and drown-out real-world distractions, allowing the participant to become more involved with the task both emotionally and cognitively, consequently resulting in a higher sense of engagement with the task.

6.5 Contributions

The work presented in this thesis makes several significant contributions, both in terms of research findings and technical achievements.

Firstly, the VR artefact itself offers a platform upon which future work can be conducted within the field of gambling research. This is due to key design decisions which enabled the creation of a tool that creates a coherent experience whilst retaining experimental control. Additionally, the VR environment was designed in such a way that it can accept any 2D Unity game on the virtual gambling machines (VGM). This opens a wide range of possibilities for researchers to use this environment as a means of hosting their own gambling tasks with control conditions specifically related to their chosen research topic. The artefact produced for the purposes of this project can act as a catalyst for experimental research concerned with gambling behaviour. It enables higher ecological validity over laboratory-based conditions whilst still enabling a safe and controlled environment for participants to engage with the gambling task.

Secondly, the detailed design and development section offers key insight into the challenges present when creating a gambling task that can be used effectively for studying behaviour. Specifically, the Five Card Draw (FCD) game which was designed to accommodate fine control over the outcomes of each poker hand. Whilst the specific rigging conditions of FCD may not be suitable to the research aims of future work, the documented design and development process demonstrates that high levels of experimental control are not inherent in simulated gambling contexts. This instead needs to be accounted for and can consume a significant amount of development time to achieve desired levels of control. However, it is possible and may also be far simpler than trying to control the outcomes in a real-world scenario where experimenters may be restricted from modifying game-play.

Lastly, the research findings demonstrate that VR might is an effective medium for retaining user engagement when compared with laboratory-based studies. The wider implication of this is that participants are unaware of that is happening in the real-world and less concerned with the fact they are taking part in an experiment within the confines of a laboratory. This might allow for more authentic behavioural responses to gambling stimuli and other stimuli present within the virtual environment, potentially improving the how well results generalise. This is achieved without any significant impact on cognitive workload, only requiring a higher physical workload when compared with sitting down within a laboratory. This type of workload might be more consistent with similar studies conducted *in vivo*, which would require the participant to stand and engage with a real video lottery terminal (VLT). Findings also demonstrate increases levels of arousal in the VR condition. This is similar to the findings of previous studies which found higher levels of arousal *in vivo* when compared to laboratory-based studies [2], [3]. Whether this emotional response is consistent with that of *in vivo* experiments remains to be seen, and future work should aim to address this.

Chapter 7

Conclusion

This project asked how effective virtual reality (VR) is as a research tool for simulating gambling environments in psychological studies, specifically for gambling research. Three specific research questions and hypotheses were created based on established knowledge in existing research, aimed at working towards an answers for the broader question.

Two artefacts were developed for the purposes of this study. The first was a gambling activity called "Five Card Draw" (FCD), used in both experimental conditions as a task which each participant was asked to complete. For the VR condition, a second artefact in the form of a virtual betting shop environment was created, which would contain and facilitate playing the first artefact within VR. To our knowledge, this is the artefact of its kind used in experimental research.

A study was conducted, which used validated subjective measures and an interview to collect both quantitative and qualitative data which might offer answers to the research questions. This study asked forty-eight individuals to participant in each of the conditions, playing FCD on both a tablet, and on a simulated gambling machine (SGM), using a HTC VIVE Pro to visualise the virtual betting shop environment.

The results of this study suggested that participants experienced a greater sense of immersion for the FCD task when playing from within the virtual environment, when compared to playing on the tablet. This allowed participants to become more engaged with the task, being disassociated from the real world and enabling the participant to feel less aware of the investigators presence. Furthermore, participants reported higher levels of emotional involvement with the FCD task, suggesting that participants may be more likely to react more clearly and intensely to both positive and negative stimuli within a given task. This suggests that VR may present a great opportunity to investigate behaviour within gambling studies, by allowing investigators to observe elicited behaviours more clearly and with greater effect size over laboratory studies. These suggestions and possible implications are formed based on statistically significant results measured within the Immersive Experience Questionnaire (IEQ), which are discussed in Section 6.1.

Results also suggested that participants experienced a higher sense of arousal when playing the FCD task in VR. This sensation has been compared between studies conducted *in vivo* and those conducted in a lab, in which *in vivo* studies show higher arousal [2], [3]. This suggests that the results of studies which use VR technology, such as the artefact in this study, may be capable of producing results with higher levels of validity that those conducted in a laboratory. This finding is very significant, as typical studies conducted within the laboratory are often criticised for how well they generalise to real-life. Gambling studies which use VR may therefore be capable of generalising results to real-life scenarios, even as much as those which are conducted *in vivo*. However, more work should be done to investigate this.

Finally, this study found that participants reported similar perceived workload for FCD across both conditions, except for physical demand which was higher in VR. It can therefore be understood that despite VR being a technology which some may find harder to grasp than others, the general consensus is that this has no impact upon task performance. This confirms no disadvantage concerning workload between laboratory and VR experiments, and might suggest that studies conducted in VR provide similar perceived workload to those conducted *in vivo*, being more physically demanding and less relaxed.

In conclusion, this study has presented numerous advantages to using VR as a tool in experimental research, when compared to standard laboratory-based studies. This is further supported by the fact that VR is able to combine experimental control with ecological validity, which laboratory-based studies are unable to do. Further work will need to be conducted to understand how VR compares to studies conducted *in vivo*, but the results of this study suggest that such a study will further reinforce VR as an effective tool for use in gambling research.

7.1 Future Work

Whilst this study has presented evidence to suggest that VR is more effective than laboratory-based studies, it does not confirm whether or not VR can offer similar results to studies conducted *in vivo*. Future work is needed to compare these two, measuring perceived workload and arousal, amongst other measures, to confirm whether both conditions are indeed similar in these regards.

The results of the study also suggested a potential caveat to using IEQ, as discussed in section 6.4. As mentioned, this is because the answers provided are not specific enough to suggest whether the results are specific to only the in-VR task, or the VR itself. Future work could look at modifying the IEQ to cater more towards the specific needs of measuring games facilitated within VR, as opposed to games facilitated within the real world. After creating and validating such a measure, the study presented in this thesis could be re-visited, and the results compared against one another to see if anything changes once the in-VR task can be more specifically targeted.

Once a greater understanding is obtained through these two suggested studies, it may be possible to use the developed artefact in a real gambling study, to see how the results compare with other studies surrounding a similar topic.

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