Simulating Social Situations in Immersive Virtual Reality - A Study of Bystander Responses to Violent Emergencies

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To Mercè Pérez

I, Aitor Rovira i Pérez, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

Abstract

The goal of this research is to show how immersive virtual reality (IVR) can be used to study human responses to extreme emergencies in social situations. Participants interact realistically with animated virtual humans. We show this through experimental studies of bystander responses to a violent confrontation, and find that there are conditions under which people intervene to help virtual characters that are threatened. We go on to show that a reinforcement learning (RL) method can capture the types of actions of virtual humans that lead to greater intervention on the part of the bystander.

It has been shown that people tend to respond realistically in social situations depicted in IVR when they have the illusion of 'being there' (Place Illusion, PI) and that what they perceive appears to be really happening (Plausibility Illusion, Psi). This has enabled IVR technology for the study of several fields including human behavioural studies, social phobia treatment and both physical and psychiatric rehabilitation. Additionally, IVR helps to overcome ethical issues such as deception that can arise from the nature of the study. The highly controlled environment reduces the variations induced by the repetition of the study, and thus, increases the internal validity. Furthermore, IVR allows setting up life-size computer-generated simulations and enables the possibility of interaction with natural body movements, making their responses close to being authentic thus increasing the ecological validity.

We carried out a series of experiments to understand the circumstances likely to make people intervene when they witness a confrontation between two people. Faced with a potentially violent situation, any individual has to decide whether to intervene to try to prevent the violence, or do nothing. Evidence demonstrates that factors such as a shared social identity between the bystander and either the victim or the aggressor, the presence of other bystanders or authority figures and their behaviour influence people's responses to an emergency. But for ethical and validity reasons, it is very difficult to set up studies with real actors which observe how people react to violence. The results of the experiments in this thesis show that the likelihood of a bystander intervention can be increased or diminished if the bystander perceives the other people present in the scene as sharing some type of affiliation with him. The main experiment variable that we manipulated was whether the people in the scene supported the same football team as the bystander, or on the contrary they did not have an explicit association with any team in particular. Additionally, this thesis provides evidence that the bystander effect also occurs in an immersive virtual environment (IVE) and that the strength of this phenomenon varies depending on the social identity of the characters present in the scene. The last part of the thesis shows that RL can provide learning capabilities to a computer to study human behaviour and use the knowledge towards eliciting pre-determined responses from real people in IVEs, such as increasing the likelihood of intervention in a violent emergency.

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Contents

List of Figures

List of Tables

Chapter 1

Introduction

Saturday afternoon, you are in a pub having a quiet pint of beer and watching sports news on TV. Two people start arguing about football. What at first seems an innocent discussion, soon escalates. One person becomes increasingly belligerent against the other, while the person being bullied tries to defuse the confrontation. They are not far away from you, but you do not seem to be acknowledged by the aggressor. What would you do, would you intervene if the victim asks you to help him? Would you be more likely to do so if the victim of the aggression shared some type of social identity with you, such as being a supporter of the football team you also support? What if there were more people in the pub, would you feel you were being backed up to do something about it, or conversely would you expect someone else to make the first move? Would you refuse to intervene because you always try to avoid violence?

Imagine this situation, picture yourself in an immersive virtual reality (IVR) system where the other people are life-sized virtual characters. They look directly to your eyes and they respond to your actions. Would your feelings be similar to those in real life, and would your responses be authentic? Do you think it would be possible for a computer program to monitor and predict your actions under these circumstances?

There is evidence that people behave realistically in scenes depicted in IVR when certain technical requirements are met. These requirements include a stereoscopic display with a minimum field of view [IJsselsteijn et al., 2001] and frame rate [Hendrix and Barfield, 1996], and a head tracking system [Barfield et al., 1999]. This phenomenon happens when the person has the illusion that he is in the virtual environment depicted [Sanchez-Vives and Slater, 2005] in the IVR system, and also perceives the events as if they were actually taking place [Slater, 2009]. This is what is known in the literature as the sense of presence. When this occurs, people's responses are close to being realistic. IVR presents a simulated experimental setup that provides both high internal and ecological validity, as the scenario depicted is a representation of the real life context and people can perceive and interact similar to how they would do in real life.

Reinforcement learning (RL) provides a computer with learning capabilities. With no need for prior knowledge about the environment or the goal, an entity called *agent* interacts with the environment, observes the changes in it resulting from the actions carried out, and thereby receives a reward which can be positive or negative depending on whether the response moved the environment further towards or away from a specified goal [Sutton and Barto, 1998, Kaelbling et al., 1996]. The experience collected is then used in future iterations to predict and maximise the chance of a specific output. RL has been applied in fields such as Robotics [Kober et al., 2012], video games [Szita, 2012], and board games [Ghory, 2004]. In this research, we use it to provide virtual characters with interaction capabilities in order to understand how people respond to the emergency situation depicted in IVR.

1.1 Research Problem and Questions

The main obstacle of the research methods that have been used for behavioural studies in social situations is their validity because it is not easy to observe people's responses to the specific situation under study, especially those that depict extreme situations such as violence. Experiments carried out in a laboratory tend to have low ecological validity, as the people are studied in an artificial setup that might lack important details that are key to understanding their responses [Schmuckler, 2001]. Questionnaires are designed to ask people to use their imagination and put themselves in a situation, but this may not be enough for them to know what they would do [Milgram, 1963]. On the other hand, studies based on the observation of events in the real world lack internal validity, as each event will not be exactly the same due to the lack of repeatability. Another limitation in observational studies is the time constraint and how much time it takes to witness the event under study. In the case of the study of violence, participants and bystanders who have been present tend to have a distorted view of the experience due to the stressful nature of the event, and little is known about how the events unfolded. Footage from closed-circuit television (CCTV) has also been used to study people's responses to an emergency situation [Levine et al., 2011] but cameras usually capture very low quality black and white images and audio is not included in the footage. Cameras have a narrow field of view and it is possible that key actions might fall out of the angle of the camera. Additionally, the presence of CCTV cameras can change people's responses if they are aware that they are under surveillance [Sivarajasingam et al., 2003]. Other studies have used confederates to play a scene in a laboratory setup but this can introduce uncontrolled differences across the participants due to small variations each time the actors perform the scenario. Furthermore, this setup can be controversial in some situations, as in the study of violence, for example [Milgram, 1963, Zimbardo, 2007]. It is not ethically acceptable to make naive participants experience a stressful situation of this nature without telling them a priori that it is acted, but telling them beforehand could invalidate the study, as genuine responses happen when the future events are unpredictable by the participant.

Another issue that researchers in behavioural fields need to deal with is the number of elements that can influence the result. The vast number of possible variations that can lead to different outcomes make it infeasible to comprehensively investigate all the possible causes of responses to a scenario. The number of experimental versions grows exponentially with the number of variables in a full factorial experiment. In order to avoid the exponential growth in the number of participants needed, experimental variables can be tried separately in single factor experiments, i.e. one at a time. However, this setup will not discover potential interactions between experimental variables [Collins et al., 2010]. In an emergency situation, the likelihood that an individual bystander will intervene depends on factors such as whether he perceives the person that requires assistance as someone who he shares a social identity with [Levine and Manning, 2013], gender [Levine and Crowther, 2008], and the number of people witnessing the scene [Darley and Latané, 1968], to mention a few examples. Important factors can be missed when focusing on a few specific variations thus limiting relevance for the scientific community.

These two issues are the focus on this research. This thesis shows how IVR can be used to study human responses to social situations that involve extreme emergencies that otherwise would be difficult to study [Loomis et al., 1999, Blascovich et al., 2002]. It allows independent exposure of the participants to the same exact situation, reducing the risk of introducing extraneous variables due to repetition when running the scenario for each participant. IVR also helps overcome some ethical issues that might arise due to the nature of the study, as participants know at all times that the experience is only a computer-generated simulation. In addition to that, RL may be used as a heuristic to help mitigate the problem of having a large number of experimental variables. In the beginning, when no knowledge about the environment is available, the RL agent chooses different actions stochastically from the pool of available actions. Then, as data is obtained, it gradually uses the experience to focus on the actions that have a higher chance of leading to the goal.

Summarising, this research addresses the following questions:

- *If a bystander shares social identity with a victim of a violent emergency depicted in IVR, is the bystander more likely to intervene? What if the victim looks directly at him a number of times during the confrontation?*

  These two questions are addressed in the experiment described in the second half of Chapter 4. A scenario was implemented in which the participants witnessed a person who could be either a supporter of the same football team they supported or somebody whose affiliation could not be identified.

Additionally, the victim of the aggression turned the head towards the participant at different times during the confrontation and we observed whether this increased the likelihood of intervention.

- *What is the impact of the technical qualities of the IVR system on the sense of presence and how might this affect people's responses to violence?*

  An experiment was set up in order to test two different display characteristics mainly with differences in luminance and pixel resolution, keeping all else constant, as described in the first half of Chapter 5.

- *Can the bystander effect be replicated in IVR? How is the bystander's behaviour influenced by the social identity of other bystanders present and their posture in front of the emergency?*

  We look at these issues in the second half of Chapter 5. Using an upgraded version of the scenario used in the experiment about the victim's affiliation, we added virtual bystanders in the scene and observed how their presence influenced the likelihood of participants helping the victim of the aggression. Bystanders were either supporters of the same football team as the participant and the victim or they wore plain shirts with no logos or badges. In addition to this, the bystanders, although they did not directly intervene, either encouraged or discouraged intervention by someone else.

- A new experimental methodology is proposed. The use of RL allows a computer to learn human behaviour by observing how real people respond to certain stimuli. This knowledge can then be used to increase the likelihood of people responding in a specific way to a situation. Chapter 6 describes how this new methodology was used in the same scenario used in Chapter 5 in which the computer observed how participants responded to the virtual characters' actions and how the experience collected was later used to maximize the chance of intervention. *Could this new methodology be used to reduce the number of participants and trials needed when the number of* *experimental variables is large and there might be interactions among them? Furthermore, can RL be used to make a VR scenario more interactive?*

1.2 Contributions

The research presented in this thesis combines three different fields: the study of people's responses to social situations, IVR, and RL. IVR offers the experimental framework in which to carry out experiments that for both validity and ethical reasons cannot be carried out in real life and shows how it can be used to study social situations to construct theories that can then be used to understand real events. As people can respond realistically to the events in the virtual environment, IVR is suitable to test hypotheses that can help to understand the circumstances that make a bystander more likely to intervene to try to defuse a violent situation in the real world. The results also provide a reusable experimental framework to use IVR for studies in social sciences, not only in situations that would be controversial in real life, but also more generally as a new way to set up accurate virtual scenarios similar to real situations that are of interest for behavioural studies. Multimodal data collection includes questionnaires, interviews and observing the participants' behaviour. Among the responses observed are verbal utterances, attempts at physical contact, position of the participant relative to the other people in the scene, and sight direction.

This thesis also provides evidence for the importance of taking into account the characteristics of the displays used in the IVR system, since changing the specifications may lead to different results, due to the fact that people perceive the scenario differently. More specifically, we took advantage of a change in our IVR system that provided a unique opportunity to test the same scenario with two different types of projectors, keeping all else equal. The main differences in the displays between the setup before the upgrade and after were the pixel resolution and the luminance.

Another contribution is the use of RL as a tool to understand how people respond in IVR and how to influence their behaviour to increase the likelihood of a specified outcome. Despite each individual having a different personality, a RL agent was able to build up a statistical model to understand how people respond on average to certain events. This statistical model was then used to influence people's responses, as well as to set up heuristics in order to focus on the variables that seem to have a significant impact and assign low priority to those that seem to have no effect on the results. Finally, the conclusions about how people respond to a violence emergency are presented and the important factors that make people more likely to intervene in an ecologically valid setup are outlined.

1.3 Scope of Thesis

This thesis does not provide proof about how people respond to real life situations, since we cannot carry out the same experiment in a real life setup with real people and compare the results for ethical reasons. There are several factors that change, especially taking into account that our experimental setup consists of a computer-mediated environment. Our research aims to show how these technologies can be used to study bystander responses to extreme social emergencies, and the results presented to help build a theory of bystander intervention real life emergencies.

The conclusions are based on the results obtained from the participants that were exposed to a scenario where a violent event takes place. The experiments were focused on the affiliation of the characters present in the scene based on whether they supported Arsenal F.C. Other football teams could be tested as well as other types of social affiliation. All participants and virtual characters were male, as gender can be a critical factor when intervening in an emergency and including both genders would have required greater sample sizes impacting on the resources and time. It is also easy to understand that while the number of variations of the scenario can be huge, we only tested a selective subset. Other types of emergency could also be studied, not only ones of a violent nature, with minimal changes to the experimental setup.

One detail that participants reported that made the scenario less plausible was that the virtual characters were unresponsive during the confrontation in the scenario. To mitigate the chance that people would fall back and become spectators due to the lack of interactivity, an initial dialogue was designed between the participant and the person who would become the victim at the end of the scenario, although it consisted of a reduced set of questions and responses. Besides the dialogue being aimed at building rapport with the victim, this also created the illusion that they could do something while the confrontation took place. Implementing compelling interaction for a free-flow conversation between a real person and a virtual character is very complex and it was not the focus of this research.

These data collected came from different sources, but other modalities of data collection could have been used, such as physiological data. For this, participants would need to wear electrode pads, cables, and a transmitter attached to their belts. Wearing extra devices and wires can restrict the participant's natural freedom of movements and make the participant more aware of being in the laboratory thus making his responses less authentic.

The RL algorithms that were tested were extracted from the Sutton and Barto book [Sutton and Barto, 1998], and were used as they are described with no modifications. This thesis describes a novel application of RL, but no research was done in the domain of RL itself.

1.4 Structure

Chapter 2 reviews the state-of-the-art on the topics related to this research in the three main fields – social psychology, IVR and RL. It also provides definitions of the terminology commonly used in this thesis from social psychology – internal validity, ecological validity, social identity, violence and the bystander effect. This terminology is used in the following chapters. It gives an extensive overview of IVR and how key concepts such as immersion, presence, place illusion and plausibility illusion are critical to understand this research. RL and how the algorithms used in this research work are explained in the last part of this chapter.

Chapter 3 contains the methodology that is common to multiple experiments. This includes a description of the scenario used and its implementation, the VR system used and other hardware, the ethics case and the experimental procedures, from the participant recruitment, the experiment execution until the data collection.

Chapter 4 describes the initial pilot study carried out during the implementation stage of the scenario and how the feedback collected from volunteers who experienced it was an invaluable source of information in order to complete the first version of the bar scenario where a violent outbreak takes place. Secondly, it covers the first experiment, in which the focus of attention was on the victim's affiliation and whether he pretended to ask for help from the participant by glancing at him at different times. The two goals of this experiment were to observe whether the participant perceived the victim as someone with a shared social identity (both supporters of the same Premier League team), and if perception of the victim as asking for help would make the participant more likely to intervene.

Chapter 5 covers two experiments. First an experiment that was carried out to evaluate the impact of the display characteristics on the sense of presence, and whether this had an impact on people's responses to the violent incident. The second experiment of the Chapter is dedicated to the bystander effect. The number of bystanders, their social identity (as determined by their appearance), and their behaviour were all manipulated in order to observe how this might shape the participants' response to the same scenario used in previous experiments.

Chapter 6 describes another two experiments, both of which used RL in order to study real people's behaviour and exploit the data collected to try to influence their behaviour. The first experiment used a video game-like scenario where participants had to avoid being hit by some virtual projectiles shot by a spacecraft. The goal was to make the participant move to a target location and stay in it the longest time possible. The second experiment introduced a RL agent into the bar scenario. The agent acted as a puppeteer of the virtual characters and made them perform different actions while observing which ones made people intervene to try to stop the incident.

Chapter 7 concludes this thesis providing a summary of all the findings provided in previous chapters and proposes future directions of the research presented in this thesis.

Chapter 2

Background

Following great improvements in technology and a growing background in research in the last two decades, immersive virtual reality (IVR) is becoming more prevalent in the lives of consumers. IVR can be defined as the technology that transports someone to a different environment where it is possible to have realistic experiences. It has been used for both applications related to entertainment, as well as study behaviour for research purposes. A major phenomenon underpinning the success of IVR is the notion of presence, an illusion in which people report having realistic feelings and behave accordingly, as if they were in the simulated environment. This enables immersive technologies to be used to carry out behavioural studies in a lab environment, which is particularly useful for social psychologists [Loomis et al., 1999, Blascovich et al., 2002].

On the other hand, reinforcement learning (RL) is a sub-area of machine learning (ML) that has been used to allow computers to solve different types of problems that require learning from experience. In the research described in this thesis, RL is used as a methodological tool that provides a novel way to explore the influence of several factors on response variables such as eliciting pre-established people's responses without the overhead of considering all possible factor combinations.

This chapter aims to put the research presented in this thesis in the context of the current state-of-the-art of the three main related research areas: what IVR offers, how RL can contribute to the study of human behaviour, and the study of people's responses to social emergencies. More specifically, we give an overview on the study of the social psychology of bystander behaviour in extreme emergencies, the use of IVR and the sense of presence to depict social situations, and RL as a tool to learn how to influence people's responses to achieve a goal.

2.1 People's Responses to Social Emergencies

Social psychology is the study of people's behaviour in situations where other people are present, or where people 'think' that others are present. While the context of these situations can be as broad as in social media, or mass media, this work refers to social emergencies in situations of immediate physical vicinity. It also encompasses a broad spectrum of social situations, from how people are individually persuaded by others, how their attitude can be changed, to the study of group dynamics. A specific topic of interest is how people respond to social emergencies and what makes individuals and groups help others who are in need of help. Researchers in this field can face many limitations when trying to design a study. Social emergencies often imply stress, anger, frustration and even violence. In the past, some behavioural studies caused a lot of controversy by placing participants in situations that involved not only deception, but also in some cases high levels of stress. These controversies sparked off a debate about the limits on research that, subsequently led to the establishment of committees to ensure that some rules about ethics were followed. This affected directly the study of emergencies, as some situations can entail a great deal of stress, or even put people in risk of physical danger [Zimbardo, 2007]. Studies with no informed consent and without the right to withdraw at any time were not permitted by ethics committees. The ethical issues arisen by the deceptive nature of this type of studies are explained more in detail in Section 2.1.4.

Traditional research methods based on questionnaires and interviews do not convey the nature of the emergency and do not elicit the same feelings in people when asked to imagine how they would respond to an emergency as the event is taken out of context [Levine, 2003]. In some situations people do not know how they would react, for example when the emergency involves aggressive behaviour. On the other hand, studies based on observations of real events, which collect data from real occurrences of the phenomenon under study, do not allow sufficient control of parameters thus the results are not generalisable. These issues are known as the ecological validity and the internal validity of an experiment respectively and are described in Section 2.1.5.

The research presented in this thesis also addresses the problem of having a large number of parameters that can influence the results of the experiment, which is the case when carrying out behavioural studies. In a typical experimental setup, researchers need to reduce the number of variables that will be tested, thus limiting the generalisability of the results. Researchers usually choose the experimental parameters based on theories, neglecting others that could be significant. The implications of this issue are further explained in Section 2.1.6.

2.1.1 Aggression

Among the different types of social emergencies, violence and aggression are two topics that have always attracted a lot of attention in the media. Violence has different shapes and forms: it spans from global conflicts such as wars, clashes between religions, the results of racism and cultural differences, to local conflicts such as gender violence, street gangs and hooliganism related to sport teams supporters. A lot of research has been carried out to understand the circumstances that cause violence to break out and how to prevent it, but such research is not easy for several different reasons. The lack of a robust experimental framework in which to study authentic responses with the degree of experimental control that a laboratory setup provides makes studying aggressive behaviours very difficult.

In studies that either use questionnaires or interview participants, people often do not know how they would respond to a case where they find themselves witnessing a violence emergency. Witness accounts from real experiences do not usually provide an accurate description of the events, as there are several events happening simultaneously, the witnesses can make premature assumptions that contribute to blurry memories about what actually happened, and even the wording of the questions can bias their memories [Loftus, 1975]. Closed-circuit television (CCTV) footage does not provide enough information about what actually happened due to having a narrow field of view, low resolution cameras, normally black-and-white images, where important details can occur out of the camera's view, and usually do not record audio. Moreover it is not possible to identify the people involved for research purposes because of data protection legislation. Surveillance cameras do not provide some relevant information such as whether the people involved consumed alcohol before the aggression [Levine et al., 2011], or whether the people involved share any type of relationship or social identity.

2.1.2 Social Identity

Social identity is defined as the feeling of belonging to a group of people that share common thoughts, goals, and even a similar look. This feeling of inclusiveness in the same social group is referred to as *ingroup* membership [Tajfel and Turner, 1986]. Conversely, when a person is not perceived as having anything in common with another, it is considered to be an *outgroup* member. Examples of ingroup range from members of the same family, same geographical origins, nationality, race, ethnicity, cultural preferences and religious beliefs. Individuals can also have the same feeling when belonging to other minorities such as urban tribes or supporting a sport team. People who belong to a group tend to see other people who support the same sport team as ingroup members despite not being previously acquainted. An individual that shares an identity with a victim of an aggression is more likely to help him. While it seems obvious that the likelihood of intervention is increased when a relative or a close friend is in need, this also applies to ingroup members who can be strangers as long as they are perceived as someone that shares an affiliation. On the other hand, outgroup members can be people not belonging to any rival group, although they can also be considered as a threat as some prejudices can be built towards them [Tajfel and Turner, 1986].

Social identity is an important predictor of bystander intervention in social emergencies. There is strong evidence that people will be more likely to help other ingroup members in a social emergency than those who are perceived as outgroup [Levine and Manning, 2013], and this is also the case of extreme emergencies. This is not only limited to the relationship between the bystander and the victim but also with the other people present, such as among bystanders, or between a bystander and a perpetrator. For example, in the case of aggression, an individual will be more likely to intervene to try to defuse the situation if the perpetrator is an ingroup member. Although it is an important factor, there are others that can have the opposite effect. For example, the number of bystanders present in the scene is thought to diminish the possibility of any individual intervening.

2.1.3 The Bystander Effect

The case of Catherine "Kitty" Genovese is perhaps one of the most studied cases of violence that initiated research into bystander behaviour. In March 1964, New York, she was on her way back home when she was assaulted by a single man. She was stabbed to death in 3 separate stages during a period of over half an hour. While the circumstances of the murder were not uncommon in big cities during that time, what made this event relevant was the way it was covered by the media in the following days. The controversy arose because apparently there were 38 people who witnessed the murder from their respective places who reportedly did nothing to prevent her death. Although the accuracy of the media reporting was subsequently called into question [Manning et al., 2007], the event sparked off the research about the circumstances that make people show prosocial behaviour to emergencies, while in other cases they fail to help to those that are in need. A few days later, the newspapers considered this case a clear example of apathy and moral decay occurring in urban areas.

Not convinced with the conclusions that the media drew from this murder case, John Darley and Bibb Latané carried out a series of experiments to understand the inaction of the bystanders who witnessed the event. Their most important conclusion was that the number of people present in the scene is an important parameter that defines the likelihood of intervention. The more people witnessing the event, the less likely that anyone would intervene [Latané and Darley, 1968].

The main reason for this was attributed to the diffusion of responsibility [Darley and Latané, 1968]. This phenomenon was coined as the *bystander effect*, and it has been one of the most robust findings in social psychology in the sense and it has been widely replicated [Latané and Nida, 1981, Fischer et al., 2011].

There are several factors that can attenuate or enhance the bystander effect, thus increasing or reducing respectively the likelihood of intervention. The level of danger of the emergency is an important cue for a bystander to evaluate the possibility of intervention [Clark III and Word, 1972]. Bystanders tend to be more likely to intervene in situations where the victim is obviously in danger, even in the presence of others [Fischer et al., 2006]. When the level of the emergency is not clear, a common reaction from a bystander is to look around to see how other people are responding to it and mimic their reaction. Other passive bystanders can make another person remain passive as well, as an active response could be interpreted as an overreaction making him feel embarrassed [Darley and Latané, 1968]. There are also cases where the presence of others can encourage intervention. Among the motivations that an individual can have to increase the likelihood of intervention are public self-awareness [van Bommel et al., 2012], the presence of bystanders who are not strangers [Latané and Nida, 1981], and the presence of ingroup bystanders that actively encourage intervention [Levine et al., 2002]. On the contrary, if they remain passive, it makes other people see it as a dissuasive response [Levine and Manning, 2013].

The bystander effect has been observed across emergencies of different types in both laboratory-based experiments and occurrences in the natural environment. Some studies are based on questionnaires, asking participants to imagine their feelings in front of the described situation. But each person can imagine it in a different way, thus leaving the data collected exposed to extraneous variables introduced by the participants' interpretation of the scene. To avoid leaving the details of the scene to participants' imagination, they can be asked to watch a violent emergency from CCTV footage and describe how they would respond to it [Levine and Crowther, 2008]. The latter is not ideal either, participants are not present in the scene and it is difficult for them to imagine how they would respond in that situation. The failure to offer assistance when other people are present is a clear example of how people's actual responses differ from how they thought they would act, as the diffusion of responsibility overrides the feeling of "safety in numbers" [Latané and Nida, 1981], yet people usually do not take it into account when giving their opinion. But placing participant in situations to study their responses to an emergency is controversial because the stressful nature of the scenario can raise ethical issues.

2.1.4 Ethical Issues

One of the reasons why ethics has been long under debate in the research community is that past experiments have generated a lot of controversy. This debate was particularly active during the 1960s and the beginning of the next decade, the time when the Milgram's study on obedience [Milgram, 1963] and the Stanford prison experiment [Haney and Zimbardo, 1973, Zimbardo, 1973] were published. These two experiments attracted a lot of attention so that even the experimental design and ethical validity of these studies is still a matter of debate 50 years later [Haslam and Reicher, 2007, Zimbardo, 2007, Haslam and Reicher, 2012]. In Milgram's study of obedience, participants were asked to inflict electric shocks to a stranger, without them knowing that the stranger was a confederate actor and was not actually being hurt. Even though the deceptive nature was debriefed after the experience, the situation induced high levels of stress in participants. The Stanford prison experiment went further, involving unplanned physical violence by the participants playing the role of guardians against their prisoners. The eruption of violence shortly after the experiment started led to the researchers cancelling the study prematurely.

The limits of what is ethically correct in research started to be discussed in order to preserve the integrity of participants, researchers and confederates. Since then, ethics has become an important factor to take into account when designing experiments. Some of the ethical issues arise from the deceptive nature of an experiment [Baumrind, 1964, Kelman, 1967]. Some of these issues are directly related to people being attacked physically or psychologically, although the issue is more concerned with the naive participant being deceived that someone is in danger, rather than the actual damage inflicted, as in the Milgram's study of obedience.

Three alternative experimental methodologies are (1) asking participants to imagine their responses to a situation without exposing them to the real stimuli, (2) observing natural occurrences in the real world, (3) the use of confederates to play the scene and participants are naive about the deceptive nature of the scenario. The first alternative can be carried out in a laboratory-based setup in which participants are asked to imagine themselves in the situation before filling out a questionnaire about what they think they would do. Although this design is ethically valid, it is limited in that people cannot imagine how they would react, especially in stressful situations. Milgram's study on obedience showed this in a very simple way [Milgram, 1963]. Before the experiment, he asked some of his colleagues to estimate the percentage of participants that would administer the highest voltage to the confederate. None of them got even close to guess the high percentage of participants that went all the way until the end inflicting a deadly electric shock, considering that a reasonable person would never inflict a deadly electric shock to someone by any means. The downside of this method is that people are not exposed to the real stimuli and their responses can differ substantially from the way they would actually respond. A questionnaire or an interview does not convey the level of danger, and thus it cannot elicit the same feelings a person would have facing the situation in real life. Some experiments have used real-life setups to study bystanders responses to emergencies, such as smoke filling the room [Latané and Darley, 1968] or the simulation of an accident [Clark III and Word, 1972] in which somebody is injured [Latané and Rodin, 1969, Levine et al., 2005]. However, although these experiments used a setup that is very similar to an authentic emergency, the nature of the emergencies represented is not violence.

Concerning observational studies, they are based on the investigation of natural occurrences of the phenomenon that is being researched. This approach does not raise additional ethical issues, since they are commonly based on eye witness accounts or CCTV footage and the experimenter does not interfere in the outcome of the events as he is not present when the event occurs. However, the occurrences can take place in different places and differ substantially in its nature to the point that the results are not generalisable. Putting this into the perspective of the study of emergencies, these alternatives may not be valid for understanding how people respond to them, depending on the nature of the emergency. In such situations, witnesses to the event can have no time to think about the best way to respond to it, in addition to having to deal with high levels of stress that can make the decision even harder. It can be very difficult for someone to predict how they would respond to a stressful situation, especially if they have not experienced similar events in the past.

The last alternative, the use of confederates to play the scenario offers the possibility to set up the study in a controlled environment and exposing participants to a stimuli that seems real to them. One disadvantage about this method is that actors can introduce small variations every time that the scenario is played that could introduce extraneous variables. The other disadvantage, as mentioned before, is that it can only be used to study non extreme situations.

The first two alternatives, studies based on asking participants' feelings about a hypothetical situation and observational studies of real events in their natural context, lack the experimental validity needed to understand all the intricacies of people's behaviour in an emergency. The use of confederate actors is a good alternative in order to increase the experimental validity, but representing extreme emergencies such as those of a violent nature is controversial, as they do not comply with present days ethical standards due to their deceptive nature. A new alternative is needed in which participants, despite knowing that they are in an experiment and the setup does not involve danger to the people in the scene, still witness extreme emergencies, feel as if they were real, and have authentic reactions to the events.

2.1.5 Experimental Design and Validity

The validity of an experiment represents the extent to which the outcome can be explained as the consequence of manipulating the dependent variables of the experiment, and whether the results of an entire population can be inferred from a sample. Behavioural studies are particularly sensitive to validity because there is the added complexity that there are not two identical people in the world. Experimental validity can be divided in three different categories: internal, external and ecological validity.

Internal validity refers to the causal relationship between the independent and the dependent variables. An experiment with a high degree of internal validity means that the manipulation of the experimental variables led to a significant change in the results. On the contrary, the internal validity is low when the variations on the results obtained across participants are a consequence of extraneous variables. Some examples that can compromise the internal validity of a behavioural experiment are not taking into account certain characteristics related to the participants (age, gender, personality traits, etc.), or variations introduced each time the experience takes place for each participant.

External validity refers to the extent to which the results of an experiment obtained from a sample can be generalised to a larger population and also to other situations similar to the one that is being studied. Firstly, the sample must be representative in order to infer the results to the entire population. Secondly, results can only be valid to other situations if the experimental setup provides those important details that are critical to these other situations. The study of aggression has been mentioned as a field in which external validity might be low [Anderson and Bushman, 1997], as researchers often neglect the differences between the types of aggression [Gottfredson and Hirschi, 1993]. This is also especially relevant in the study of people's responses to emergencies, as there are no two identical emergency situations.

Ecological validity defines the extent to which the results obtained can be used to predict the outcome of the phenomenon under study in the environment where it usually takes place [Schmuckler, 2001]. This normally refers to real-life settings, especially in behavioural studies. The closer to the real life experience the experimental setup is, the greater ecological validity. The number of interfering elements added by the experimental environment needs to be minimised (e.g. leaving distinctive laboratory elements visible to the participants) and it also needs to include the important properties of the topic under study [Brofenbrenner, 1977]. The stimuli need to be administered as accurately as possible compared to a real life experience, considering that it can be a multi-sensory experience allowing the participant the possibility to respond in a natural way, as they would do in real life. In addition to that, the data collected needs to be based on these natural responses and to be representative of the phenomenon that is being studied.

2.1.6 Experimental Variables and Interaction

Another important issue when designing behavioural studies is to decide the experimental variables that will be studied. When the focus of the study is the responses of people, they can be interpreted based on multiple variations of the stimuli. However, when an experiment is designed, only a few of these variations can be tried. In order to keep the experimental setup simple, the results from studies with a reduced set of variables are more difficult to generalise as some variations that could be important in similar situations to the one studied are not tried. Keeping the set of variables large and manipulating their values separately could make the results lead to different conclusions, as they can interact with other variables, obtaining different results compared with manipulating them together. If all the experimental variable permutations need to be tried, it can easily make the study unfeasible, since the number of participants required grows exponentially with the increase in the number of variables and factors. Furthermore, trying all the permutations is very inefficient, as some variables increase the complexity of the study and, in the end may turn out to have no effect on the responses.

In the study of people's responses to emergencies, not all the important aspects related to the scenario or the participants can be covered in one experiment. During their series of experiments, in order to find an explanation to unresponsive bystander behaviour [Latané and Nida, 1981], both the gender of the victim and the violent nature of the event [Cherry, 1995] were neglected thus the conclusions reached could not be generalised. This is an example of experiments that, despite having high ecological validity, the results cannot be extended to the entire population, thus having low external validity.

2.1.7 Summary

The study of interpersonal relationships and helping behaviour in social emergencies entails complex intricacies that makes it very difficult to set up compelling scenarios that comply with the contemporary ethical standards and, at the same time showing believable extreme emergency situations to observe people's responses. Traditional experimental setups present a number of limitations that can make the study of a situation unfeasible due to ethical issues or having low ecological validity when the phenomenon under study is being decontextualised. While other traditional research methods present these obstacles that researchers need to address before extracting the conclusions of a study, IVR has been proposed as an alternative to carry out experiments in social psychology [Loomis et al., 1999]. This technology offers some advantages that include higher internal validity than observational studies, higher ecological validity than experiments that only rely on questionnaires to collect data, and also helps to overcome some ethical issues derived from the nature of the experiment. This research aims to take advantage of IVR to carry out experiments to study people's responses to extreme social emergencies.

The large number of parameters that can influence the results is an issue that needs to be taken into account when generalising the results of a study. This is a problem that this thesis addresses by using RL in order to focus on the experimental variables that seem to be more significant on the results of the phenomenon under study. RL is introduced in Section 2.3.

2.2 Immersive Virtual Reality

From the 1960s until the present day, IVR has evolved considerably, especially in the last two decades. The progress not only affects the hardware but also the knowledge of what makes it a powerful tool that allows people to feel the effects of computer-generated experiences in a more believable way compared to other more conventional setups such as desktop systems. Ivan Sutherland invented the first device to be considered a virtual reality (VR) system in the 1960s, the Sword of Damocles [Sutherland, 1968]. It was the first attempt to materialize his idea of the ultimate display [Sutherland, 1965], a room where computer generated objects coexisted with real people, who could perceive and interact with them as if they were real. This resulted in the first head-mounted display (HMD).

The interest in IVR increased towards the end of the 20th century. During that period, new models of HMDs appeared incorporating the new technology, while other new architectures were created, such as projection rooms with multiple displays, for example the CAVE [Cruz-Neira et al., 1993]. Cave-like systems and HMDs are currently the most popular configurations in academic research. These two configurations offer the technology to be able to turn around and look at the environment with natural movements of the body, while setups containing one projection surface only do not offer this possibility.

2.2.1 The Sense of Presence

One of the most important concepts in IVR is the sense of presence. These technologies allow the creation of a strong illusion in users that they are in the virtual place depicted in an IVR system, known as immersive virtual environment (IVE). This illusion is compatible with the idea that people know that what they are perceiving is a simulation, therefore knowing all the time that what they see and feel is just a computer generated environment. For example, standing at the edge of a virtual precipice elicits an increase of the heart rate, skin temperature drops and begins to sweat [Meehan et al., 2002], feelings that can be associated when facing a similar situation in real life.

The most common accepted definition of presence is the extent to which a person feels as ‘being there’ [Zahorik and Jenison, 1998, Witmer and Singer, 1998, Sanchez-Vives and Slater, 2005], in the place depicted. An early contributor to understanding presence was [Sheridan, 1992]. Its meaning origins are in the teleoperated machines industry, when Marvin Minsky defined the feeling that an operator can have as if he was at the place where the machine he controls is as telepresence. This illusion can be achieved by manipulating objects the same way as a person would do with his own body and receiving the feedback that he expects [Minsky, 1980]. Presence is the equivalent to telepresence but applied to IVEs, among other technologies [Lombard and Ditton, 1997]. To create the strong illusion that a person is in the virtual environment, he needs, to some extent, to have the possibility to perceive it as he would feel the real world and interact with it using the natural movements of his body. Different technical factors are considered essential to achieve the sense of presence. These are a stereoscopic display with a minimum field of view [IJsselsteijn et al., 2001] and frame rate [Hendrix and Barfield, 1996], a head tracking system [Barfield et al., 1999] to adjust the images to the user's perspective in real time and with a low latency between the user's actions and the results in the displays [Meehan et al., 2003]. Presence and immersion are two interrelated concepts, although they are not exactly synonyms. We adopt the definition of immersion formulated by [Slater, 1999], which refers to purely technical aspects of the VR system and its capabilities to allow the user to perceive the virtual environment as if he was surrounded by it. Presence involves a subjective state that the user has the perceptual illusion that he is in the place depicted. Immersion can lead to presence, as the system setup needs to allow the user to look around in order to be considered immersive, and this is usually achieved with the use of a tracking system or simply a multiple displays setup in which the person is allowed to look around.

However, a person could have the illusion of being in the virtual environment without behaving realistically, as he feels he is more a spectator who can see the events happening around him but he cannot interact with the environment. Therefore, to elicit realistic behaviour in an IVE, presence should not only refer to the feeling of being there but also the illusion that you are part of the scene and your actions can change the course of events. [Slater, 2009] proposes that presence is the combination of two different components called place illusion (PI) and plausibility illusion (Psi). PI describes the initial definition of presence, allowing the user to perceive the IVE with natural movements of his body, the same way he would do in the real world. The illusion of being in that place will be stronger depending on the sensorimotor contingencies (SCs) [Noe, 2004] that the IVR system supports. An example to this would be when someone moves closer to an object, he expects to see it bigger, and the display that is used to render the object does not interfere by showing a pixelated version of the object. Psi refers to the extent the real person in the scene has the illusion that the events occurring in the IVE are actually happening. This is achieved through making him feel he can interact with the entities in the scene, that these entities react to his actions, and that such interaction fulfils his expectations of what a natural interaction is, as in real life. When both PI and Psi occur, people respond to the events happening in the IVE in a similar way to what they would do in real life, hence the name "response-as-if-real" (RAIR).

PI is a key concept of our research, the participants needed to feel that the scenario, including the virtual characters in it, were believable. This would trigger physiological responses similar to those they would feel in an actual violent emergency such as heart rate increase, a feeling of discomfort with the situation, and possibly the feeling that they want to do something to try to stop it. In terms of Psi, they also needed to believe that they could do something about it, that their intervention could change the course of events.

2.2.2 Interaction with Virtual Humans

There is some confusion in the literature about when to use the terms virtual characters and avatars. Virtual characters, also called virtual humans, refer to any animated computer generated simulation of a living being that can start a physical action, regardless of how their actions are controlled. On the other hand, avatars are the representations of real people in the virtual environment. The research presented in this thesis does not include avatars, but only pre-programmed virtual humans. Since all the studies took place in a VR system where people directly see their own real bodies, there was no need for any further self representation.

IVR allows the setup of scenarios where people can interact with virtual characters, and the sense of presence contributes to eliciting realistic behaviour by participants to study their responses in a controlled laboratory environment. It has been observed that people tend to behave realistically in response to virtual characters and there are examples on both non-verbal communication [Bailenson et al., 2001, Kastanis and Slater, 2012] and verbal [Pan et al., 2008]. Eye gaze has been suggested as one of the most important cues in our judgement of the realism of virtual characters [Bailenson et al., 2001, Vinayagamoorthy et al., 2004]. This is an example of Psi, where realistic behaviour includes acknowledging the real person and behaving in accordance to his actions. The way a scene reacts to the person's actions includes virtual characters looking directly to the person, changing direction when walking to avoid physical contact, and even establishing a conversation with him.

Interactive virtual humans are important to make people respond realistically to a social situation in an IVE. However, designing a pre-programmed interaction with characters resulting in somebody having a free-flow conversation with the virtual humans is a very complex task, as each individual will have a different response to the same situation and part of a realistic interaction is, not only having the right response, but also the timing. Putting this into the perspective of our research, eliciting authentic physiological responses that are typically associated with extreme emergencies, such as discomfort and anxiety can make people more likely to intervene to help somebody that is in danger. Having a realistic interaction experience with virtual humans can possibly make people feel that they can do something in front of an extreme emergency, and discomfort can also make them feel that they should do something about it. This idea was used in our research in order to observe what made people more likely to intervene in this type of emergencies.

2.2.3 Studies of Presence

There is an extensive literature of studies that take advantage of presence in IVR and virtual characters in order to observe the responses people have in front of a situation. This section describes the most relevant studies carried out in presence and uses this as a starting point in the research presented in this thesis. [Spanlang et al., 2007] describes a pilot study on how people respond to an emergency of a non-violent nature. The goal of this study was to use IVR to observe how people respond to a fire emergency in a place where other people are present and run away when the fire starts. This study was an example on how IVR can be used to set up scenarios that are difficult to create in real life, due to their complexity and also to avoid placing participants in danger. Our research also aims to use IVR to depict extreme situations in which human behaviour could be studied in a highly realistic setup. [Spanlang et al., 2007] describes a scenario where an emergency situation happens. He also mentions that interaction between the participants and virtual characters could be implemented in an experiment following up the preliminary results shown in the report. It is one goal of our research to create the feeling in participants that they can interact with the virtual characters to test our hypothesis, although it has been mentioned before that it is a very complex task to implement realistic dialogues with virtual characters. Our goal is to implement a basic interaction that is necessary to elicit people's responses. A shared social identity with a virtual character can be easily achieved simply by making him wear a shirt of the same football team that the participant supports but building rapport in a short period of time can only be achieved through a conversation, as described in more detail in Section 2.1.2.

Another precursor study was the virtual reprise of Stanley Milgram's Obedience experiment [Slater et al., 2006]. People were recruited to participate in an experiment where they had to ask questions to a virtual character and administer what seemed to be electric shocks to him every time his answer was incorrect. The results showed that participants who were able to see the virtual character receiving the virtual shocks tended to show more signs of discomfort, and also were more likely to withdraw before administering all the shocks, compared to participants who could only interact with the virtual character using a text interface. The original Milgram experiment [Milgram, 1963] was the source of a lot of controversy, as explained in Section 2.1.4, and the original experimental setup could not be repeated nowadays, as it does not comply with current ethical standards. However, IVR has allowed a version that overcame these ethical issues, since the participants knew the scenario was computer generated and that nobody was actually being hurt.

The virtual Milgram experiment [Slater et al., 2006] and our research have in common that both studies used IVR to overcome ethical issues, as these experiments could have not been carried out in a setup using real confederates. Participants were exposed to a stressful situation in which the participant had an important active role where he needed to decide how to respond to the situation. In the Milgram experiment, participants showed symptoms of discomfort. In terms of interaction, the participant could not talk to the virtual character, although he was the one who had to decide whether to stop inflicting the electric shocks or comply with the researcher and carry on with the experiment. In the violent emergencies scenario, our goal is to create the illusion that the participant can step up and try to stop the argument, not only with verbal utterances but also by moving close to them or trying to reach out to them in order to get their attention.

2.2.4 Overcoming Ethical Issues

IVR helps to overcome some ethical issues since participants know at all times that they are in a simulation. There is no deception in the sense that participants know that the events they witness are not actually happening, that no one will get hurt. However, the use of these technologies is a deception in itself as it still tricks people to the extent that they show realistic responses such as anxiety and frustration when facing a stressful situation. This discrepancy between being aware that the events they perceive are not actually happening and still feeling it as it is real is a very interesting point and a key concept upon which behavioural studies in IVR are based. The responses that participants have are similar to those that would be expected in the same situation in real life, as has been observed in other studies, for example, Milgram's experiment. In the virtual reprise of the study on obedience [Slater et al., 2006], people showed symptoms of anxiety and nervousness similar to those of the participants in the original experiment [Milgram, 1963]. The results are not identical because there are other differences between the two versions besides one being carried out in an IVE and the other using real confederates. Firstly, these two experiments were carried out more than 40 years apart, and secondly participants were informed about the nature of the experiment beforehand in the virtual reprise (in order to comply with current experimental ethics standards).

2.2.5 Improving Experimental Validity

IVR offers an experimental framework with a higher degree of internal validity compared to studies that are based on observations in the real world. Although observational studies are highly ecologically valid, every event is likely to contain differences that might affect the outcome, thus making difficult to generalise the results. In an IVR setup, a scripted scenario can be run as many times as necessary and the virtual characters' performance will be identical every time, considerably reducing the risk of variations created by people performing the same scene different times. In addition to that, IVR provides the technology to deliver multi-sensory experiences and, with the help of the sense of presence due to having strong SCs, elicit authentic responses. Therefore, IVR offers the possibility of conducting experiments in a laboratory-based setup, thus being internally valid as well as keeping the ecological validity high.

2.3 Reinforcement Learning

Social studies often face the problem of having a large number of experimental variables to try, as several factors can influence people's responses and the results of the study. Nevertheless, not all the variables can be studied without spending a large amount of time and resources. This thesis addresses this problem with the use of RL, a sub-area in machine learning ML that aims to solve problems without the requirement for prior knowledge about the goal or potential solutions. The concept is similar to learning by trial and error. An active entity known as the RL agent, or simply *agent*, interacts with its environment, observes what happens and decides what to do next in order to try to reach the goal. During the interaction process, it can receive rewards or punishments that will help the agent learn how to achieve the goal. A RL problem is designed as a Markov Decision Process (MDP) in which the agent is able to observe the state of the environment and change it. The experience accumulated helps the agent adjust the strategy to maximise the likelihood of the

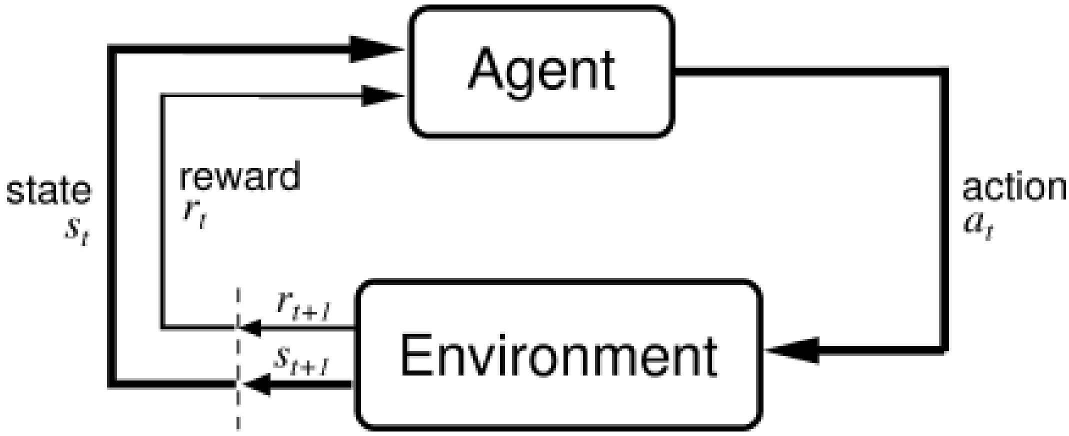


Figure 2.1: RL state-action-reward diagram [Sutton and Barto, 1998]

.

desired outcome [Kaelbling et al., 1996, Sutton and Barto, 1998, Wiering and van Otterlo, 2012].

2.3.1 State, Action, Reward

The agent interacts with its environment in a stepwise process in which each step is decided on the current state (s) and the experience obtained previously taking actions from that state. Each time the agent interacts with the environment by taking an action (a) and observes the changes in the environment. It may also receive a reward (r) in the form of a numerical value. The changes reflect the environment state, which is defined by a finite set of state variables. This process is repeated in a loop (Fig. 2.1) until a ending condition is triggered, which could be that a final state has been reached or that the time has run out. If the problem is episodic, the agent will repeat this process multiple times, each time starting from the initial state, accumulating the experience over the episodes.

A reward is usually obtained when a final state is reached but this can also happen in any other stage. The long term goal is to maximise the sum of the rewards (R) obtained (eq. 2.1). The reward might also come with a discount factor (γ, $0 < \gamma < 1$) that decides the percentage of the reward that will be accumulated depending on the time elapsed from the start of the episode. This discount factor could be applied if e.g. the goal is to reach the final state as quickly as possible.

$$R_t = \sum_{k=0}^{T} \gamma^k r_{t+k+1} \tag{2.1}$$

2.3.2 Value Function and Policy

The experience that the agent collects from taking actions and visiting different states is used to build up a statistical model that updates and assigns a numerical value for each either state, $V(s)$, or state-action pair, $Q(s,a)$, that gives an idea of how likely it is to obtain a reward if a state is visited (or state-action tried). The set of values is known as the value function. If many rewards are obtained after visiting one specific state, it will have a high value associated with it, thus it will be more likely to be visited in future tries when the experience will be exploited. However, it is also important to collect information from the less visited states, as they can possibly lead to a path with higher reward that it is not known to the agent yet. The strategy, or policy (π), that the agent follows decides when to exploit the knowledge and when to take exploration moves. A RL problem can be seen as the process of finding optimal policy (π^*) that knows the best actions in each case to obtain the maximum reward.

In a standard setup, epsilon (ε, $0 < \varepsilon < 1$) is the parameter that decides whether to explore or to exploit for each action taken. It determines the probability that the next action will be exploratory or will make the best possible move based on what has been observed so far. A greedy policy that only exploits experience, $\varepsilon = 0$, will lack knowledge to determine what action is the best and will not focus on the exploration of the unknown alternatives. On the other hand, a policy that only explores, $\varepsilon = 1$, will have an accurate idea on how the environment is but it will never take advantage of the experience. A good policy is based on finding a good balance between exploration and exploitation. ε does not necessarily need to remain constant throughout the episode and in the early stages it can be set higher to encourage exploration. Along the experience collection process, the likelihood of performing an exploration step is gradually reduced to increasingly use the experience. The policy that finds the perfect balance and knows the best following step for each state is called the optimal policy ($\pi^*(s)$).

2.3.3 Applications

The important aspects that influenced early applications were the possibilities to describe the environment with a finite set of variable states that led to the unequivocal description of the states. The first successful applications of RL were used to train computers to learn from experience to play board games. After a computer successfully learned to play checkers [Samuel, 1959, Samuel, 1967], other board games followed, such as Chess [Thrun, 1995, Baxter et al., 2000], Go [Silver et al., 2007], Backgammon [Tesauro, 1995] and Othello [van Eck et al., 2008]. Board games provide a discrete and finite deterministic environment ideal for simple RL problems [Wiering and Patist, 2005]. Also, they are deterministic problems, given the current state, the same action will always lead to the same following state. They are also repeatable, as the agent can play as many games as needed episodically and the experience is accumulated to improve the outcome in future games.

However, the possibilities of RL are not limited to environments with a small number of possible states and a low level of uncertainty. More complex setups have been tried, such as different types of video games. For example learning to play a role-playing game [Spronck et al., 2003], command an entire army in a real-time strategy game with the use of various agents concurrently [Marthi et al., 2005], and, more recently, a computer that successfully learned to play different old arcade games [Mnih et al., 2015] and exceeding human performance in most of them without any previous knowledge of what the specific goal in each was.

RL has also been applied extensively in different levels of robotics. It has been demonstrated that a mechanical robot learns how use motor primitives [Peters et al., 2008] to perform physical tasks [Kober et al., 2012, Kormushev et al., 2013]. While having a large number of possible states is a problem that can be present in any field, robotics has the added difficulty of having to guess the current state from the data obtained from sensors. The sensors are not highly accurate in some cases, so the current state can only be estimated. Other applications of RL in fields related to robotics are systems control and path planning, such as learning to find the path to a target position in dynamic environments avoiding moving obstacles [Vigorito, 2007]. This can be used for autonomous entities such as virtual characters [Treuille et al., 2007], quadruped robots [Kolter and Ng, 2009], and unmanned aerial vehicles [Ng et al., 2004, Hoffmann et al., 2005].

Our research aims to use RL in IVEs to elicit human responses, and there is limited research on this. In [Kastanis and Slater, 2012], a scenario was set up in which a virtual character had to learn to make people move backwards to a specified location. Based on the principle of proxemics [Hall, 1966], the RL agent learned that the participant will move backwards if the virtual character invades the personal space, as described in the proxemics theory. In just few minutes and without prior experience, the RL agent learned that making the virtual character move forward towards the participant made him, sometimes, move backwards. The participant only moved backwards when the virtual character was not far away. In such case, the RL agent had to learn that then the best action was to call him to move forward towards the virtual character and away from the goal. This is an example of how obtaining a small negative reward is sometimes necessary in order to reach a bigger positive reward afterwards. In this research, we aim to design virtual characters that can learn to make the participant reach a goal in IVE, not limiting the goal to perform physical actions but also eliciting more complex behaviours in situations where they face an social emergency and they need to decide how to respond to it.

2.3.4 Addressing Large Experimental Variables Sets

There are no references in the literature that explicitly make use of RL to tackle the problem of having a large set of experimental variables. However, in a RL problem, the agent tries different actions and observes the changes. Considering that the actions are the possible experimental variables and the goal is to elicit a specific response from people, the agent could try all the possibilities that it is allowed to try and build up a statistical model of what makes people more likely to respond according to the goal.

Furthermore, in more complex situations, obtaining a specific response might only be achieved by performing a sequence of the actions available, as in [Kastanis and Slater, 2012], where the agent learned to make a person move forward and reduce the gap between him and the virtual character in order to subsequently make the latter enter the participant's personal space. This experiment would have been difficult to succeed making the either the participant or the virtual character move forward were studied separately. It would be very unlikely that a participant who is asked to move away from the goal would reach the destination position behind him if the only action available was to call him to move towards the virtual character. On the other hand, moving the virtual character towards him would only work in some cases, but the combination of the two in a sequence made 75% of the participants reach the goal position in Kastanis's study. This led to the results that could have possibly not been predicted prior to the experiment, as well as discovering interaction between the experiment variables. This is a very interesting point and this research aims to apply it to more complex social situations. In particular, this thesis aims to observe how the behaviour of the virtual characters in a scene can influence people's responses to an emergency. People can behave in multiple ways, but in an experiment only a few of these behaviours can be tried. By using this new experimental framework, we expect that more actions can be tried without exponentially increasing the number of participants needed.

2.4 Related Work

The lack of an experimental framework in which bystander responses to violence can be studied preserving high experimental validity and without raising ethical issues, has made researchers use other setups that are not ideal, as described throughout Section 2.1. In order to overcome these ethical issues, researchers have limited their research about paradigms such as social identity and the bystander effect to non-violent emergencies [Levine and Manning, 2013]. These emergencies include accidents such as a person falling off a ladder, filling a room with smoke [Latané and Darley, 1968], or witnessing a jogger tripping over [Levine et al., 2005]. But there is evidence that the bystander effect can be diminished when the dangerous nature of an emergency is clear [Fischer et al., 2011], therefore making the results obtained in other non-dangerous emergencies not generalisable.

An alternative to real-world setups is to use computer-mediated environments. There has been a long discussion about whether video games contribute to violent behaviour [Anderson and Bushman, 2001]. This seems to be similar to the debate about whether violence in TV could foster aggressive behaviour to viewers [Himmelweit and al., 1970, Messner, 1986] applied to new types of entertainment. Furthermore, [Calvert and Tan, 1994] showed that people who participated in a video game featuring violence reported higher levels of aggressiveness compared to those who were only spectators. One concept often mentioned is the user desensitisation to violence [Bartholow et al., 2006, Carnagey et al., 2007] that may lead to both increasing the level of aggressiveness and reducing the likelihood of showing helping behaviour to other experiencing aggression. The results are not always consistent, as several studies have not found evidence that there is a direct relationship between the exposure to violence in media and the subsequent behaviour [Ferguson, 2007]. However, only a few studies are focused on understanding how people would respond to an emergency situation instead on looking at what makes someone become more aggressive.

Some studies that have looked at this topic exposed the participants to violence in computer-mediated environments and measured whether they felt either more aggressive or showed pro-social behaviour once the exposure to the stimuli had ended. For example, [Calvert and Tan, 1994] asked participants to play Dactyl Nightmare[1], a first-person shooting game in which two players played one against the other in one version or where they had to team up to defeat a computer-controlled character. In the first condition, the results showed an increased level of aggressiveness, while in the second one, participants showed pro-social behaviour. Other phenomena have also been studied with the use of computers, such as the bystander effect. [Stenico and Greitemeyer, 2014] studied

[1] http://www.arcade-history.com/?n=dactyl-nightmare&page=detail&id=12493

whether playing Counter Strike: Condition Zero[2] would change the participants' helping behaviour in real life, also looking at how the number of people present in the video game scenario was significant. However, it associated the bystander effect with number of allies in a fight, but neglected the fact that the number of opponents also increased, besides that everyone was part of one team or the other, no one was a bystander. The helping behaviour was rated on how much participant were willing to participate in another study afterwards, rather than intervening in an emergency.

Other studies have focused their attention on the participants' responses at the moment when the emergency takes place. [Kozlov and Johansen, 2010] looked at whether the bystander effect occurs in the video game scenario, asking participants in advance to imagine that the virtual characters were real. The results showed that people stopped less often to help a virtual character in need of help in a non-violent emergency when there were 19 virtual bystanders present in the room, compared to the version when there were only four of them. [King et al., 2008] used Second Life[3] to represent a more mundane situation in which a man shows confrontational behaviour against a woman, even becoming sexually aggressive. The results showed that participants' responses were biased by the media used, as a common answer participants said that the authority figures should ban such behaviours, in this case the virtual world administrators. Furthermore, this paper assumed that the bystander effect would not occur in Second Life because no real people are actually harmed.

Our research used IVR in order to place participants in an environment that they can perceive with natural movements of the body. To our knowledge, this is the first time that IVR is used to study extreme social emergencies in which people saw one character intimidating another without having to imagine the situation. Participants were not given instructions beforehand or asked how they would respond to the events. IVR has the advantage that it allows to make participants feel as if they actually were in the environment depicted, with life-sized characters that can respond to the participants' actions, for example chatting with a participant or looking directly at him, thus increasing the plausibility of the scenario. Video game

[2] http://counterstrike.wikia.com/wiki/Counter-Strike:_Condition_Zero
[3] http://secondlife.com/

scenarios are not ideal, as they are usually played in a computer monitor or using a projector, providing an experience with low level of immersion. This setup does not block the peripheral vision, revealing elements that can remind participants that they are in a laboratory. Another disadvantage in Second Life is that people know that the events occur in an environment where different rules apply, for example knowing the existence of an authority figure related to the setup. The goal of our research was to expose naive participants to the situation, without knowing what would happen beyond the information sheet that was provided before the exposure to IVR, including an explanation to avoid ethical issues, as explained more in detail in Section 3.3.

2.5 Chapter Summary

This chapter has presented an overview of the three main fields involved in this research. Firstly, it described the topic of people's responses to emergencies as a sub-area in social psychology in which the research is focused on the people's behaviour in a scene where other people are present and the contributors that either make people more likely to do something about the emergency or reduce the chance of intervention. This field of research faces different obstacles that make traditional experimental methods not ideal. The problems that this research addresses are ecological validity, internal validity and ethical issues that could arise from the nature of the experiment.

IVR offers an alternative to other research methods such as experiments based on questionnaires and observational studies. Delivering life-size computer generated graphics, stereoscopic capabilities and head tracking allows people to perceive the environment with strong SCs, as if it were real, despite knowing at all times that they are in a simulation. This experimental framework not only helps overcome some ethical issues but also helps to increase ecological validity. Furthermore, internal validity is also improved compared to observational studies and other setups with confederate actors, as, since it is a computer generated simulation, the scenario can be run identically as many times as necessary. We want to take advantage of these technologies to study the people's responses to extreme emergencies.

In addition to that, we also aim to use RL to address the problem of having a large number of experimental variables that can potentially interact with each other. Normally this would lead to a study in which the permutations of experimental variables would require an unreasonably large number of participants and experiment trials. However, this sub-area of ML can be used to define a novel experimental methodology in which the machine is provided with learning capabilities. A learning entity collects information about people's responses and decides the actions to be more likely to have a higher contribution on the results.

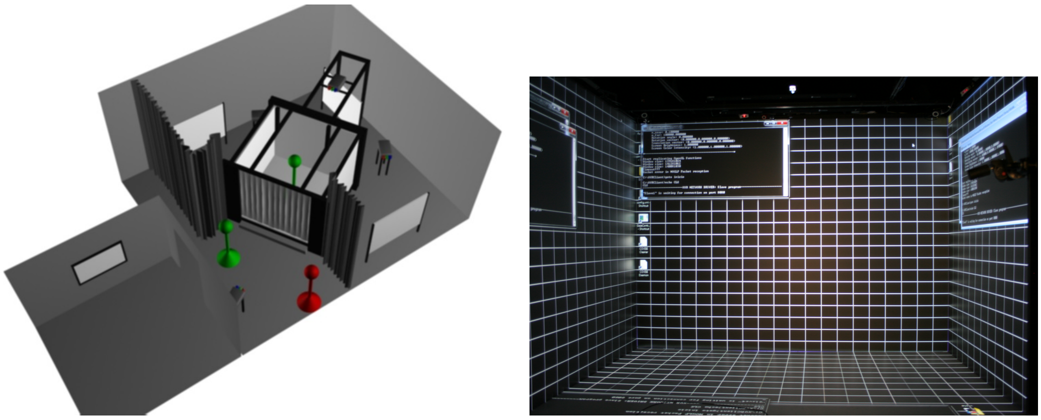
Chapter 3

Methods

This chapter describes the common methods that were used in the series of experiments where we study contributors to the number of bystander interventions in a violent emergency. It includes a description of the VR system used, the scenario implemented in which a violent emergency takes place, the experimental setup and procedures, ethical considerations, common measures such as questionnaires and the counting of the number of interventions, and how these data were analysed.

3.1 The Virtual Reality System

All the experiments explained in this report were carried out in the Virtual Reality Lab in Malet Place Engineering Building at UCL. The VR system used was a Trimension ReaCTor (Fig. 3.1), similar to the CAVE described in [Cruz-Neira et al., 1993], which is referred to throughout this report with the generic name *Cave*. The user is placed inside a room of a roughly cubic shape with 3 walls and no ceiling, where he has freedom of movement. The rendered scene is displayed on all 3 walls and the floor with imagery connected seamlessly on the edges where two projection surfaces meet. The entrance is situated where the fourth wall should be. Walls are 3 metres wide and 2.2 metres high and are made of translucent material allowing the images to be rear-projected. The floor is opaque, with the image projected from the top, with a size of 3×3 metres. Originally, the Cave was composed of a set of CRT projectors, which were replaced by new DLP ones during this research. The projector upgrade is the central topic in the experiment on visual realism discussed



(a) A 3D-model of the Cave in the VR lab at UCL.

(b) A photo taken from the entrance of the Cave at UCL.

Figure 3.1: Trimension ReaCtor. The Cave VR system used in all experiments.

in Section 5.2. Further details about the projectors are provided in Section 5.2.2. Projection surfaces receive the image from a projector with the mediation of a mirror. These mirrors are standard to Cave systems, they do not have a glass layer to avoid refraction and double reflections of the image. Additionally, mirrors make the system more compact by allowing it to fit in a smaller room.

Projectors are controlled by a PC cluster composed of four machines, each one equipped with an Nvidia Quadro FX 5600 graphics card, delivering stereoscopic graphics. Graphics cards are connected to a set of 6 infrared light emitters, strategically placed around the Cave to send the signal to the Crystal Eyes shutter glasses, also referred as goggles, that the user wears in order to provide active stereoscopic vision. An Intersense IS-900 tracking system provides 6-DoF at a frequency rate of 120Hz with accuracy between 2.0 and 3.0mm. This is a hybrid tracking system that utilises accelerometers and gyros to provide position and orientation data, with an ultrasonic ranging system for drift correction. The user wears a small device containing the inertial components as well as 2 small microphones to detect the ultrasonic chirps from a grid of emitters arranged above the volume of the Cave. This tracking system allows for real time adjustments to the imagery according to the user's perspective, so he can look at the scene from different locations and angles.

3.2 The Scenario

The chosen scenario was related to football for two main reasons. Firstly, there is a long standing association of violent behaviour and hooliganism in football, which can transcend socioeconomic boundaries and can occur domestically and internationally. Football fans can behave aggressively against people who support other teams or are from other nations, especially when there has been significant alcohol consumption. Secondly, it makes it easy to manipulate the affiliation of the virtual characters used and simplifies the task of making the participant feel that he has a shared social identity with other characters by simply changing the appearance of the shirt they wear. The scenario was identical for all the experiments with some variations in the actual design in each one of them. The following paragraph describes a summarised version of the script, the full version is provided in Appendix B.

Each participant (all participants were male Arsenal F.C. supporters, as explained in Section 3.4.1), individually entered the VR environment, where he found himself in a virtual bar on his own. They were given 2 minutes approximately in order to get used to wearing the goggles and acclimatise to the visual stimuli and the stereoscopic vision. During that time, the participant was instructed to look for objects related to football in the environment. It was made clear that this experiment was not a memory test, so they did not have to memorise everything they saw. After this, a first virtual character, the victim (V), entered the virtual bar through a door in front of the participant and walked towards the participant. Once he acknowledged V, V started a conversation about the English Premier League team, Arsenal F.C. At some point during the conversation, a second man, the perpetrator (P), entered the scene and sat down by the bar, not far from where the participant and V were having their chat. After exchanging their opinion about different matters related to Arsenal F.C. for about 2 minutes, P stood up and started to argue with V, accusing V of staring at him for no reason, while V responded that he was not looking at him. P asserted that he does not like Arsenal and people talking about them in the bar. V tried to defuse the situation by avoiding an escalation of the argument, but

P's behaviour became increasingly more aggressive. The confrontation ended after 2 minutes and 12 seconds from the moment P stood up. At that point, P started to push V towards the wall, the image faded out, and the scenario ended.

3.2.1 The Virtual Characters

Two professional actors were hired to perform a motion capture session to create the animations and audio for the two characters, the victim and the perpetrator, that appeared in all the experiments in which the bar scenario was used. A Vicon[1] system with 6 infrared cameras was used to capture the movements of both actors simultaneously. This required each actor to wear 32 retroreflective markers, placed at specific locations on their bodies. The animations were cleaned up using the Vicon software (Fig. 3.2) and Autodesk 3ds Max[2] software. Audio was recorded simultaneously using clip-on wireless microphones and Audacity[3] software. The raw audio data was then equalised and split into separate files so that each one could be arbitrarily played later on as required. The last step was to synchronise the audio files with the animations.

3.2.2 Technical Implementation

The development environment used was XVR[4] [Tecchia, 2010], a VR platform that runs on Windows machines and allows users to develop VR scenarios independently of the VR system specifications it will be used in. Although developing in XVR is done using its own scripting language, the integrated development environment (IDE) also provides the feature to include external dynamic libraries to run routines implemented in other programming languages, such as C++ and C#.

The virtual characters were controlled with the use of HALCA[5] (Hardware Accelerated Library for Character Animation, [Gillies and Spanlang, 2010]), a library based on the Cal3D[6] (Character Animation Library 3D) standard to define and control characters. During the experiment the free-flowing conversation

[1] http://www.vicon.com/
[2] http://www.autodesk.co.uk/products/3ds-max/overview
[3] http://sourceforge.net/projects/audacity/
[4] http://www.vrmedia.it/en/xvr.html
[5] http://www.cs.upc.edu/~bspanlang/animation/avatarslib/doc/
[6] http://gna.org/projects/cal3d/

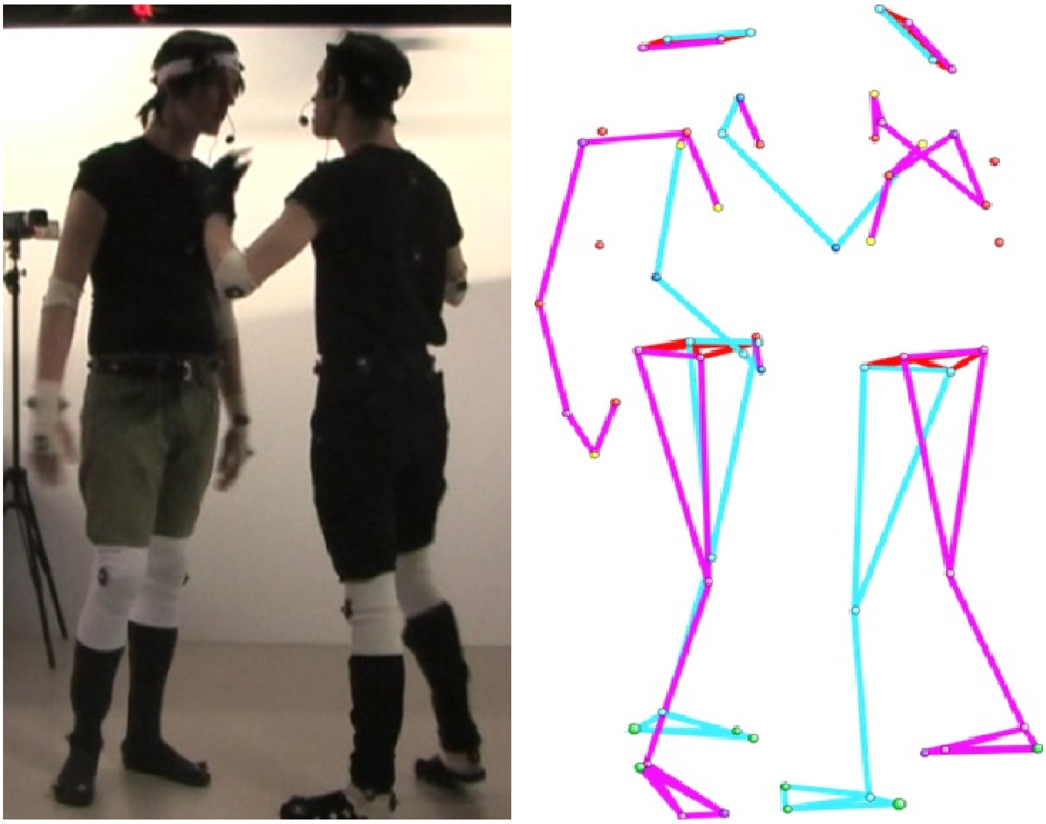


Figure 3.2: Motion capture session performed by two professional actors and the result obtained in the Vicon software.

between the participant and V was achieved by operator control. A number of utterances had been recorded, either making a statement or asking a question of the participant. Each such utterance was selected interactively by an operator who could hear the responses of the participant, while the participant was not aware of the responses being selected by a person behind the screen. The operator sat by a computer screen, and all the phrases were represented visually as selectable buttons on the screen (Fig. 3.3). When a button was selected (by point-and-click with the mouse) then V would say the phrase and play the corresponding animation. There was a defined script that the operator followed, but when the participant said something that fell outside of the script, then a number of general phrases could be selected by the operator in order to keep the conversation going in a natural way. For example, if the participant said something unplanned, the operator could select a generic phrase such as *"I totally agree with you"* which would then be said by V. The strategy was to make the virtual character lead the conversation by asking questions and preventing the participant time to ask his own questions that could diverge from the script. Once the participant responded to a question, a suitable response was chosen, and the following question in the script was triggered right after it. The overall effect for most participants was as if it were a normal conversation between the participant and V. The UI to trigger animations was developed with Qt[7] and integrated in XVR as an external library. HALCA allows the smooth blending of different animations, so every time a new one was triggered, the old animation was faded out and the new one faded in using linear interpolation.

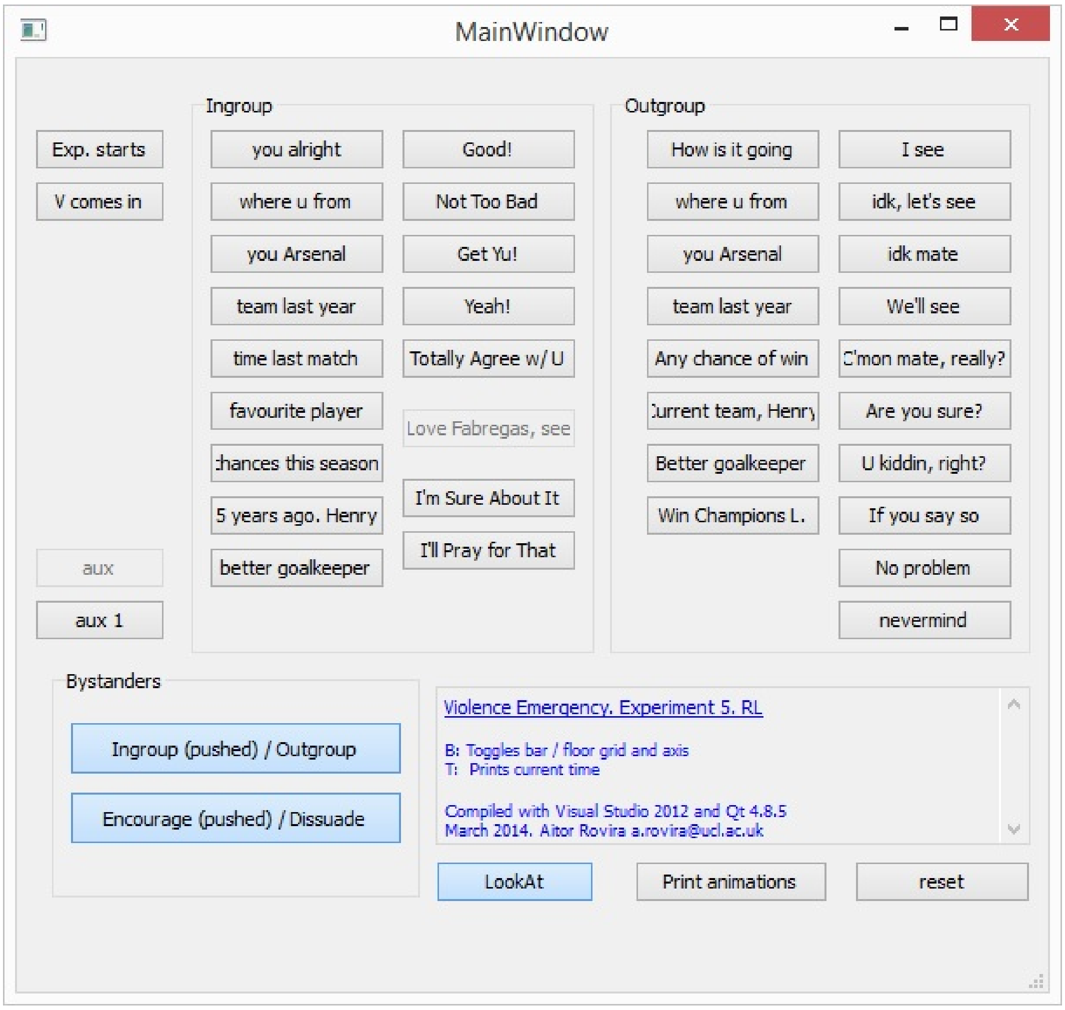


Figure 3.3: The UI used to trigger the animations and utterances for the initial conversation with the victim.

[7]http://www.qt.io/

3.3 Ethics and Data Protection

An Ethics case was submitted to the UCL Ethics Research Committee. It described all the steps in the experiment that were to be undertaken as well as measures to prevent potential hazards that could put either participants or researchers in danger. The most important ethical issue was that, even though the study of violence can be controversial especially in behavioural studies, IVR allowed placement of participants in such situations. Despite the highly realistic displays and behaviour shown by participants, they knew they were in a simulation at all times, and that no one was harmed during the experience.

As part of the standard procedures, the participants recruited were at least 18 years old. Once they arrived at the VR laboratory, they had to read the information sheet that warned them about potential hazards such as disorientation and dizziness that might be experienced, usually after using a VR system that has not been properly calibrated. They were recommended not to drive or ride a bicycle for three hours after the VR experience.

The information sheet also included other warnings such as the use of bad language by the characters in the scenario. It also stated that they could ask any question to the researchers, and that they could withdraw from the experiment at any time without having to give any reason. Once they had read the information sheet, they had to fill out and sign the consent form in order to make sure that they understood all the information provided and gave consent to be part of the study. The consent form was also required for certifying that the participant did not have epilepsy.

The pre-experience questionnaire also contained two questions related to the Ethics case. First, participants had to declare if they were taking any medication. This may possibly indicate unlikely cases of seizure episodes where cognitive states have been affected. The questionnaire also asked about alcohol consumption prior to the VR experience.

Once the questionnaire was filled out, they were warned again by the researcher about the bad language in the scenario to make sure they had read that point. They were recommended to, where applicable, wear prescription spectacles under the VR goggles. They were told that if they felt nauseous, they had to indicate it clearly as we would have to stop the experiment session immediately. They were warned to be careful with the cable from the goggles to prevent it getting tangled up. Lastly, they were asked if they could be videotaped, and it was clarified that the videos would be used by the researchers only and would never be shown to the public.

Data collected through questionnaires were anonymised using a numerical ID for each participant, which was assigned as a sequence as soon as they arrived at the laboratory. For documents where personal information was required, such as the consent form and the payment form, the ID was not included.

3.4 Experimental Procedures

An experimental procedure document was prepared for each experiment to follow a strict order of the events for each day of experiments and for each participant. A fully-detailed version of the experimental procedures is provided in Appendix C, and a copy of all the documents mentioned in this section are provided in Appendix D. While there were some minor changes for each experiment, the main structure for all of them was:

- When the participant arrives, ask him to read the information sheet (App. D.5), sign the consent form (App. D.6) and complete the pre-experience questionnaire (App. D.7).
- The participant moves into the Cave and is given a brief explanation about how VR system works.
- He is explained that his task is to look for objects related to football, warned about the bad language contained in the scenario and told again that he can withdraw at any time without giving any explanation.
- The scenario starts, V enters the bar and they both had a conversation about Arsenal F.C.
- The scenario continues with the confrontation.

- After the scenario has ended, participant is asked to fill out the post-experience questionnaire (App. D.8) and interviewed about the experience he just had (App. D.10).

- He fills out the Payment form (App. D.11) and is paid £7 as a compensation for his time and for coming to the VR laboratory, which corresponds the standard rate for participating to one experiment for one hour at UCL.

3.4.1 Participant Recruitment

Research participants were recruited around University College London (UCL), posting advertisements on boards (App. D.1), and distributing e-mails that were send to all undergraduate and graduate students at UCL (App. D.2). No one got in touch with us via the e-mail address provided on the board announcements, so this form of recruitment was not used in the experiments after the first one. Other methods were used such as posting an advert on the UCL Psychology Subject Pool, but this turned out to be very inefficient to find Arsenal F.C. supporters. Another advert was posted in a busy online forum for Arsenal supporters but no one was recruited this way either. In the end, all participants were recruited via an e-mail sent to all the undergraduate and graduate students at UCL, as we had several hundred people signing up every time we sent an e-mail and it was clearly the most effective way to recruit them. They were asked to follow a link where they could read a short explanation (App. D.3) about the study and they were asked to fill out an online form (App. D.4).

The recruitment criteria were based on their answers to the questions on the online form. The requirements were that they had to be male, Arsenal F.C supporters and be a minimum of 18 years. The scenario was implemented only for Arsenal supporters. Therefore, any potential participant who supported a different Premier League team had to be filtered out. The only reason why this team was chosen before any other was because it is one of the most popular teams in the area of London where UCL main campus is located. Female participants were also discarded to avoid the gender variability, as gender is often an explanatory variable in behavioural studies about social emergencies [Levine and Crowther, 2008]. The second reason was that females represented a small percentage of football supporters, therefore it was not easy to find enough to be around the 50% of the sample. The last selection criterion was on the question "*How much do you support your team?*" where they had to score 4 or higher, on a scale from 1 (*Not at all*) to 7 (*Very much so*) as we wanted to have supporters with low variance with respect to how strong their feelings were towards their favourite Premier League team.

3.4.2 Information Sheet and Pre-experience Questionnaire

The information sheet D.5 and the consent form D.6 were part of the Ethics case. The main purpose of the information sheet was to provide a general idea of what the experiment is about and the type of equipment that was going to be used. It also said that the participant had the right to ask any question about the experiment, although some questions would be answered after the experience in VR, and also to make sure that participants knew that they could withdraw at any time, without giving a reason. The information sheet also warned about potential hazards that, although they had a minimal risk, had to be mentioned. The consent form was required to be signed, and also contained some questions to make sure that the participant was not under the effect of medication or alcoholic beverages.

A questionnaire also needed to be filled out before the exposure in VR. This questionnaire included questions about the participant's English level to make sure that they would be able to understand what the virtual characters say. It also included two questions mentioned in the ethics case, asking whether they gave their consent to be video and audio taped, as well as questions about their computer literacy and the amount of time they spent playing video games. These latter questions were asked in case these factors might turn out to be explanatory variables for the results.

Variable	Statement
Uncomfortable	After the argument started, I was feeling uncomfortable with the situation.
OtherSafety	After the argument started, I was sometimes concerned for the safety of the man being threatened.
OwnSafety	After the argument started, I was sometimes concerned for my own safety.
HelpMe	After the argument started, I looked around for help.
OtherPeople	After the argument started, I looked around to check in case other people might arrive to make the situation worse.
VictimLooked	After the argument started, the victim looked at me wanting help.
MoveAway	After the argument started, I felt I should move away from those people.
AgressorAware	After the argument started, the aggressor was aware of me looking at him.
ShouldStopIt	After the argument started, I felt I should do something to stop it.
CouldStopIt	After the argument started, I felt I could do something to stop it.
GetOut	After the argument started, I felt that I needed to get out.
Thinking	My mind started wandering and thinking about other things during the argument.

Table 3.1: The Post-experience questionnaire and corresponding variable names. Participants had to answer, on a 1..7 scale, how much each statement applied to themselves, where 1 means ‘not at all’ or ‘at no time’, and 7 means ‘very much so’ or ‘almost all the time’

3.4.3 Post-experience Questionnaire and Interview

The post-experience questionnaire (App. D.8) was composed of questions related to the thoughts and feelings of the participants while witnessing the confrontation. The variables extracted from the questionnaire are listed in Table 3.1. The data collected was used as explanatory variables for the statistical analysis.

In the interview (App. D.10), the questions were also about their feelings while the confrontation was happening. The interview also contained questions about how realistic the scenario was in their opinion, and whether there was any specific technical aspect that stood out and made the experience less real.

3.5 Data Collection

The main source of data collection was through the post-experience questionnaire and the interview, as explained in the previous section. Both sources provided data about the feelings they had during the confrontation as well as their feedback about how realistic the scenario was. The answers in the questionnaire were provided in a 1 to 7 Likert scale form, while in the interview, participants could explain their experience with their own words. Their interviews were audio recorded with the participants' consent, so the researchers could replay them and transcribe them.

However, while questionnaires can help to understand participants' responses, they may not be sufficient [Slater, 2004]. For this reason, participants were also audio and video recorded during the experience in VR (also after giving their consent) in order to be able to replay their performance after they left the laboratory. A camera mounted on the Cave's floor projector provided a view from above of the entire Cave volume. The microphone was placed hanging from the ceiling of the Cave to maximise the clarity of the participant's utterances, even if the virtual characters were talking at the same time. The recordings allowed to observe whether the participant tried to intervene in the confrontation, either verbally or physically.

Manual annotations were also taken by the researchers observing from behind the curtain while participants were in the VR system, although important details could be easily missed, especially when they intervened multiple times in short intervals. A log file containing the position and orientation of the participant's head during the scenario was also stored but the tracking data was not used in the data analysis.

3.6 Interventions Coding

The audio and video recordings were systematically coded to identify actions that could be interpreted as interventions. Any action, verbal or physical, that was executed in order to catch the attention of someone else in the scene was considered an intervention. A verbal intervention was anything that the participant said to either the victim, perpetrator, or any other bystander that could be present if its objective was to catch their attention. This did not include utterances there were not directed at these characters (e.g. "think-aloud" utterances). A physical intervention was considered as any attempt to make physical contact with any other characters in the scene, such as reaching out to P, moving very close to him, walking in between victim and perpetrator to try to separate them, moving into P's field of view to catch his attention, waving a hand, or any other hand gesture that was not complementary body language.

Two consecutive actions were considered two different interventions if there was a gap between them of at least two seconds long, as per the interventions coding used by [Levine et al., 2011]. This is the minimum time established that a person takes to observe the situation after intervening and wait for a reaction before intervening again. Some participants carried on talking to either the victim, the perpetrator, or to both of them but if they did not stop for a moment to see the consequences of their interventions, then it was considered just one intervention. Our coding did not take into account the length of interventions. An example is the case when a participant moved in between P and V, but staying in that position was not counted as multiple interventions unless they stepped back and moved towards them again.

3.7 Chapter Summary

This chapter has outlined the common methods that were used in the experiments. It described the VR system used in all the experiments, the design and implementation of both the virtual bar where participants were placed and the violent emergency took place, the implementation of the characters' animation and audio recording, and finally the data that was collected and the methods of analysis. The next three chapters describe the experiments that were carried out in this research about how people respond to a violent emergency. The same scenario was used in all experiments with some variations, except for the experiment described in Section 6.2.

Chapter 4

Bystander Responses to a Virtual Violent Emergency

This chapter covers the initial pilot study and the first experiment of the series where participants were exposed to a social situation in which other people are present, all of them virtual characters except the participant. It is based on the preliminary results presented on the paper "The use of virtual reality in the study of people's responses to violent incidents" and the experimental results presented on the paper "Bystander responses to a violent incident in an immersive virtual environment". In the scenario, participants witnessed a situation where two people start arguing in a bar. What starts like a simple argument, escalates with one of them becoming increasingly threatening towards the other, until the point that it becomes physical violence. Participants had to decide whether to intervene, or, on the contrary, step back and do nothing about it.

The first goal was to assess the level of authenticity of the participants' behaviour during the violent emergency in order to understand what parameters would make people more likely to intervene in the following experiments. Participants subjectively rated how authentic their responses were during the violent emergency once the experience had ended. This first hypothesis was initially tested during the piloting that was carried out during the implementation stage. During this stage, attention was mainly directed at detecting possible technical issues that could affect the plausibility of the scenario. The experiment was aimed at manipulating

Figure 4.1: The intial version of the virtual bar where the violent emergency took place.

different parameters related to the victim of the aggression and studying how these changes influenced the likelihood of intervention from participants.

4.1 Initial Bar Scenario

For the initial piloting and the first experiment, both described in this chapter, the bar scene was adapted from a previous study about how people would respond to a fire emergency in a bar [Spanlang et al., 2007]. The 3D model was used without introducing any modification (Fig. 4.1), which looked more like a musical venue rather than a traditional English pub.

The animations captured as described in Section 3.2.1 were retargeted to two off-the-shelf aXYZ[1] characters (Fig. 4.2), in which the only modification involved the texture of one of them to make him wear an Arsenal F.C. shirt.

4.2 Piloting People's Responses to a Violent Emergency

25 volunteers were asked to experience an early version of the bar scenario described in Section 3.2. Volunteers were instructed that this was a pilot study and the scenario could contain glitches as it was still under development. The data

[1] https://secure.axyz-design.com/

(a) The victim. **(b)** The perpetrator.

Figure 4.2: Initial version of the 3D models used to represent the victim and the perpetrator.

collected during the piloting was only used to help us improve the scenario.

4.2.1 Variables and Hypothesis

The piloting was carried out while the scenario was under development to provide guidance towards implementing a realistic experiment, based on the feedback provided by the volunteers. The main manipulated variable was whether the victim looked at the participant a few times during the confrontation (LookAt = [On | Off], Fig. 4.4). When Lookat was enabled, the victim would look directly at the bystander five times, each time for two seconds. In the other version, the victim did not intentionally look at the participant at any time during the confrontation. The main hypothesis (and the goal of the piloting) stated that volunteers would have feelings that could be associated with witnessing a similar situation in the real world. These feelings include discomfort, anxiety and wanting to do something about it to either try to defuse the confrontation or escalate it.

4.2.2 Results

13 of the volunteers experienced the scenario with the glances activated (LookAt=on) and the remainder not (LookAt=off). Although in fact there is nothing that the participants could do to change the course of the argument, they did not know this, and so an attempt at intervention was certainly possible. We took as signalling an intervention a statement towards the virtual characters by the participant, a physical attempt to intervene by reaching out as if to touch one of the characters, or moving their body directly into the field-of-view of the characters, as explained in greater detail in Section 3.6. Also from the pilot studies we realised that non-intervention may be the realistic response for some volunteers – in a similar situation in real life they might not intervene. Of the 11 out of 25 who did intervene, 7 experienced the gaze condition and 4 did not. Three who did not intervene but said that they would not have intervened in reality were all in the version were the victim (V) did not look at them. The remaining 11 who did not intervene were almost equally divided between the two conditions. The verbal interventions that occurred were as follows, each statement made to the perpetrator (P):

- "Calm down mate, there is no problem here".
- "What's wrong with Arsenal?".
- "Come on mate, we were just talking about football". He also put his hand out trying to reach the perpetrator a couple of times.
- "Leave him alone"
- "Relax", and tried to reach him.
- "I don't think he was looking at you" and he tried to reach the victim.
- "Guys, there's no point to fight" and "Calm down".

General statements about their responses by the participants in the interview after the experience included:

- "The guy was overreacting, if it was a real situation I might have done more, I would have stopped it".
- "I had the same feeling about them as the feeling I had in a similar experience in the real life. I thought that they were acting stupidly".
- "I did not feel anxious, but it made me feel I had to intervene, I should say something".
- "First seconds of the conversation I was quite shocked".
- "I recoiled from both of them, I wanted to get away".
- "I had no feeling at all, but at the end, when the aggressor started acting wildly, I could feel my body temperature rising and the heartbeat rate slightly increasing".
- "I felt a bit uncomfortable. It was an intense clash between two people that does not make much sense to me".
- "I was feeling uncomfortable, not very pleasant being there".

- "I could feel my hands sweating".
- "I knew it was not real, so I did not want to intervene".
- "I felt a bit uncomfortable, I did not want to be there".
- "I felt a natural feeling that I wanted to do something".
- "I was quite scared that the aggressor would have turned around and looked at me. I felt like stepping into the discussion".
- "I was wondering if it was to involve me. I was feeling sorry for the guy with the red T-shirt. I thought I would have actually intervened (to test the system). I moved closer to the character to get into his field-of-view. I felt quite uncomfortable".
- "During the confrontation, I was trying to get involved, but there was a detachment when I saw no interaction from them. From this point I felt more as a spectator".
- "Put hand out a couple of times, trying to reach P".
- "I had this strong feeling that I had to intervene. I noticed that I was moving as if I was between the two and I had to step back. More people around would have made me less likely to intervene, because I do not want to embarrass myself".
- "I had the feeling that I wanted to do something, step in".
- "I felt this kind of paralysis when you are aware that something is about to happen, and you should do something, as in real life".
- "I was a kind of scared, I did not know what to do. I was thinking about whether to say something, but I was not sure if I could interact. I would have said something to defend the victim, like 'he was not looking at you'. I had the feeling that I could not interact with them, like I was watching a movie".

- "I was the third party in there, but I was ignored".
- "I stepped back, as I would do in real life".
- "I felt anxious. I was more concerned about my own safety than for victim".

We noticed very early during the piloting that participants invariably suddenly started to look around at some moment, and on questioning them they said that they were looking to see if someone else was around in the scenario. Ten out of the 25 volunteers did look around, and we asked them about this: "Did you look around to look for other people?"

- "Yes, when the confrontation starts, looking for an exit, to find somebody else to talk to, to break off from the Arsenal guy because it seemed it would escalate violently".
- "Yes, frequently, I was scared about the possibility that more people would come and escalate it".
- "Yes, I was just exploring".
- "Both for help and somebody who would have engaged in the discussion".
- "I looked around looking for the barman a few times".
- "Looked for other people to try to stop it".
- "I glanced around to see if other characters would be introduced to see if somebody else would step in, whether to escalate or de-escalate".
- "I looked around looking for somebody who might escalate the confrontation".
- "Yes. I was checking the perimeter whether there would be somebody else, for no particular reason".
- "I looked around looking for an authority".

We were not only interested about the reason why some people did not intervene, but also about whether volunteers who said something or reached out to them would have done it again. We asked: "What would have made it more likely for you to intervene?"

- "If there was more than one aggressor or the victim would have asked for help".
- "No, same in reality, I wanted to keep away".
- "I would not have intervened at all for any reason".
- "Nothing, I did not want to intervene".
- "I knew that I could not have any capability to do so, so I did not want to intervene".
- "If there were more people that I knew, or even more people in general".
- "If I had seen that it was a threat to myself".
- "If the victim would have asked for help or the aggressor would have been a threat to me".
- "I was expecting the victim to move away, but he did not do it. He did back up, but he did not move away".
- "If I would have known that my intervention would have changed something".
- "If the aggressor would have acknowledged me".
- "There was no reaction from the system".
- "If there had been tactile interface".
- "If the aggressor would have been smaller than me".
- "I was waiting for him (P) to start something with me. It would have been different if the victim was a woman. But this guy was Arsenal and he was not... friendly".

- "If I would have been more involved by the aggressor. I did not get any feedback from my intervention, so I became more passive".

- "They were interacting physically, so I do not think I would ever had intervened, since my intervention would have been physical and I knew that was not possible".

- "If there would have been a response from them to my interventions".

- "Nothing would have made it any more likely for me to intervene".

- "If they would have been more aware of me, or if the victim would have asked me for help".

The most common items that reduced the overall credibility of the scenario was that there was no interaction with the participant during the confrontation (7 participants mentioned this). Five stated that the dialogue itself was not realistic. When asked about technical issues that should be addressed to improve the overall realism, 10 drew attention to the lack of lip sync, 8 to the lack of realism of the hand movements, 5 mentioned the lack of eye blinking, and there were other comments made by individual participants. There were two fundamental conclusions from this set of pilot trials. The first is that, in spite of the technical issues (e.g., the lack of lip sync), a number of people did become quite involved in a realistic way in the scenario – they spontaneously made remarks (mainly to the perpetrator) that were clear signs of intervention. Many who did not intervene reported feelings and thoughts about intervention, or about their personal safety in that situation. The second major conclusion is that people were less likely to intervene if they knew (from a technical point of view) that their intervention could not achieve anything. This is a matter of Psi: their actions had no response, they moved into the field-of-view of the characters or attempted to reach out and touched the characters, or even talked to them, and nothing happened. As one participant said, once this point was realised the game was lost – the volunteer became a spectator rather than a participant. It has been observed in other experiments that PI can be temporarily broken (for example, by reaching out to touch an object and feeling nothing) but that it can quickly reform again once natural SCs continue to operate. However, once Psi is broken it typically does not form again – once Psi is lost the events in the scenario are no longer personally applicable to the participant (it becomes more like a movie) [Slater, 2009].

4.2.3 Discussion

The main conclusion from the pilot studies is that IVR can be used to carry out experiments to observe how a person responds to extreme situations where other people are present. It is arguable that the results obtained in an IVE can be compared to the results that would be obtained in an experimental setup with the help of real people performing the argument. However, an experimental setup using confederates and making participants experience a stressful situation does not meet the ethical standards required in present research studies. The general statements provide an insight into the feelings the volunteers had. The reported feelings can be considered to be close to those a person might have in the same situation if it happened in the real world, albeit this does not provide enough evidence how a person would respond to a real life event of this nature. Even though all volunteers knew that they were in a simulation, they described high levels of discomfort and talked about the other characters as if they were real, rather than considering them computer generated entities. Many of them also looked around to see if there was someone else present in the scene, which can be associated with realistic behaviour when facing an unexpected situation, especially an emergency: if one does not know what to do, his first reaction will be to look at what the other people are doing to evaluate the level of danger of the situation.

Their responses during the confrontation were also directed to either the victim or the perpetrator, talking to them the same way they would do to real people and expecting a realistic response from them. Despite that, the scenario was scripted from the moment when the confrontation started so that anything that people did could not change the course of events. This did not prevent people reporting a high level of authenticity in their feelings and responses. Confirming this point was critical in order to increase the validity of later experiments. Careful design of simulated environments, and implementations that give participants the belief that they can actually effect changes in the virtual world, and that spark physiological, emotional, behavioural and cognitive responses that are similar to what would occur in reality, present an interesting way forward in the study of extreme social situations.

4.3 Experiment. Bystander Responses to Victim's Affiliation

This experiment was the first formal study about people's responses in the violence scenario. It was designed to understand how manipulating certain parameters related to the victim of the confrontation would make participants more likely to intervene in order to try to defuse the confrontation (or to escalate it). The feedback provided by the volunteers during the pilots was invaluable data that helped to polish the scenario in order to maximize the authenticity of the participants' responses.

4.3.1 Experimental Variables and Hypothesis

The first goal was to confirm that the participants would feel the same degree of presence when exposed to the scenario as was obtained with the pilot volunteers, confirming the preliminary results of the pilot study. The expectations were that participants should have the illusion that the events they saw were actually happening, as observed in previous studies using IVR where a real person was placed in a scenario where virtual characters were present, for example in the virtual reprise of the Milgram's experiment [Slater et al., 2006]. Participants should have feelings about what was happening that were close to real, thus eliciting authentic responses.

Assuming participant's realistic responses, the experiment hypotheses were that the participant would be more likely to intervene if the victim was somebody that, despite being a stranger, had a shared social identity (in this experiment represented by being supporters of the same football team). The first experimental

Figure 4.3: Victim wearing a red shirt (a) with the Arsenal badge in the Ingroup version and (b) with no logos in the Outgroup version.

variable referred to the victim's affiliation, which could be either ingroup or outgroup (Fig. 4.3) in respect of the participant. In the ingroup version, he wore a red shirt with the badge of Arsenal F.C. at the level of the chest, actively considering himself a supporter of this team. During the conversation with the participant during the first half of the scenario, he asked questions about Arsenal, referring to them as *our team* and showing a lot of optimism about the team winning a trophy in the current season. In the outgroup version, the victim still wore a red shirt, but without any distinguishable sign about Arsenal. The conversation with the participant was still about Arsenal, but he referred to the team as *they*, and also showed indifference and skepticism towards Arsenal having chances of winning any trophy in the current season.

The second variable referred to whether the victim actively tried to look at the participant (Fig. 4.4), as was tested during the initial piloting, a feature we refer as *LookAt*. When LookAt was on, the victim looked directly at the participant 5 times during the confrontation, overriding the character's animation. Each time, the victim looked at the participant for two seconds and then, after that, it would go back to the scripted animation smoothly, interacting with the perpetrator. When the LookAt was not active, the victim's animation was not overridden by the head turn at any time. The victim might still look towards the participant, but it was only a coincidental occurrence.

Figure 4.4: Victim (a) looking at the participant (b) not looking at the participant at any time.

4.3.2 Experimental Design

The experiment used a between-groups design, with $n = 40$, 10 participants allocated alternately to one of the four cells of the 2×2 table as soon as they arrived at the VR laboratory. Upon arrival, they followed the standard procedures, as described in Section 3.4. All participants were between 18 and 34 years old with mean=23.5 ± 3.6, with no significant differences between experimental groups. Their level of support for Arsenal was at least 4 in a scale from 1 (not at all) to 7 (very much so) with an overall mean= 6 ± 1, following the standard recruitment procedure described in Section 3.4.1. All participants were naive about the experience when they first arrived at the laboratory and, even though it was made clear that they could ask questions before the VR exposure, they were told that some questions would be addressed at the end when the purpose of the experiment was explained. Each participant was payed £7 to compensate for their time (approximately 40 minutes) and the travel expenses to get to the university campus.

4.3.3 Results

The main response variable was the extent to which the participant attempted to intervene during the confrontation. The standard criteria to classify interventions was followed, as explained in Section 3.6. The data indicated that the numbers of verbal and physical interventions clearly followed different distributions, therefore they were analysed separately.

4.3.3.1 Number of Interventions

Table 4.1 shows the means and standard errors of the numbers of interventions indicating that the mean number of interventions was higher for the Ingroup than the Outgroup, but that the LookAt factor had no effect. Two-way analysis of variance was carried out on the response variables, the number of physical (nPhys) and number of verbal (nVerb) interventions. ANOVA for nPhys indicates that the mean is greater for the Ingroup than for the Outgroup condition ($P = 0.02$) but with no significant differences for the LookAt factor and no interaction effect. However, the residual errors of the fit were strongly non-normal (Shapiro-Wilk test (SW) $P = 0.0008$). To overcome this problem a square root transformation was applied to nPhys. This resulted in the same conclusions for group ($P = 0.016$, partial $\eta^2 = 0.15$) and no significance for LookAt ($P = 0.297$, partial $\eta^2 = 0.03$). The normality of the residuals is improved although not ideal (SW $P = 0.034$). For the response variable nVerb, the results were similar: ANOVA of nVerb on group and LookAt shows no significant interaction term, group has significance level $P = 0.095$, and for LookAt $P = 0.228$. However, again the residual errors are far from normal (SW $P = 0.0008$). The square root transformation gives $P = 0.060$, partial $\eta^2 = 0.10$ for group and $P = 0.112$, partial $\eta^2 = 0.07$ for LookAt. The residual errors are compatible with normality (SW $P = 0.24$). The factor LookAt represents whether the victim was programmed to occasionally look towards the participants. Additionally, the post-experience questionnaire included the statement (VictimLooked) "After the argument started, the victim looked at me wanting help" which was scored on a scale from 1 (least agreement) to 7 (most agreement). VictimLooked therefore represents the belief of the participants as to whether the victim looked towards them for help. There is no significant difference between the mean VictimLooked score of those who were in the group LookAt=on (mean=3.3, SD=1.8, n=20) and those in the group LookAt=off (mean=4.0, SD=1.5, n=20) (Mann-Whitney U $P = 0.12$). Hence the response to this question was not based

Group	LookAt		
	No. of Verbal Interventions		
	Off	On	All
Outgroup	3.9 ± 1.4	2.0 ± 1.3	2.9 ± 1.0
Ingroup	6.8 ± 1.8	4.7 ± 1.9	5.8 ± 1.3
All	5.4 ± 1.2	3.4 ± 1.2	4.4 ± 0.8
	No. of Physical Interventions		
Outgroup	2.8 ± 1.1	1.8 ± 1.0	2.3 ± 0.7
Ingroup	6.8 ± 2.1	6.1 ± 2.2	6.5 ± 1.5
All	4.9 ± 1.3	4.1 ± 1.3	4.5 ± 0.9

Table 4.1: Means and standard errors of the number of interventions.

on the number of actual looks of the victim towards the participant, and therefore was a belief. It turns out that VictimLooked plays a significant role in the number of interventions.

Figure 4.5 shows the scatter plots of nPhys and nVerb on the questionnaire response VictimLooked for the Outgroup and Ingroup. These reveal a quite different relationship in the two cases. In the case of the Ingroup there is a positive association between the number of interventions (verbal or physical) and the perception that the victim was looking towards the participant for help. In the case of the Outgroup there appears to be no relationship in the nPhys case and a possible negative relationship in the nVerb case. Using the same strategy as above in order to obtain residual errors compatible with normality, an analysis of covariance (ANCOVA) of $\sqrt{nPhys}$ on group with VictimLooked as a covariate shows that the slopes of the regression line are different between the Ingroup and Outgroup ($P = 0.004$, partial $\eta^2 = 0.22$ for the slopes, SW $P = 0.18$). For the number of verbal interventions, using $\sqrt{nVerb}$ the difference in slopes between Ingroup and Outgroup is significant at $P = 0.004$ (partial $\eta^2 = 0.22$ for the slope, SW $P = 0.12$). These results indicate that the response to the belief that the victim was looking towards the bystander for help was different between the Ingroup and Outgroup. For those in the Ingroup condition the greater their belief that the victim was looking to them for help the greater the number of verbal and physical interventions. For those in the Outgroup condition there is no such association. These results are further corroborated using multivariate analysis of variance on the response vector ($\sqrt{nPhys}$, $\sqrt{nVerb}$). These response variables are highly correlated ($r = 0.74$, $P < 0.00005$), and therefore a multivariate analysis of variance (MANOVA) with the joint response vector (nPhys, nVerb) should also be taken into account. The Doornik-Hansen test [Doornik and Hansen, 2008] rejects the hypothesis of bivariate normality ($P < 0.00005$) as would be expected from the two univariate cases. Following the same strategy as in the univariate case using a square root transformation on each of the variables gives a result compatible with bivariate normality ($P = 0.45$). MANOVA of ($\sqrt{nPhys}$, $\sqrt{nVerb}$) on group and LookAt gives a significance level for group of $P = 0.057$, and for LookAt $P = 0.282$ using Wilks' lambda. Including the covariate VictimLooked results in a significant interaction term between VictimLooked and group (Wilks' lambda, $P = 0.023$), showing that just as found in the univariate cases, the relationship between the response vector and VictimLooked is different between the Ingroup and Outgroup conditions. For those in the Ingroup the greater the belief that the victim was looking to them for help the greater the tendency for physical and verbal interactions, which was not the case for those in the Outgroup.

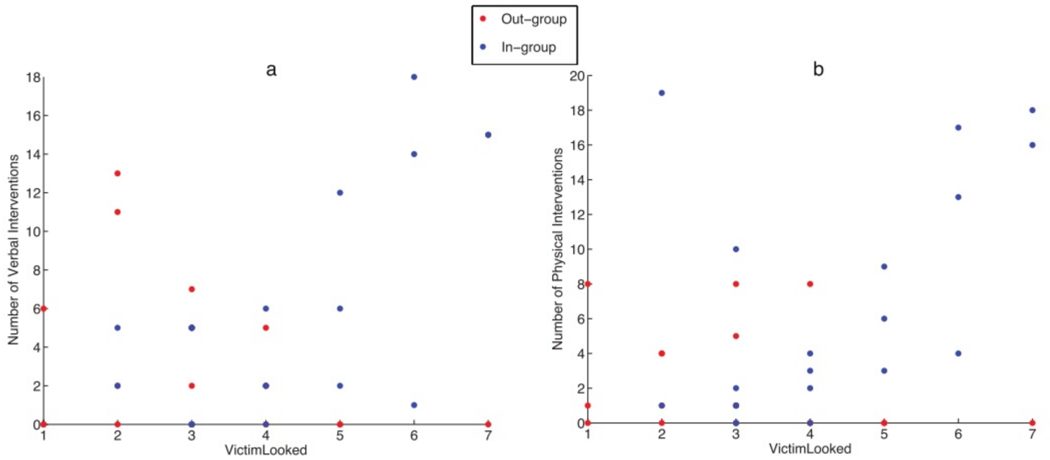


Figure 4.5: Number of interventions VictimLooked and Group. (a) For the verbal interventions and (b) for the physical interventions.

4.3.3.2 Interviews

After the experimental trial and the post-experience questionnaire, there was a short interview with the participants, followed by their debriefing where the purposes of the experiment were explained. The interviews concentrated on several main questions: their feelings and responses during their experience, the extent to which they judged their responses to be realistic, factors that might have increased their intervention, and factors that drew them out of the experience. Summaries of the interviews were coded into key codes and frequency tables constructed using the HyperResearch[2] software.

We consider first the responses and feelings of participants during their experience. Table 4.2 shows the codes and two example sentences of each code and Table 4.3 the code frequencies. The impression from the interviews as shown in Table 4.3 is that those in the Outgroup tended to sympathise with or feel sorry for the victim. Also many of them wanted to just leave the situation, felt uninvolved, or a few found the situation silly. For those in the Ingroup it seems to be more anger and frustration that could be the driving force of their intervention, and their response was more likely to be a confrontational one. None of them felt uninvolved, found the situation funny or silly, felt sorry for the victim or wanted to leave. Some of the

[2] http://www.researchware.com/products/hyperresearch.html

Ingroup expressed surprise at their own responses even though they were aware that it was virtual reality, whereas none of the Outgroup expressed such surprise. This fits with the fact that many of the Outgroup felt uninvolved and none of the Ingroup felt so.

Tables 4.4 and 4.5 give the results for the interview question regarding the authenticity of response in comparison with reality. We do not show the separate tables for Ingroup and Outgroup since there is no difference between them in this regard, although there is some suggestion of a difference between the LookAt groups. It seems that those in the LookAt=off group were more likely to remark on the lack of interaction, and to contrast their behaviour in reality and virtual reality. They were less likely to report their responses as being realistic. In the combined sample just over half found that their responses were realistic.

Participants were asked what might have increased or decreased their degree of intervention. The results are shown in Tables 4.6 and 4.7. Most frequently they said that if the setup had been more interactive (i.e., the characters responding to their actions after the argument had started) then they would have been more likely to intervene. There were two other aspects that are opposed. On the one side a number of participants said that they would have been more likely to intervene if the perpetrator had become more aggressive. On the other side some participants said that they might have intervened had the perpetrator been less aggressive. Others emphasised that had the victim explicitly called for help they would have been more likely to have intervened. Another important contributory factor could have been greater rapport – for example, the victim having been a friend – or someone in need such as a child.

Finally participants were asked to talk about technical factors that drew them out of the experience. Although there was no lip synch implemented or any other facial expression, it was barely noticeable when immersed in the environment with the life-sized characters. The combination of gesture and natural turn taking in conversation, amongst other things, are probably factors in making this glaring defect not noticeable. Only 5 out of 40 people mentioned the lack of lip sync and it was the fifth most mentioned aspect in this question. Table 4.8 shows the list of topics raised by the participants and the number of times they were mentioned. By far the greatest number of issues were concerned with the plausibility of the situation itself, and the technical factors tend to come down lower in the list.

Code	Example Statements
wanted to stop it	1. I felt like I would like to stop it (the confrontation) myself, basically back up the person that I was speaking to Arsenal about, protect him. 2. I wanted to calm him down. I wanted to separate them.
uncomfortable	1. I felt very uncomfortable. 2. I felt a little bit uncomfortable.
torn about intervening	1. I thought about intervening, do something about it, try to calm him down, but probably would have made it worse. 2. I wanted to do something, but I felt I probably couldn't and if I did, I might make things worse to myself. So I just tried to calm him down a little bit, but obviously he didn't want.
would avoid confrontation	1. I would avoid confrontation. 2. I would probably have walked out of the Cave, like I would have done in real life if there was a problem. I was a bit afraid of talking to the man with the white shirt, in case that he would interact with me and get aggressive.
even though VR	1. I knew it was VR, and I'm quite surprise how so angry made me feel, the other guy (P), ... I got to the point that I wanted touch him physically or pushing away I felt a bit frustrated I couldn't. 2. I was aware it was a simulation, and I was safe in that respect. I knew it was an aggressive confrontation and I think that has some impact and kind of made me a bit nervous.
anger	1. I was quite angry as well, about the way he (P) was treating him, the Arsenal fan. 2. I'm quite surprise how so angry made me feel.
frustration	1. I got to the point that I wanted touch him physically or pushing away I felt a bit frustrated I couldn't. 2. ...but it was a kind of frustrating I couldn't because I tried to speak to the guy (P) and he just ignored me.
anxiety or fear	1. Very similar feelings as in real life: flustered, panic, helpless and wanting to resolve the situation and not knowing how. 2. Frightened, I was feeling more alert, more mentally prepared for a fight.
helplessness	1. Helplessness, unable to help the Arsenal supporter. 2. Helpless because even if was to get involved, I don't know how useful I would be.
confrontational	1. I wanted to say I'm wearing an Arsenal shirt as well [he was], so your problem is with me as well, I was just criticising his argument basically. 2. I thought about punching the aggressor.
uninvolved	1. I felt like an observer all the time. 2. To be honest, with VR, I was quite divorced, I was just a kind of watching.
silly or humorous	1. I thought it was a bit silly. 2. Humorous.

concerned for or felt sorry for V	1. I was concerned for the safety for the man with the red shirt. 2. I felt a bit sorry for the victim, a little compassion for him.
wanted to leave	1. I did feel that I wanted to leave. 2. I wanted to leave I didn't want to get involved.

Table 4.2: Codes for the interview questions: What feelings/responses did you have while this was happening?

Code	**Frequency of Statement**	
	Outgroup %	**Ingroup %**
wanted to stop it	16	18
uncomfortable	2	9
torn about intervening	11	13
would avoid confrontation	5	2
even though VR	0	7
anger	0	7
frustration	0	7
anxiety or fear	14	18
helplessness	7	7
confrontational	7	13
uninvolved	11	0
silly or humorous	5	0
concerned for or felt sorry for V	16	0
wanted to leave	7	0
TOTAL no. of statements	44	45

Table 4.3: Frequencies of the codes in table 4.2.

Code	**Example Statements**
realistic or quite realistic	1. I think that's what I would do in real life. 2. Pretty authentic. I've been in situation like this before, and run your mind afterwards think 'I could have done this, I could have done that, or I should have done this'. but at that time you feel like a deer in the headlights, you are sort of frozen.
lacked interaction	1. The fact that he (P) didn't recognised me when he came over, I felt I was just watching. 2. I behaved as in real life up to the point that I realised that there was no reaction from them.
contrasts VR and reality	1. In real life, I would try to put some distance between them and me, pub fights might be tricky, they might have weapons. 2. I thought about it, but I wasn't sure if they would respond to me. Anyway, in real life I would probably have not intervened.
detached	1. I was completely detached. 2. It was not authentic at all.

Table 4.4: Codes for the interview question: Were your responses realistic?

Code	**Frequency of Statement**		
	LookAt off %	**LookAt on %**	**Combined %**
realistic or quite realistic	44	62	52
lacked interaction	15	5	10
contrasts VR and reality	37	24	31
detached	4	10	6
TOTAL no. of statements	27	21	48

Table 4.5: Frequencies of the codes in table 4.4.

Code	**Example Statements**
	Aspects that would have increased intervention...
call for help	1. If the guy who was threatened would have directly spoken to me. 2. If V would have looked at me and said something to me at some point, something like this "Can you believe this guy?"
more interactivity	1. If P would have said anything to me. 2. If there had been a reaction from them to my first interventions.
more aggression	1. If the aggressor started punching, if the situation would become more physical. 2. If it had turned physical, I would have stepped in. If there was another person joining, I would have definitely stepped in.
more rapport	1. If it was a child against a man or a woman against a man, or even if he is a stranger if I maybe spent a match or discuss the football before hand, so there a was a bit of relationship. 2. If the victim was my friend, probably if there was a connection between him and I.
more realism	1. A greater degree of realism.
safety of intervention	1. Maybe if the person with the white shirt would have been less aggressive. 2. If P would not have said that he hated Gooners, or if there were more Arsenal fans around.
	Aspects that would have decreased intervention...
knew it was VR	1. I knew I was in virtual reality, I wouldn't intervene because I didn't know if I had to. 2. Deep down I knew it was virtual reality.

Table 4.6: Codes for the interview question: What would have made it more likely for you to intervene?

Code	**Frequency of Statement**
call for help	11
more interactivity	41
more aggression	16
more rapport	11
more realism	3
safety of intervention	11
knew it was VR	8
TOTAL no. of statements	37

Table 4.7: Frequencies of the codes in table 4.6.

Topic	**No. of people**
No other people around	9
The pub does not look like a real English pub	7
Dialogue with the victim not realistic	7
No response from characters during the argument	6
No background noise or music	5
No mouth movement of the characters	5
Lack of sense of touch	5
Animations not smooth	5
Cave walls and edges visible	4
Aggressor appears from nowhere	3
Mirror on top not appropriate	2
Illumination not realistic	2
Victim appears from nowhere at the start	2
Anatomical proportions of the characters	2
No bar staff	2
Clipping (part of a character going out of view)	1
Lack of sense of smell	1
The victim was too defensive	1
Victim looks ghostly due to Cave rendering	1
Lack of Facial Animation	1
TOTAL no. of statements	71

Table 4.8: Frequencies of statements in response to the interview question: What factors tended to draw you out of the experience?

4.3.4 Discussion

The principal finding of this experiment with respect to the bystander issue is that participants in the Ingroup condition made more attempts at physical and verbal intervention than those in the Outgroup condition. A second finding is that for those in the Ingroup the number of verbal and physical interventions were associated with the belief that the victim was looking towards them for help. This second finding relies on the important distinction between the experimentally manipulated LookAt factor, and the questionnaire report after the experiment about how much the subjects thought that the victim was looking towards them for help, rather than the victim actually looking at them. The belief that the victim was looking towards the participant for help had a differential effect depending on group. For those in the Ingroup condition, if they believed that the victim was looking towards them for help their number of interventions tended to be greater. For those in the Outgroup condition this relationship did not occur. This would not be surprising if it occurred in reality. If you consider you have a group affiliation with someone and that person is looking to you for help surely this would be a more important event, more likely to move you to action, than if someone with whom you have no affiliation looks towards you for help. It is especially striking then that this also occurs in IVR (where the only real people were the participants themselves): the more that the participants believed that the victim was looking towards them for help the more often did they intervene – but only those in the Ingroup condition.

An important issue is the extent to which these findings are generalisable. We have shown an example where the group affiliation was a real one: strong supporters of a particular football team. This is unlike many laboratory-based experiments where an abstract group affiliation is created for the purposes of the experiment. Our experimental manipulation involved activating the Arsenal affiliation through the victim wearing an Arsenal football shirt, and talking enthusiastically about the club (Ingroup). The affiliation was not activated for those in the Outgroup condition, since the victim was not wearing an Arsenal shirt, and did not engage in enthusiastic conversation about the club. Our interest focused on the extent to which this activated (or not) psychological group affiliation impacted intervention behaviour. Our procedure was therefore designed to generate meaningful psychological group membership – the Arsenal fans were representative of a particular group. Our claim is that it is the perception that the victim belongs to the same group as the participant (in this context he was 'one of us') that leads people to be more likely to intervene. Hence our general hypothesis is that had the group identification been through some other means (social class, race, members of a tennis club, or even arbitrary groups conjured for an experiment) the results would have been similar.

Now we consider how our experiment could be improved. In [Slater, 2009] the concept of Plausibility of experiences in IVEs was introduced, referring to the illusion of participants that the virtual events are really happening (even though they know that this is not the case). It was argued that plausibility depends at least on three factors: (i) the extent to which there are events that refer personally to the participant, (ii) the extent to which the environment responds to actions of the participant, (iii) and the credibility of the scenario in terms of how much they fit expectations from a similar situation in reality. With respect to the technical setup there were no differences between Ingroup and Outgroup, and this is reflected in the fact that there are no differences in reported responses and feelings elicited through the interviews. However, the evidence does suggest (Table 4.4) a greater tendency for the group with LookAt to say that their responses were realistic, and for those without LookAt to mention the lack of interaction. This is consistent with (i) above.

An aspect of plausibility that would need to be improved based on the results of this experiment is the credibility of the scenario itself (iii). As seen in Table 4.8 the types of factors that drew people out of the scenario were to do with the setting rather than the technical aspects of the display: no other people around in the pub, it did not look like a real English pub, and the dialogue with the victim itself not being realistic. More than 50% of the statements made in Table 4.8 refer to these types of general credibility, and the remainder are specific technical issues such as 'Illumination not realistic' or 'Lack of facial animation', none of which were commonly stated. By technical issues we refer to aspects of the scenario that require only programming to solve (such as the provision of lip sync). By more general credibility issues we refer to the simulation itself – aspects that require a better understanding of what needs to be there for this to be believable as a fight in a London pub.

Apart from the introduction of interactivity and other issues relating to credibility, there are several improvements for later versions of this experiment. For example, we have not said anything about the role of the social identity of the perpetrator with respect to the participant. Moreover there are clearly other issues involved – such as participant fear of being harmed by the perpetrator or the number of bystanders present in the scene. Changing the level of danger is not addressed in this thesis, but could also be easily incorporated into an experiment through manipulation of the appearance of the perpetrator (for example, to look more or less menacing). The next chapter contains an experiment that investigates the impact of the number of bystanders and their affiliation on the participants' responses.

We have shown that IVR can be usefully exploited to study the likelihood of bystander intervention in interpersonal violent incidents. The paradigm allows the investigation of what participants actually did and think during an experience involving violence rather than their opinion of what they might do or what they think others might do – whether based on watching a video or on a verbal description of a situation [Banyard, 2008]. Of course, there is still no proof that what participants would do in a physically real situation would match that which we find in virtual reality. However, as reported in Section 2.2 there is evidence to suggest that people do respond realistically in IVEs. In fact since these experiments can never be carried out in reality, ultimately the question of the validity of people's responses to the virtual situation cannot be known through laboratory-based experiments of any kind. However, our approach can be used in the process of constructing theories, that can then be further tested with the use of experiments in VR, and moreover ultimately examine how well these theories fit what might be found in actual experiences in the field.

To conclude, the results presented in this chapter open the possibility not only to use this experimental framework to study people's responses to social situations, but also to design situations in order to elicit certain types of behaviour. This includes encouraging pro-social responses in situations where a person needs help from bystanders, as well as preventing people to put themselves in danger when trying to assist somebody who needs help. The experiment showed how the helping behaviour is increased by manipulating the social identity of the people involved, but this also leaves the question of what would make people show more proactive behaviour in order to help others who are not ingroup members.

4.4 Chapter Summary

This chapter has covered the development and testing of the first version of the bar scenario during the piloting, including the first experiment. In the scenario, participants witnessed a violent outbreak between two life-size virtual characters in an IVE. The feedback provided by the volunteers during the piloting helped refine the scenario to achieve the necessary level of realism to elicit authentic responses from participants.

The findings in the first experiment confirmed that IVR can be used to carry out experiments studying human behaviour that, for either technical or ethical reasons, cannot be implemented in real life with the use of confederate actors. In the bar scenario, people responded to a violent emergency and the number of interventions (especially physical interventions) was directly related to whether the participant had a shared social affiliation with the victim of the aggression. However, regardless of the social identity of the victim, participants showed signs of discomfort when witnessing the two virtual characters arguing. Some participants thought it was infuriating to hear someone being derogatory of the football team the participant supported; other people felt sorry about the person being bullied, even though both victim and perpetrator were computer-generated characters.

The experiment described in this chapter has focused on the social identity of the victim of the aggression but it is easy to see that many other parameters that were not tried could have made an impact on the participants' responses. A major benefit of using IVR for these types of studies is that it is very easy to control and manipulate many different variables. For example, in our bar scenario currently the perpetrator is quite large and looks dangerous, but it would be straightforward to make him look smaller and weaker, keeping the rest of the scenario identical. How would that affect the propensity to intervention? We can also manipulate specific elements in the environment keeping all else constant in order to study which parameters have a stronger influence on the bystander's likelihood of intervention in a violent emergency.

As this was the first experiment in the series, a lot of attention was paid to the details that could be improved to make the scenario more believable, and this knowledge was used to prepare the scenario for future experiments. The next two chapters describe experiments that were aimed at testing new experimental parameters such as the number of bystanders present in the bar, in order to investigate not only whether the bystander effect (Section 2.1.3) occurs in an IVE, but also to study whether their presence and their social identity can encourage (or diminish) pro-social behaviour.

Chapter 5

The Bystander Effect in Immersive Virtual Environments

This chapter describes two experiments carried out with a visually enhanced version of the bar scenario and the virtual characters, compared to the ones used in the experiments explained in the previous chapter. Taking into account the feedback provided by the people who participated in the previous experiment (Section 4.3), the bar was refurbished in order to look more like a traditional English pub, including several objects related to sports. The virtual characters were also replaced by new models with higher degree of visual realism, as well as including new features such as mouth animation for the lip synch.

The first experiment examines how an upgrade to the VR system have an impact on the people's responses to the violent incident. This upgrade provided a rare opportunity to observe the behaviour of participant changing only one component of the system and keeping all else identical, including the scenario. The upgrade refers to the replacement of the old CRT projectors used in the Cave for new DLP ones with higher luminance and pixel resolution. The goal was to observe whether this change, that could be associated with higher degree of PI, would make people behave differently. The results were published on the "The impact of enhanced projector display on the responses of people to a violent scenario in immersive virtual reality" paper.

The second experiment aimed to observe whether the bystander effect also occurs in an IVE. The bystander effect predicts that the likelihood of intervention by any bystander in an emergency situation is inversely proportional to the number of bystanders present in the scene. So, the higher number of people witnessing the events, the less likely that anyone will do something about it. The study does not only study the effect of the number of bystanders, but also explores whether their social identity and their behaviour have an impact on the participants' responses. The results of the second experiment are presented in the paper with title "Bystander Affiliation Influences Intervention Behaviour – An Immersive Virtual Reality Study", under revision at the time of printing this thesis.

5.1 Improved Bar Scenario

The virtual bar was redesigned to make it look like an English pub with decorative elements related to football (Fig. 5.1). To look like a realistic pub interior, the new bar contained three football related posters on the walls depicting the English national team indicating that the pub is football themed, but not affiliated with a particular Premier League team. Some shelves were also added with some trophies that could be associated with sports events. The scene was lit to realistically simulate soft ceiling lighting to enrich the visual quality and enhance the realism of the scene. Lighting was also rendered artificially bright in order to compensate for the darkening effect of the stereo shutter glasses. The radiosity solution was baked onto the textures of the final bar model. All modelling, texturing and skinning tasks were performed in Autodesk Maya[1]. A TV with a sport magazine program showing was also added in order to provide some background noise.

The virtual characters were revamped at the same time that the virtual bar was redesigned. For the new version, a 3D modeller was hired to carry out this task and, with the help of colleagues from Bournemouth University, two new characters were created from still pictures taken of two volunteers (Fig. 5.2). A set of high resolution photographs from 8 angles of both full body and face close-up (16 in total) were collected for each of 28 participants. From this set, two Caucasian male

[1] http://www.autodesk.co.uk/products/maya/overview

Figure 5.1: The visually improved version of the virtual bar where the violent emergency took place.

characters were chosen of similar age and height as the victim and perpetrator (Fig. 5.2). The new 3D models also included facial bones in order to implement lip sync, which was a feature the previous setup did not have (Fig. 5.3).

The face and body of each character was then modelled by perturbing the vertices of a compatible base mesh to align with the projected silhouette of each image. Particular attention was paid to the placement of extraordinary vertices behind the ears in order to reduce rendering artefacts. In order to ensure that clothing was interchangeable to account for experimental variations, texture parameterisations of the shirt, legs and shoes were made compatible. Both characters were skinned using compatible skeletons consisting of the same skeleton structure. Roll bones were used to distribute arm and leg rotations in order to reduce twisting artefacts during animations (Fig. 5.3).

Eye gaze was implemented along with the head turn, adding a simple "slow in, slow out" interpolation model [Kochanek and Bartels, 1984] to ensure that activation of the gaze function was smooth. In this model, a looking action follows a simple state machine: (a) the eyes rotate towards the target; (b) when the eyes are at their maximum extent, both the head and eyes rotate towards the target; (c) when

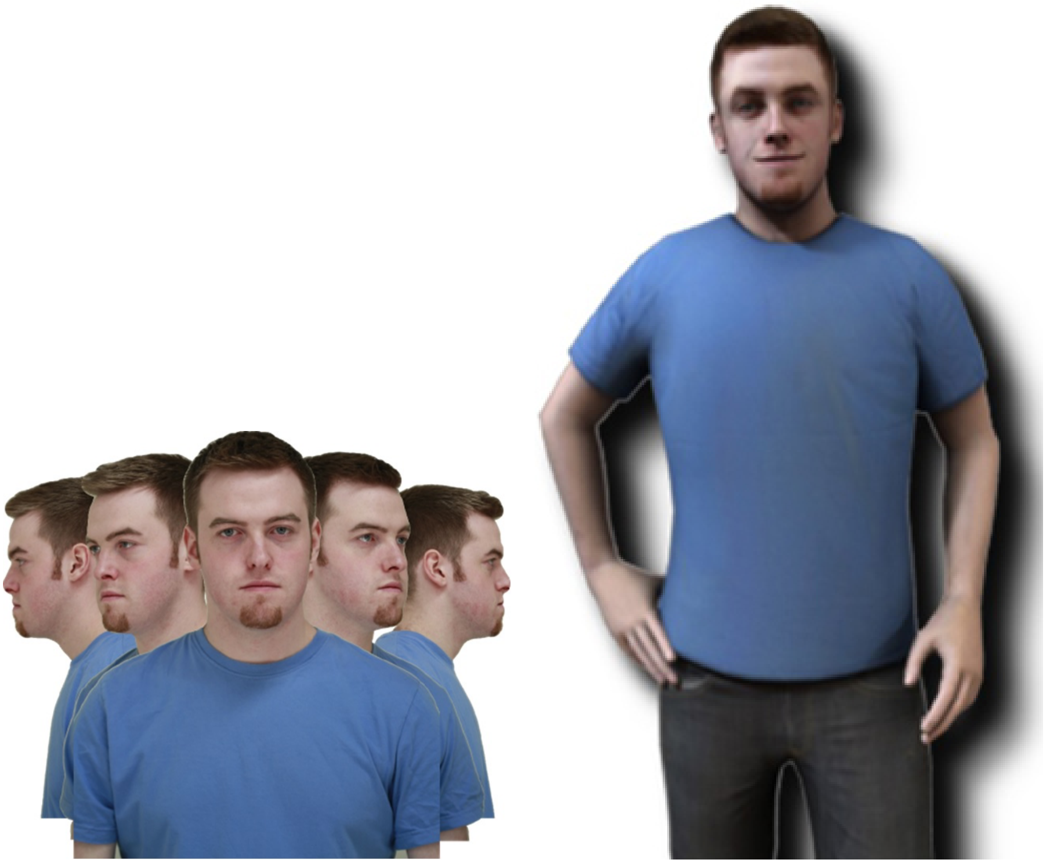


Figure 5.2: Latest version of the perpetrator 3D model created from still pictures taken from different angles.

the eyes reach the target they lock on, and the head catches up. The speed of the looking function was also made parameterisable.

5.2 Experiment. Displays Luminance and Pixel Resolution

During the time of this research, the Cave that was used for the experiments underwent a major upgrade. All four CRT projectors were replaced by a new set of DLP ones, as described in Section 5.2.2. At the time of testing the new projectors, it was obvious that the illuminance was significantly increased, in conjunction with higher pixel resolution, keeping the displays size constant.

In this experiment we considered the impact of a global improvement in the display characteristics of the virtual reality system, while holding all else constant

(a) The victim. **(b)** The perpetrator.

Figure 5.3: Improved version of the 3D models used to represent the victim and the perpetrator.

– including the content and rendering of the scenario. In particular the focus of this experiment is on the impact on responses of participants to the changes caused by an upgrade to the projector system. Note that this is not concerned with realism of illumination as in other papers [Zimmons and Panter, 2003, Yu et al., 2011], nor on behavioural realism [Garau et al., 2003, Bailenson et al., 2005] but purely is concerned with the characteristics of the display.

5.2.1 Experimental Variables and Hypothesis

There was one experimental variable that referred to the projectors that were used to display the scenario (Fig. 5.4), with two factors, Pre-upgrade and Post-upgrade. In the Pre-upgrade version, the set of CRT projectors were used. Post-upgrade meant that the DLP projectors were installed and had replaced the old projectors. The initial hypothesis was that, even though the behaviour of the virtual characters remains the same, the higher levels of illuminance and image resolution reducing the pixel size could have an impact on the people's responses to a violent emergency. This result would be in accordance that higher pixel resolution would increase the sense of Presence, or PI, as illuminance could be adjusted closer to natural light and pixel size would make the imagery look smoother.

5.2.2 Cave Projectors

The original set of projectors were four SEOS Prodas, which were basically a modified version of the Barco 808. They were based on CRT technology with a refresh rate of 90Hz. Maximum resolution was 1024×768 and manufacturer's stated luminance was 1250 Lumens. With the maximum resolution used, pixel size on the walls was 2.8×2.9mm. On the floor, the pixels were stretched to cover the entire surface, therefore the size of each one was 3.9×2.9mm. One of these projectors is shown in Fig. 5.4, on the left side of the image. At the time of their decommission, these projectors were 11 years old, although the tubes had been replaced on a 3 to 4 year interval.

The new projectors are Christie DS+6K-M as shown on the right side of Fig. 5.4. They provide images with a 1440×1050 pixel resolution at a refresh rate

Figure 5.4: Projectors used in the Cave system. An old CRT projector on the left part of the picture and a new DLP one in the right side.

of 100Hz. The luminance provided in single lamp mode is 3150 Lumens. The image projected on the floor needs to be cropped to 1100×1050 to adjust it to the surface dimensions, since in DLP projectors pixels cannot be stretched. That also leaves a blank stripe on the floor at the entrance of about 15cms wide. Pixel size is approximately 2.1×2.1mm on the walls and 2.7×2.7mm on the floor.

5.2.2.1 Differences in the Projector Display Characteristics

Taken at face value, the luminance data suggest that for participants in the post-upgrade group, the illuminance was 2.5 times greater than for pre-upgrade. However there are many other factors that should be considered. Firstly, it is likely that manufacturer specifications will tend to be maximum achievable values. The luminance figures for both sets of projectors would be moderated by the actual images projected for the scenario and this was the same for both sets of projectors. Likewise, illuminance is a function of the transmission of light by the rear-projected screens (or the reflection of light by the front-projected floor screen), so also there would be the same effect for both sets of projectors. However the following aspects would not be the same:

- The DLP projectors used for the post-upgrade setup operate at almost maximum power all the time (notwithstanding small reductions to accommodate colour balance across the 4 projectors). This is not the case for the CRT projectors used for the pre-upgrade setup, for which running at maximum power can burn out the phosphor of the CRTs very quickly. A rough estimate is that they operated at 75-85% of their maximum output.

- The phosphor on the surface of the CRTs of the projectors had deteriorated (they were 4 years old) and so this would have further reduced luminance.

- The luminance from projectors is also affected by the lens used – it is hard to say how much this affects either the DLP or the CRT projectors. One obvious reduction in luminance will have come from the blanking of part of the image of the DLP floor projector (post-upgrade).

The accumulated effect of these differences most likely accentuates the difference between the two sets of projectors (i.e. the ratio of luminance values is likely much greater than 2.5) since the factors stated above affect the CRT projectors more than the DLP projectors.

However, there is a further confounding aspect to this comparison, since we are really concerned with the perceived difference between the two sets of projectors. Even carefully-measured illuminance values cannot provide an accurate comparison. At the start of each trial, the participants experienced the virtual scenario for one minute at least before the victim entered. During this time their eyes would have adapted, to some degree, to the lighting levels of the projection setup used.

The combination of higher illuminance and smaller pixel size in the DLP projectors produces an image that is obviously clearer and more detailed than that of the CRTs, but it is not sufficient to describe this in a quantitative way. The DLPs are around 2.5 times brighter, and have almost double the number of pixels, than the CRT projectors; but how exactly this affects the perception of the images and the responses to a virtual environment is less quantifiable. We can speculate as to how the greater detail that can be perceived enhances our responses to the virtual world. For example being able to see facial expressions in greater detail might encourage more empathic responses to virtual characters, while a reduction in clarity or resolution might tend to break the illusion of the virtual world.

5.2.3 Experimental Design

20 male participants, all of them strong Arsenal supporters, were recruited using the standard recruitment procedure (Section 3.4.1) and assigned arbitrarily to one of the two groups. The pre-upgrade group's degree of support for Arsenal was between 4 and 7 and the post-upgrade group between 5 and 7, with no significant difference between the groups. The age distribution of both groups was between 18 and 34 with no differences between them.

5.2.4 Results

The response variables were counts of the number of physical (nPhys) and the number of verbal (nVerb) interventions. Box plots of the numbers of responses are shown in Fig. 5.5. It can be seen that the distributions are highly skewed and are not Gaussian. In fact count data response variables are appropriately analysed using a log-linear Poisson regression model of the form:

$$\log(\mu_i) = \beta_0 + \sum_{j=1}^{k} \beta_j x_{ij}, i = 1, ..., n \tag{5.1}$$

for n observations on the response variable $y_i, i = 1, ..., n$ and k explanatory variables $x_{i1}, ..., x_{ik}$ and each y_i being independently Poisson distributed with the expected value $E(y_i) = \mu_i$ [McCullagh and Nelder, 1989].

The independent variable here is the binary variable Upgrade (pre-upgrade=0, post-upgrade=1), $n = 20$ (10 in each upgrade condition) and the explanatory variables are the questionnaire responses. These are included in order to take account of any potential interpersonal differences between the two groups in their subjective responses to the scenario. The response variable was the number of interventions. As in all other experiments, interventions were divided into verbal utterances (nVerb) and physical actions (nPhys) and studied separately.

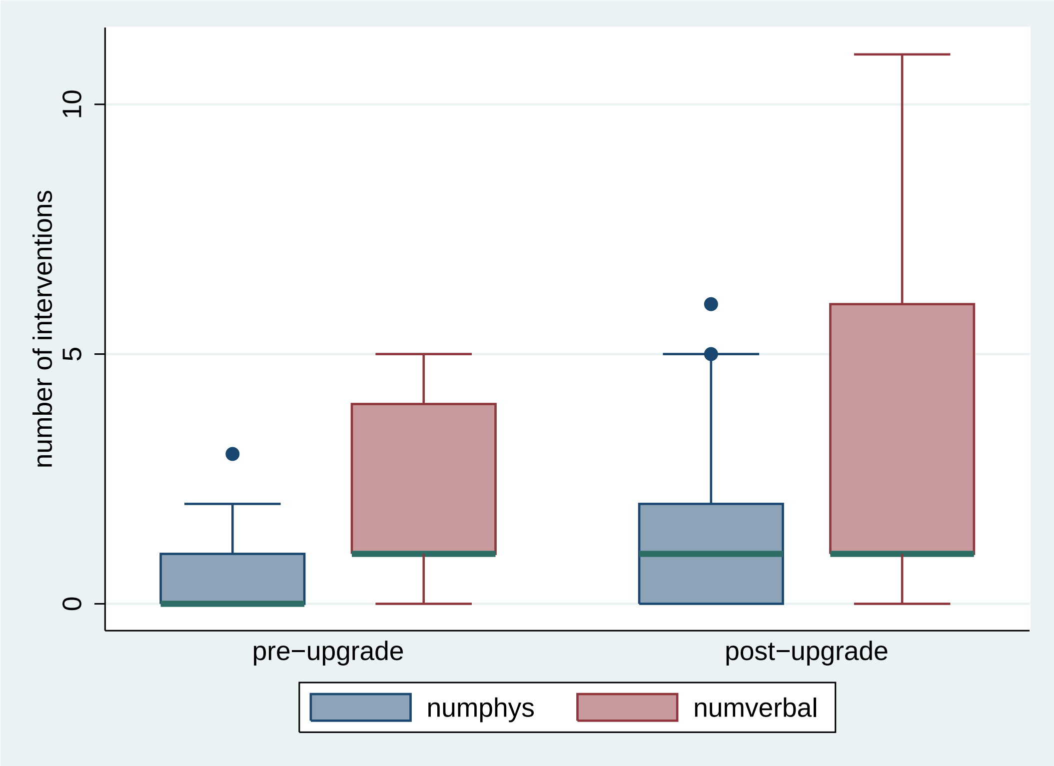


Figure 5.5: Box plots of the numbers of interventions by Upgrade. The median is shown as the thicker line, and the box is the interquartile range. The bars extend to 1.5 the interquartile range. Points outside of the bars are shown as dots.

In order to identify the minimal set of right-hand side variables to include in the model we adopted a highly stringent stepwise approach. A stepwise regression starts by including in the fit all the variables, and then iteratively removes variables with significance $P < \alpha_1$, but includes variables which if added would have significance $P < \alpha_0$, typically with $\alpha_0 < \alpha_1$. Here we chose $\alpha_0 = 0.005$ and $\alpha_1 = 0.01$. The analysis was carried out using the Stata 12[2] stepwise procedure with Poisson regression. All variables, both Upgrade and the questionnaire variables were of the same status in terms of inclusion or not in the final regression, so that were Upgrade to be included this would be entirely the result of the stepwise procedure and was not predetermined.

The results are given in Table 5.1. It can be seen that the stepwise procedure includes Upgrade for both response variables, and that the post-upgrade condition is significantly and positively associated with the number of interventions. Also in

[2] http://stata.com/stata12/

the case of both responses, being uncomfortable was positively associated with the number of interventions. The feeling of wanting to move away from the virtual characters (MoveAway) was negatively associated with the number of physical interventions. However, the belief that the perpetrator was aware that the participant was looking at him (MeLooking) was associated with an increase in the number of verbal interventions. Fear by the participants for their own safety was associated with a decrease in the number of interventions. In each case the greatest contributor in absolute terms was Upgrade, which has the greatest absolute coefficient, which is especially the case for nPhys.

Variable	**Coeff. (β)**	**S.E. (β)**	**P**	R^2	$\chi^2(16)$
nPhys:				0.42	13.0, P=0.68
Upgrade	2.44	0.62	<0.0005		
MoveAway	-0.56	0.17	0.001		
Uncomfortable	0.61	0.20	0.003		
β_0	-2.65	1.23	0.031		
nVerb:				0.33	23.5, P=0.07
Upgrade	1.07	0.37	0.004		
Uncomfortable	0.61	0.15	<0.0005		
MeLooking	0.97	0.22	<0.0005		
OwnSafety	-0.70	0.24	0.004		
β_0	-2.79	0.85	0.001		

Table 5.1: Poisson log-linear regressions of nPhys and nVerb on the independent variable upgrade, and the questionnaire variables from Table 3.1. The final result is from a stepwise regression with bidirectional elimination with inclusion significance level of 0.005 and exclusion significance level of 0.01. R^2 is the pseudo multiple squared correlation which indicates the proportion of variance in the response explained by the model. χ^2 is a test of goodness of fit of the model, based on the deviance of the fit, with 16 d.f. Low values of χ^2 (greater values of associated P) indicate a good fit.

It should be noted that if we choose still more stringent values for the inclusion significance level α_0 and the exclusion α_1 we get very similar results. For example, consider $\alpha_0 = 0.001$ and $\alpha_1 = 0.005$. In the case of nPhys the final model fit includes upgrade ($P = 0.001$) and MoveAway ($P = 0.001$). In the case of nVerb the fit does not change.

One caveat that is sometimes argued (appropriately) is that for stepwise fits the final significance values are not strictly valid, since there would have been several significance tests during the stepwise fitting process. In fact in the case of nPhys there were 12 iterations (removal and addition of a variable) before reaching the final fit, and in the case of nVerb there were 9 such iterations. So even if we go to the extreme of adopting the Bonferroni correction of dividing the traditional 0.05 significance level by 12 and 9 respectively, the results are still well into the usual significance zone.

Table 5.2 shows the marginal predicted mean number of interventions, that is, after the elimination of the effects of the questionnaire variables. The results emphasise the relatively large change in the predicted number of interventions for the post-upgrade condition compared to the pre-upgrade, other things being equal.

Condition	Predicted Mean	S.E.	95% CI
nPhys:			
Pre-upgrade	0.42	0.16	0.10 - 0.74
Post-upgrade	4.85	2.06	0.81 - 8.90
nVerb:			
Pre-upgrade	1.48	0.34	0.82 - 2.14
Post-upgrade	5.14	1.22	2.75 - 7.53

Table 5.2: Predicted Marginal Number of Interventions eliminating the effect of the questionnaire variables.

5.2.5 Discussion

The results show a significant difference in the number of interventions between groups. The number of both physical and verbal interventions tends to be higher in the post-upgrade version of the scenario (others things being equal). The Upgrade variable is the one with a stronger effect on the number of interventions, but others extracted from the questionnaire are also important. For example, the feeling of being uncomfortable with the situation or whether the participant thought the aggressor knew he was looking at him are positively associated with the number of interventions as well. Other variables had the opposite effect. Participants who reported a strong feeling of wanting to move away or those who were concerned about their own safety intervened less.

The results of this experiment can be also put into the context of the PI and Psi paradigm discussed in [Slater, 2009]. PI was argued to occur when sensorimotor contingencies SCs match those of real life. In particular with head-tracked virtual reality participants can perceive the world visually through close-to-normal use of their head to change gaze direction. However, SCs also depend on the display characteristics. If moving the head towards a virtual object reveals its pixelated structure this does not conform with expectations from (SCs) in reality. Here both the luminance was greater and the pixels were smaller in the post-upgrade condition compared to the pre-upgrade. We speculate that the different behaviour in the post-upgrade setting was likely due to a greater sense of being there, a component of presence, that participants would have likely felt compared to those in the pre-upgrade condition.

Special attention needs to be given to what technology is being used, since different results might be obtained from different setups and these could differ in important ways from the results obtained from real-life based experiments. The change in our projector system offered us a rare and valuable opportunity to examine the impact of such a global change in the display while holding all else constant. This has allowed an interesting insight into how such changes can apparently result in changed participant responses.

5.3 Experiment. The Bystander Effect

The experiment described next also used the visually enhanced version of the bar scenario, as described in the previous sections. The only addition was three extra virtual characters in the bar. The main goal in this experiment was to observe whether the presence of others would make the participant less likely to intervene, as the bystander effect predicts. The results obtained from the 10 participants who experienced the post-upgrade version in the previous experiment were compared to the results obtained in this one, which were carried out with one week's difference. We also studied whether the bystanders sharing a social identity with both the participant and the victim of the aggression, here defined as supporters of the same football team (Arsenal F.C.), would influence the people's responses compared to the same situation where the virtual bystanders could not be associated with any football team in particular. The last scenario manipulation was whether the virtual bystanders encouraged or tried to dissuade participants from intervening by means of two utterances during the confrontation.

5.3.1 The Virtual Bystanders

Three new virtual characters were added to the scene. Initially they were all sitting by the tables on the background and watching the TV program. Their jerseys were changed according to the experimental condition. They remained passive during the initial conversation between participant and the victim. When the perpetrator and the victim started the argument, they became more alert, looking directly to the people involved in the confrontation.

Right after the bystanders expressed their surprise about the situation for the first time, one of the bystanders stood up and moved close to where the participant was. If the participant looked directly at the standing virtual bystander at any time, the bystander would look back at him and shrug to provide a simple cue of interactivity, but he did not take any further action. The remaining seated bystanders uttered three times in order to try to influence participants' responses. When one uttered something, the other turned his head to look at him.

5.3.2 Experimental Variables and Hypothesis

This experiment was designed as a $2 \times 2 + 1$ experiment. We first looked at whether the presence of three virtual bystanders influenced the participant's responses. We used the data collected from the participants in the previous experiment that experienced the scenario with the new DLP projectors and compared it to a group of participants with the same system characteristics but including the virtual bystanders in the scene. The second part of the study looked at the participants' responses depending on whether the bystanders could be identified as ingroup members or, otherwise, were outgroup (Fig. 5.6). In the Ingroup version, all three bystanders were wearing the official Arsenal jersey, while in the Outgroup version they wore a plain grey shirt that could not be associated with any football team in

(a) Bystanders Ingroup.

(b) Bystanders Outgroup.

Figure 5.6: Bystanders wearing (a) the Arsenal jersey in the Ingroup version or (b) an unbranded shirt in the Outgroup.

particular. The last experimental variable referred to the nature of the bystanders' utterances. The first utterance was the same in both versions, and the last two were different depending on whether they wanted to encourage intervention or try to dissuade anyone from doing so (Table 5.3).

Bystanders encourage intervention	
0’30”	“What is this guy doing?”
0’58”	“Hey, hold on, we should do something about this”.
1’14”	“This guy has lost it, we’ve got do something now”. – referring to P.
Bystanders tried to dissuade anytone from intervening	
0’30”	“What is this guy doing?”
0’58”	“There is nothing we can do about it, let’s leave him alone”. – referring to P.
1’13”	“This isn’t our business, let’s leave him alone”.

Table 5.3: List of utterances that virtual bystanders shouted out during the confrontation and their timing on each version of the scenario.

The first hypothesis was that the bystander effect would be observed in the IVE, therefore the number of interventions when the bystanders were present was expected to be lower than in the version in which the participant was the only person who witnessed the argument. Variations on how the rest of the bystanders are perceived by the participants could have an impact on the participant’s responses, either eliciting pro-social behaviour as in [Levine et al., 2002] or not altering the feeling of diffusion of responsibility.

5.3.3 Results

Helping behaviour was measured by the number of times that participants intervened during the argument. An intervention could be verbal (the participant saying something to V or P) or physical (e.g., the participant trying to step between them, as described in Section 3.6). Participants also completed the standard post-experience questionnaire (Section 3.4.3), that provided the scores of the response variables listed in table 3.1 with the addition of 4 extra questions (table 5.4). These new questions were focused on understanding how the presence of the other bystanders and their behaviour affected the participants’ responses.

Figure 5.7 (top panel) shows the means and standard errors of the number of interventions under the various conditions (the bottom panel is explained later).

Variable name	Question
BystIn	The presence of other people in the bar encouraged (or dissuaded) me to intervene.
BystPersuaded	The other people in the bar tried to persuade me...
BystUtterances	The other people's utterances had an impact on my behaviour
BystEncDis	Were the other people's utterances encouraging or trying to dissuade you to intervene?

Table 5.4: Post-experience questionnaire additional questions about the virtual bystanders.

Source	d.f.	F-Ratio	P	Partial η^2
Affiliation	1	12.93	0.001	0.26
Encouragement	1	0.33	0.567	0.009
Affiliation• Encouragement	1	0.05	0.820	0.0001

Table 5.5: ANOVA of square root of number of interventions on Affiliation and Encouragement. Affiliation (Outgroup=0, Ingroup=1) and Encouragement (Discourage=0,Encourage=1). Overall fit: $F(3,36) = 4.44$, $P = 0.009$, $R^2 = 0.27$, Shapiro-Wilk test for normality of residual errors: $P = 0.09$.

The evidence suggests that the level of intervention was less when the bystanders were Arsenal supporters (Ingroup). These are count variables, and when an ANOVA is fitted for the model $(Affiliation) + (Encouragement) + (Affiliation) \bullet (Encouragement)$ or any subset of this the residual error of the fit does not satisfy normality by far (for example, the SW test gives $P = 0.00003$ for full model and $P = 0.00009$ for the model that only includes Affiliation). As is common for count data a square root transformation resolves this problem (the same was found in the experiment about the victim's affiliation, Section 4.3). Hence we work with the square root of the number of interventions. The results of a two-way ANOVA are presented in Table 5.5.

Confidence intervals for all pairwise comparisons of marginal means were computed with an overall 95% confidence level (using Scheffe multiple comparisons). In line with what is shown in Table 5.5, the main effect difference

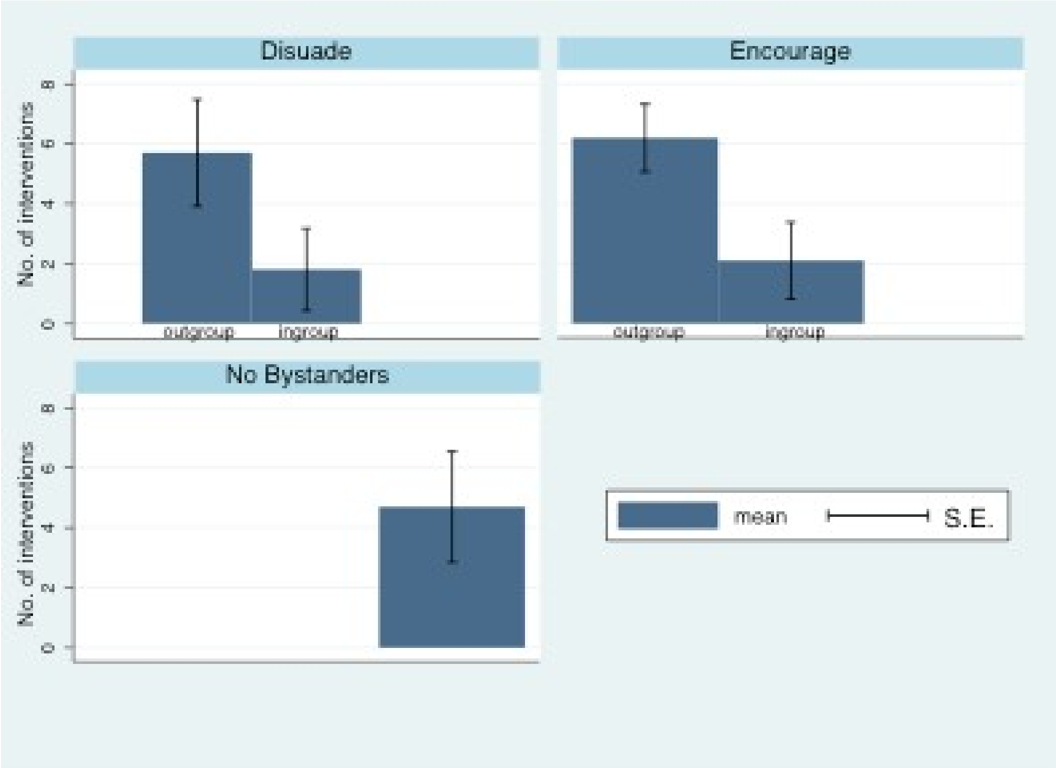


Figure 5.7: Bar charts showing the means and standard errors of the number of interventions by Affiliation (Outgroup, Ingroup) and Encouragement.

between ingroup and outgroup Affiliation did not include 0 (-2.15 to -0.60). Additionally, the confidence interval for the difference in the means of the conditions (Ingroup, Discourage) and (Outgroup, Encourage) was negative (-3.17 to -0.01). All other intervals included 0.

Since neither the interaction term nor Encouragement as a main effect contribute to the fit we can delete these terms from the model, fitting only Affiliation. In this case F(1,38)=13.50, $P = 0.0007$, $R^2 = \eta^2 = 0.26$. As can be seen from R^2 the overall goodness of fit remains the same, and the residual errors satisfy normality (SW $P = 0.24$). Hence overall the estimated model fits well what can be seen in the top plots in Figure 5.7, supporting the idea that when the bystanders are ingroup the amount of helping behaviour decreases.

In order to directly address the bystander effect itself, we can compare these data with those from the previous experiment, described in Section 5.2. In this experiment, carried out one week prior to the one described in this section, there were 10 participants, again all Arsenal supporters, who experienced the identical scenario using the same equipment but where there were no bystanders. The mean and standard error of their number of interventions is shown in Figure 5.7, bottom panel. It is clear that the result is almost identical to the Outgroup affiliation condition. A one-way ANOVA for the square root of the number of interventions shows that there is no difference between the Outgroup affiliation and no bystander condition. An overall 95% confidence interval for all mean differences between the conditions (Scheffe) is -2.34 to -0.40 for Ingroup–Outgroup, but -1.61 to 0.77 for No bystanders–Outgroup and -0.24 to 2.15 for No bystanders–Ingroup. The overall fit has $F(2,47) = 6.52$, $P = 0.003$, $R^2 = \eta^2 = 0.22$, and partial $\eta^2 = 0.21$ for the Ingroup condition.

The conditions (Affiliation, Encouragement) had no noticeable effect on any of the questionnaire responses. However the question about the feeling that the participant should stop it (ShouldStopIt) is positively correlated with the number of interventions (independent of condition) (Spearman's rho = 0.4, $P = 0.004$, $n = 50$). If we add this variable to the regression of the square root of the number of interventions on Affiliation its coefficient is 0.28 ± 0.10, with confidence interval 0.08 to 0.47, partial $\eta^2 = 0.26$, with overall $R^2 = 0.32$.

The level of encouragement or discouragement offered by the bystanders was quite low in intensity. The bystanders made three comments, one neutral and two either encouraging intervention or discouraging it (Table 5.3). At the end of the VR exposure participants were asked: "Were the other people's utterances encouraging or trying to dissuade you to intervene?" with possible answers: Dissuade, Encourage, or nothing noticed. The responses are given in Table 5.6. Hence 9 out of 20 of those in the Discourage condition and 11 out of 20 of those in the Persuade condition noticed the corresponding interventions, whereas 19 out of 40 participants did not notice any intervention. Instead of using the designed factor Encouragement we can use this questionnaire response as a categorical explanatory factor PerceivedEncouragement:(Dissuade, Nothing, Persuade). The results are similar to those when Encouragement is used –

Answer / Encouragement	Dissuade	Nothing	Persuade	Total
Discourage	9	10	1	20
Encourage	0	9	11	20
Total	9	19	12	40

Table 5.6: Frequencies of answers to the question "Were the other people's utterances encouraging or trying to dissuade you to intervene?"

there is no influence of PerceivedEncouragement on the number of interventions. ANOVA of the square root of the number of interventions on (Affiliation) + (PerceivedEncouragement) + (Affiliation)•(PerceivedEncouragement) shows only a main effect of Affiliation ($F(1,34) = 10.35$, $P = 0.003$, Partial $\eta^2 = 0.23$) and no effect at all of PerceivedEncouragement ($F(2,34) = 0.80$, $P = 0.46$, Partial $\eta^2 = 0.04$) or of the interaction term ($F(2,34) = 0.08$, $P = 0.92$, Partial $\eta^2 = 0.005$). The residual errors are compatible with normality (Shapiro-Wilk $P = 0.29$). Removing the interaction term makes no difference. Moreover, we also excluded those 19 who did not perceive any intervention from the bystanders, but even in this model only Affiliation remains significant ($P = 0.03$) and nothing else comes close. Hence in this particular experimental setup the evidence suggests that the actual and perceived bystander interventions to encourage or dissuade participants to intervene had no effect at all on the number of interventions.

5.3.4 Discussion

The most well-verified result in bystander studies is that passive bystanders tend to reduce helping behaviour [Fischer et al., 2011]. Also we know from the results obtained in the experiment about the victim's affiliation (Section 4.3) that in the absence of bystanders and when the victim is outgroup, the number of interventions is less than when the victim is ingroup. The present study supports the notion that the social identity of bystanders has an important effect: shared group affiliation (ingroup) with the participant is associated with a decrease in helping behaviour compared to when the bystanders are outgroup. The number of interventions when the bystanders are outgroup and the victim ingroup is approximately the same as when there are no other bystanders besides the participant.

The meta analysis of [Fischer et al., 2011] as well as verifying the original bystander effect also found that this effect is attenuated by the level of the perceived danger of the emergency. The scenario that we displayed could leave any onlooker in no doubt that it would end in violence. Every attempt made by the victim to be submissive and calm the situation led to increased aggression. Of the three reasons mentioned by [Fischer et al., 2011] why helping behaviour may be increased in the presence of clear danger the first seems most relevant – that "dangerous emergencies are more clearly perceived as actual emergencies" and that therefore arousal of the focal bystander (the participant) is uncomfortably increased and intervention may help to decrease it.

The review by [Levine and Manning, 2013] suggested that the presence of ingroup bystanders increases the capacity of the group to influence any particular member – in line with the norms and the values of the group. When the group favours intervention, then ingroup bystanders should enhance this tendency. When the group favours inaction, then individuals in the group should be less likely to intervene. We have not found support for this in this experiment. While we have a clear effect for the influence of group membership, it appears to be unrelated to the norms of the group. In fact, messages about encouraging or discouraging intervention seem to have had no influence on behaviour. This could be a matter that bystanders said out loud only utterances to try to influence the participants' responses only twice, or how they faded into the confrontation. Almost 50% of the participants did not know exactly what the bystanders tried to say. The fact that we still find an effect of group membership suggests that the interaction between identity and feelings of responsibility is more likely to contribute towards an explanation of the behaviour of participants.

The differences between our findings and the traditional social identity account might also be a function of the IVR. The advantage of using IVR in these types of studies is that faced with life-sized human characters in an IVE may produce an overwhelming need to decrease arousal discomfort (in spite of the sure knowledge that nothing is really happening) – for example, as illustrated by the stress exhibited by participants in the virtual reprise of one of the conditions of Stanley Milgram's obedience studies (Section 2.2.3) [Slater et al., 2006]. Thus concern with arousal reduction might produce different behaviour to situations where participants are just required to express an opinion about intervention.

A second way in which responses to bystanders in the IVR might be different is in terms of perceived efficacy of the other bystanders. Work on collective action [van Zomeren et al., 2008] shows that judgements about the efficacy of others play an important part in individuals' decisions to act. While virtual humans may be able to signal group membership, or to create emotionally charged environments, they were not programmed to actually intervene in this scenario. Thus participants could not have expected physical support from fellow bystanders should they have chosen to intervene. In our study, the bystander characters are possible objects on which to diffuse responsibility – particularly when trying to reduce anxiety. However, it remains to be seen whether the possibility of actual physical support from bystanders could create conditions that enhance intervention in violence.

Nevertheless our findings help to develop our understanding of how diffusion of responsibility works by combining elements of both the classic bystander effect and social identity theory [Tajfel and Turner, 1986]. Classic diffusion of responsibility predicts that responsibility will be distributed across the numbers of others present, irrespective of their psychological relationship to each other. Based on the current findings we argue that the social identity of the bystanders changes the participant's perception of responsibility. This is, to our knowledge, the first demonstration of the importance of social identification in shaping the limits of diffusion of responsibility. More specifically, we argue that responsibility will only be diffused across those who are perceived by the participant to have an equal responsibility to help. When bystanders are outgroup to the participant (in a context where both participant and victim are ingroup) they will not be seen to have the same responsibility to act, and thus diffusion of responsibility will not occur. In the context of the current study, when participants face a clear violent emergency, with the knowledge that the outgroup members are unlikely to help, it falls squarely and only on the shoulders of the participant to help the victim.

To summarise the model that we draw from this study is that a lone bystander will be more likely to help an ingroup victim than an outgroup victim. When the emergency is violent and clear, so that someone has to act, the presence of other ingroup members decreases the probability of action precisely because of shared responsibility. But for the same reasons, when the others are outgroup, the only one who has the responsibility to act to save a fellow ingroup member is the participant. On the other hand, the encouraging or dissuading utterances by the other bystanders had not effect on the participants' interventions. These statements were clear and should have been heard by the participants, given the emotionally charged situation of the attack on the victim by the perpetrator. It is possible that in the presence of the bystanders a great deal of attention was paid to the actual confrontation, and while the comments of the bystanders should have been heard they were not processed.

A critical missing element in VR studies is the lack of the possibility of physical intervention – so that the participant can have no rational fear of being attacked by the perpetrator on intervention. This is not to say that there may not still be some fear simply based on the perceived situation. However, it is possible for there to be an interactive element whereby when the participant intervenes the perpetrator responds aggressively to the participant, and even some level of haptic feedback where the participant can feel friendly or aggressive touch from the victim and perpetrator. Adding this element of greater physicality is an important way forward in this methodology.

5.4 Chapter Summary

This chapter covered two experiments that used the bar scenario (Section 3.2) in order to understand how different parameters shape the bystander's intervention behaviour in front of a violent emergency. While the two experiments used the same scenario with the only variation being the number of bystanders present in the scene, they looked at two different things. The first experiment focussed on the technical aspects of the VR used. It aimed at understanding how a change to the display characteristics of the VR system could lead to a different number of interventions. The results showed that greater pixel resolution and illuminance of the displays had an impact on the number of times participants tried to intervene in the confrontation. We speculated that greater SCs led to a stronger illusion of 'being there', thus making a difference in the participants' behaviour. The main conclusion is that special attention must be given to ensuring that the VR system configuration remains constant throughout an experiment, as this could be the source of extraneous variables.

The second experiment focused on parameters that are associated with social psychology. The main goal was to test whether the bystander effect occurs in a virtual environment. We looked at it by exposing the participants to the violent emergency, in which the number of people present in the scene was manipulated. Additionally, we changed the social identity of the virtual bystanders and how their behaviour can influence the participant's responses. The results showed that participants intervened less when the bystanders were ingroup, providing evidence on the theory of the diffusion of responsibility. This did not happen when the other bystanders were outgroup. In this case, the results were similar to those obtained when the participant was the only bystander. The bystanders' utterances that aimed to influence the participant's behaviour by either encouraging intervention (or trying to persuade him not to do so) did not show any significant result. We have argued that this could be a matter of how the VR scene was implemented. Despite the fact that their utterances were loud and clear, almost 50% of the participants did not seem to remember what the other bystanders had said. We argued that the nature of the emergency could have caused their attention to be fully focused on the two characters arguing, ignoring all other events happening around them. Another issue is that the number of utterances would have not been enough for the participant to feel encouraged to intervene or dissuaded from doing so.

These two experiments were designed to test different parameters that can have an impact on the participant's responses when manipulated. We assumed that the variable Upgrade in the first experiment probably could not interact with the variables in the second experiment. The latter was designed as a 2×2 experiment with the two experimental variables being bystanders' affiliation and nature of the bystanders' utterances. These two variables can interact in other emergency situations [Levine and Manning, 2013], and variables with a chance of interaction need to be studied concurrently but his leads to the problem of the number of experimental conditions that need to be included, facing an exponential growth number of participants and an unreasonably large number of trials to be carried out. In the next chapter, we aim to use RL to address this issue presenting a new experimental methodology where different experimental variables can be tried without having to test them in a full factorial experiment, and preserving the possibility of discovering potential interactions among them thus reducing the number of participants needed compared to other traditional experimental designs.

Chapter 6

Reinforcement Learning in Immersive Virtual Reality

This chapter presents the last two experiments carried out in this research. Each one used a different scenario, but their general goal was the same one: to investigate how, by providing learning capabilities with the use of RL, the knowledge acquired by observing how people respond to certain events could be used to influence their responses in situations depicted in IVR. The first experiment used a scenario that resembled a video game where an active entity, called *RL agent*, had to learn how to make participants move to a target location and stay in it the longest time possible. The idea behind this experiment was to understand how RL works and provide evidence that RL can be used to influence people's behaviour in a simple scenario, supporting the findings presented in [Kastanis and Slater, 2012]. The results of the first experiment are presented in the paper "Reinforcement Learning as a tool to make people move to a specific location in Immersive Virtual Reality", under revision at the time of printing this thesis.

The second experiment aimed to use a more complex scenario: the violent emergency in the virtual bar that has been discussed in previous chapters. In this new experiment, the agent controlled the virtual characters in the scene and, by making them perform different actions, it observed which actions made the participants more likely to intervene in the confrontation. While during the performance of the first participants the goal was only to observe how they responded to the actions, the agent progressively reduced the chance that the virtual characters performed actions at random and used the experience collected instead in order to maximize the likelihood of the participants intervening.

6.1 The Reinforcement Learning Algorithm

Two RL algorithms were initially considered, Sarsa and Q-learning. Model-based RL algorithms [Sutton and Barto, 1998] were discarded since they do not perform well in rapidly changing and unpredictable environments. A model-based algorithm creates artificial experience from actions taken in the past, so the RL agent would be creating new experience from past actions, which could be inaccurate with respect to the current state of the environment. Putting this concept in the perspective of our research, people can change their behaviour over time. A person can be more (or less) likely to intervene at the beginning of the scene and decide to stay back towards the end or, vice versa.

Q-learning and Sarsa are very similar algorithms. As with any RL algorithm, an agent:

- 1: Observes the current state, s. If s is a final state, end process.
- 2: Chooses an action, a, according to the policy.
- 3: Performs the action, observes in the environment and checks if any reward was obtained.
- 4: Updates the policy. Go to step 1.

Our implementation used a standard Q table to store one numerical value for each state-action pair, indicated by $Q(s,a)$. Higher values mean that in a given state, one action has led, directly or indirectly, to greater rewards than others in the past, and it is more likely to be chosen again in the future. Both Sarsa and Q-learning algorithms are online, therefore Q values are updated as soon as a reward is obtained, and the experience is ready to be used right after it is obtained. The difference between them is in the values used to update the policy. Sarsa is an on-policy algorithm, meaning that the current state-action pair value $Q(s,a)$ will be updated with the $Q(s',a')$ value, where s' is the upcoming state and a' is the action that will be taken in that state s'. It is called *on-policy* because the state-action value used to update the Q table is the same state-action pair that will be tried next. On the other hand, Q-learning is the off-policy counterpart. This algorithm will update the current $Q(s,a)$ value with $Q(s',a^*)$, where a^* is the best action possible in the upcoming state. a' is not necessarily equal to a^*, hence the Q value that will be used to update the current state-action value might not be the same that the policy decides to try next.

The main implication that this difference carries is that Q-learning will return the optimal policy but can perform worse when certain actions near the optimal path return high negative rewards. Sarsa, on the other hand, will choose a safer route that avoids the possibility of receiving big punishments. An explanatory example is the cliff-walking problem, as shown in [Sutton and Barto, 1998] (Fig. 6.1). In this episodic task, the agent needs to find the way from the start, s=S, and reach the goal, s=G. Shorter paths will return a higher reward when the agent reaches the goal but if the agent chooses an action that makes it fall off the cliff, the reward obtained will be negative and much higher in magnitude than the one that would be obtained taking a longer and safer path. After a sufficient number of tries, Q-learning always returns the optimal solution, which is walking along the edge of the cliff, while Sarsa returns a safer option. When negative rewards are not obtainable in the setup, both algorithms will return the same path but Q-learning will find the solution faster than Sarsa. The designer of the RL implementation needs to decide for each problem what the best path is, the shortest or the safest. The risk of falling off a cliff may or may not be worthwhile, depending on the magnitude of the negative reward obtained when this happens.

In terms of our research, the search for potential pitfalls was needed in order to choose the algorithm. The goal was to increase the likelihood of intervention from participants when confronted by a violent incident. One thing that could drop the number of interventions dramatically was the break of Psi. In this case,

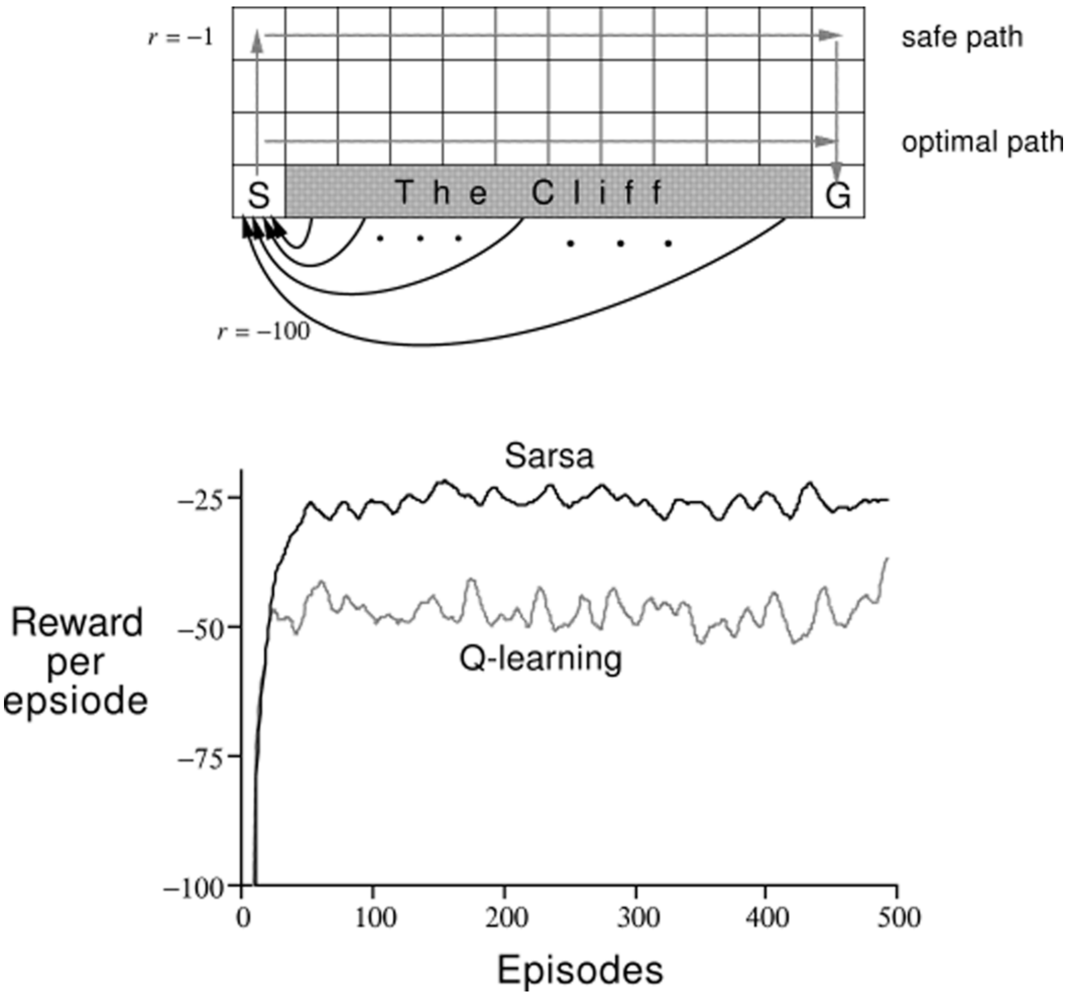


Figure 6.1: The Cliff-Walking task diagram, source: [Sutton and Barto, 1998].

the experience collected during the experiments described in previous chapters was very valuable to decide the design of the RL problem. We observed that Psi was lost for many participants when they intervened and realised that they were not acknowledged by the other people in the scene. This break on Psi was reported as the consequence of the lack of interaction in the scenario. Once Psi is lost, it is unlikely that it will be regained again [Slater, 2009]. We observed that, when this happened, participants tended to fall back and become spectators, knowing that anything they did would not change the course of events. However, this cannot be attributed to the actions that the characters performed, therefore Q-learning was chosen in the end.

The algorithm was implemented following the standard implementation explained in [Sutton and Barto, 1998], introducing minimal changes to suit the requirements of our problem (Algorithm 1). Eligibility traces were also included in order to assign rewards to actions that returned a positive reward indirectly. For example, it could be possible that a participant only intervened when he was close to the virtual characters arguing, and an early action was necessary to make him move closer to them to increase the chance of intervention. Such action, although it might not return a reward, led to a situation that was favourable to having an intervention. In our algorithm, when the best action had to be chosen but multiple actions had the same highest value, one of them was chosen at random. Q-learning algorithm contains different parameters that need to be set in order to decide following actions and the amount of the reward obtained that will be used to update the Q table. These parameters are:

- Learning rate (α, $0 < \alpha < 1$): percentage of the absolute value of the received rewards that will be used to update the Q values. Higher values of α means that the RL agent will learn faster but is more susceptible to lead to a wrong solution if sporadic high values are obtained.

- Discount factor (γ, $0 < \gamma < 1$): importance of the time needed to obtain rewards. Low values of γ motivate the agent to find the rewards as soon as possible, and high values give less importance to when the rewards are obtained.

- Randomness (ε, $0 < \varepsilon < 1$): it is the main parameter of the policy, it indicates the probability that an action taken will be chosen randomly from amongst the set available for the given current state, or it will take the action that performed better in previous tries. In our implementation, when several actions had the same best value, one of them was chosen randomly.

- Decay rate of the eligibility traces (λ, $0 < \lambda < 1$): it indicates that $Q(s,a)$ visited before will be updated when a reward is obtained with a percentage of the reward value. Eligibility traces are reset when an action taken is not the optimal action for the current state. This parameter is particularly important in order to discover if a sequence of actions led to a reward, not only the last one taken.

Algorithm 1 The Watkin's $Q(\lambda)$ algorithm, as described in [Sutton and Barto, 1998]. s is the current state, s' is the next state that will be visited, a is the action taken in s, a^* is the best action in s', a' is the action that will be taken in s', and r is the reward obtained after a.

```
Initialize Q(s,a), for all s,a
Initialize e(s,a) = 0, for all s,a
while scenario has not ended do
    Observe current s
    Choose action according to the ε-policy
    Perform action a, observe r,s'
    Choose a' from s' using policy derived from Q
    a* ← argmax_b Q(s',b)
    δ ← r + γQ(s',a*) − Q(s,a)
    e(s,a) ← e(s,a) + 1
    for all s,a do
        Q(s,a) ← Q(s,a) + αδe(s,a)
        if a' == a* then
            e(s,a) ← γλe(s,a)
        else
            e(s,a) ← 0
        end if
    end for
    s ← s'
    a ← a'
end while
```

6.2 Experiment. Using RL to Make People Move to a Location

The first goal in the first experiment using a RL algorithm was to assess whether a RL algorithm could be used learn how to elicit pre-specified behaviour in people in an IVE. This experiment used the study described in [Kastanis and Slater, 2012] as the starting point. That earlier study used RL to learn how to make every individual achieve a goal in the virtual environment, without the use of any previous knowledge by the RL observing how participants responded to the actions of a virtual character that it controlled. The participant was placed in an alley and the goal was to make them move to a location that was behind them by only using the principle of Proxemics [Hall, 1966] so that participants would tend to move backwards, away from a RL controlled virtual character when it invaded their personal space. This study showed how the actions of the virtual character would adapt depending on the person's behaviour and individually for each participant. However, there are substantial differences between Kastanis's study and the experiment described in this section. In [Kastanis and Slater, 2012], the participant's movements were limited to one dimension and were performed by leaning the body forward or backwards. Our study allowed participants to move around the space within the Cave walls with natural movements of the body.

6.2.1 The Scenario

A new video game-type scenario was designed for this experiment to be used in the Cave (Fig. 6.2). Under the assumption that people would try to avoid virtual projectiles flying towards them, a spacecraft moved along the width of the virtual space shooting the projectiles, while the RL agent, observed the participants' movements. The scenario included typical game interface elements such as a set of icons on the top left corner to represent the number of lives left before the game was over, a timer showing how much time left in the game there was, and a scoreboard with a numerical counter. These elements were displayed on the front wall of the Cave, at the same depth as the physical screen. A star field was also included as decoration, to provide greater sense of depth and make the experience more engaging.

The spacecraft shot one projectile every 3 seconds and the total duration of the game was 7 minutes. A shot was considered a *hit* if the participant was in the trajectory of the projectile when it flew by, and a *miss* otherwise. The scoreboard value was incremented by 1 every time that the participant avoided one projectile, and was reset if the participant was hit. The projectiles travelled quickly enough so that a participant could not avoid it once it was shot ($7.5m/s$ and the participant was between $0.5m$ and $3.5m$ away). It was designed this way to encourage participants to try to develop a strategy based on prediction rather than making a game based

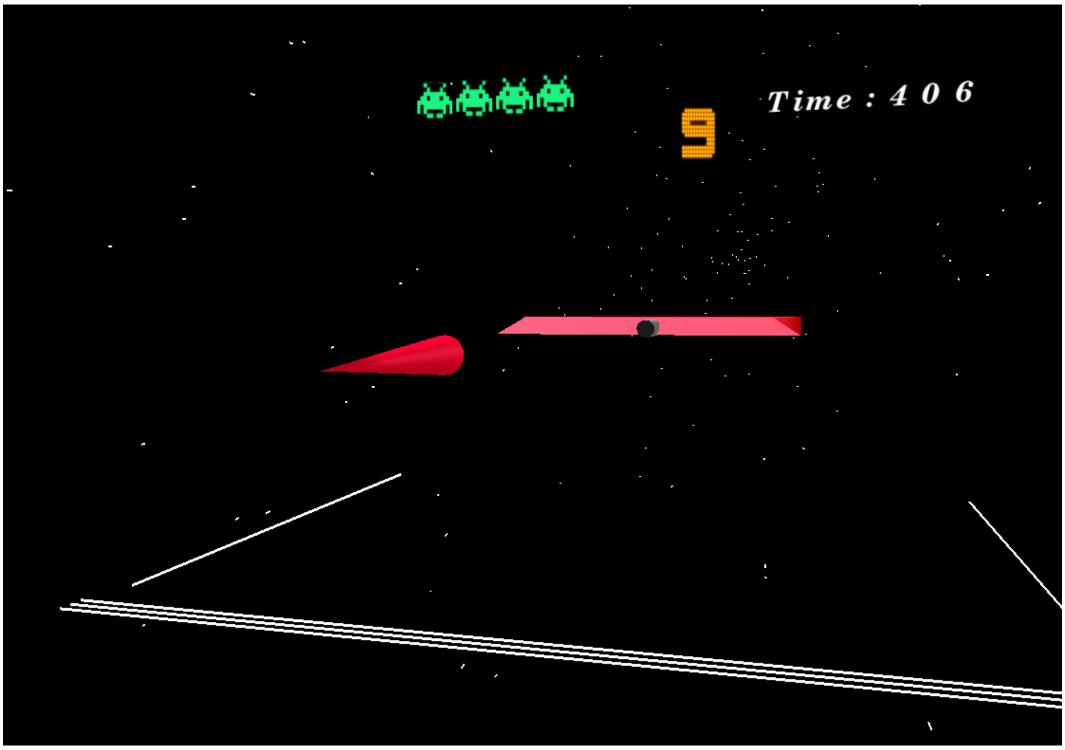


Figure 6.2: Screen shot of the video game scenario in the first RL experiment. A spacecraft kept shooting projectiles towards the participant and he had to avoid them. The scoreboard indicated how many projectiles had been avoided since the last time one hit the participant. The white lines indicate the edges of the Cave floor.

on reflexes. The game score and the number of lives left were not relevant for the experiment and were not included in the data analysis, but they proved to be very useful to keep the participants engaged in the game. Participants were instructed to continue for the full duration of the scenario, even if they had no lives left.

6.2.2 Reinforcement Learning setup

The floor surface was divided into 5 lanes along the depth dimension, from the entrance of the Cave towards the front wall, 60 cms wide each. The current state of the RL machine was the lane the participant was currently in when a new projectile was about to be shot, and the goal was to make the participant move to a pre-specified position, depending on the experimental condition. The RL agent decided which lane the spacecraft would shoot from and the projectile would then travel along the lane towards the participant. In summary, there were 5 lanes that the participant could possibly be in and 5 possible positions the spacecraft could shoot from. All 5 actions were available in all 5 states. Therefore, the state-action map size was 5×5 leading to 25 state-action possible permutations. The reward obtained on each try was a discrete value that depended on the distance from the goal. If the participant was at the goal, then the reward was 5. The reward was reduced by 1 for each lane away from the target.

We used Watkins's Q(λ) algorithm [Watkins and Dayan, 1992, Sutton and Barto, 1998] with the following RL parameters: learning rate $\alpha = 0.5$, discount rate $\gamma = 1$ and decay rate for the eligibility traces $\lambda = 0.2$. α value is usually decided in accordance of the absolute values of the rewards that can potentially be obtained. High values could make RL agent converge to a wrong solution. This was not possible in the setup of this experiment, as rewards had no local maximum values, the reward linearly increased towards the goal. Therefore, α value could not lead to a non-optimal solution. γ was set to its recommended maximum value. If the goal state was reached for a certain amount of time, it was not important that it was reached earlier. The decay rate parameter for the eligibility traces was set to a small value to assign a small amount of the rewards obtained to previous actions that led to an action that returned a reward. ε was initially set to 1 for all participants and was progressively reduced throughout the scenario depending on the experimental version, until it reached its minimum established value, 0.1. A 10% chance of taking an exploration action was left to have the possibility of detecting if the participant had changed his strategy towards the end of the scenario. The experience collected from previous participants was not used in subsequent participants, therefore the agent learned with no initial experience for each one of them. All the parameters, including the number of states and actions were decided after the results obtained during the pilot study and a simulation carried out afterwards with the data collected from the volunteers. App. E.1 provides further details of the simulation trials carried out which were used to decide the best values for the RL parameters.

6.2.3 Experimental Variables and Hypothesis

This was a single factor experiment, Version, with three levels depending on where the spacecraft was trying to guide the participants to. In the Left condition, the target location was the leftmost lane. In the Right condition, the spacecraft goal was to make them move to the opposite lane, the rightmost one. The last condition was Random, it meant that the RL agent did not use the experience collected and commanded the spacecraft to shoot at any lane randomly throughout the length of the game. The decision to use the outermost areas of the IVR as the goal came after asking volunteers during the piloting about the place they felt safest. Most of them said that the centre was the safest, since staying there allowed them to move in any direction. One of the research questions was whether we could override this feeling of safety and make them stay in one side of the environment, thereby contradicting the most common response. In the Random condition, ε value was not reduced thus it remained 1 throught the scenario.

6.2.4 Results

The main response variable was the total reward obtained by the RL agent, as this measures how close a participant was to the goal. High reward values mean that a participant stayed closer to the goal and for longer periods of time compared to others with lower scores. The first hypothesis was that the agent would be able to learn how to guide people to the target location and let them stay in it or near it the longest time possible. In that case, the total reward obtained in Left and Right version would be similar and both would be greater than in Random. Secondly, we expected the reward per action obtained in Left and Right during the game to increase over the time. ε value is negatively correlated with the average reward per action obtained for these two versions.

The mean and standard deviation values in condition Left was 900.2 ± 140.5, Right was 977 ± 110.6, and Random 764.2 ± 99.5. The results of a regression analysis of Reward on Version ($F(2,27) = 8.31$, $P = 0.0015$, $\mathrm{R}^2 = 0.38$) are presented in Table 6.1. Shapiro-Wilk test on the residual errors of the fit does not reject the assumption of normality ($P > 0.85$). Scheffe method overall confidence

	Coef.	Std. Err.	t	P	95% Conf. Interval	Partial η^2
Intercept	900.2	37.4	24.09	0.000	823.5 to 976.9	
Version: Right	76.8	52.96	1.45	0.158	-31.6 to 185.2	0.07
Version: Random	-136	52.9	-2.57	0.016	-244.4 to -27.6	0.20

Table 6.1: Regression of Reward on Version.

intervals for marginal differences show no significant difference between Right and Left (-60.09 to 213.69), a clear difference between Right and Random (-349.69 to -75.91) and support for difference between Left and Random (-272.89 to 0.89). Šidák multiple comparisons between groups provide further support for these results, having the 95% confidence interval values on the difference between Random versus Left -270.5 to -1.5.

Concerning the progression of the rewards over the time, Figure 6.3 shows the average reward obtained in actions taken for each value of ε with the standard deviation represented by the whiskers on the bars. In early stages of the game, when $\varepsilon = 1.0$, the agent was only exploring and therefore the average reward obtained in Left and Right was similar to the reward obtained in Random ($Left = 1.91 \pm 0.74; Right = 2.18 \pm 0.82; Random = 1.86 \pm 0.87$). As ε started to decrease, the agent made greater use of the data collected and chose the actions that were more likely to lead to higher reward. In the final stage of the game, for $\varepsilon = 0.1$, the rewards obtained were Left (2.73 ± 0.61) and Right (2.9 ± 0.75).

The rewards obtained over time can also be interpreted as the time spent in each area for each participant, since the reward is inversely related to the distance from the goal area. The histograms of the distribution of time spent in each area for Left and Right version have a bell shape with the median roughly on the centre value representing the middle lane in the IVR. Figure 6.4 shows the histogram in three different stages, in the first stage of the experiment (Fig. 6.4a), half way through

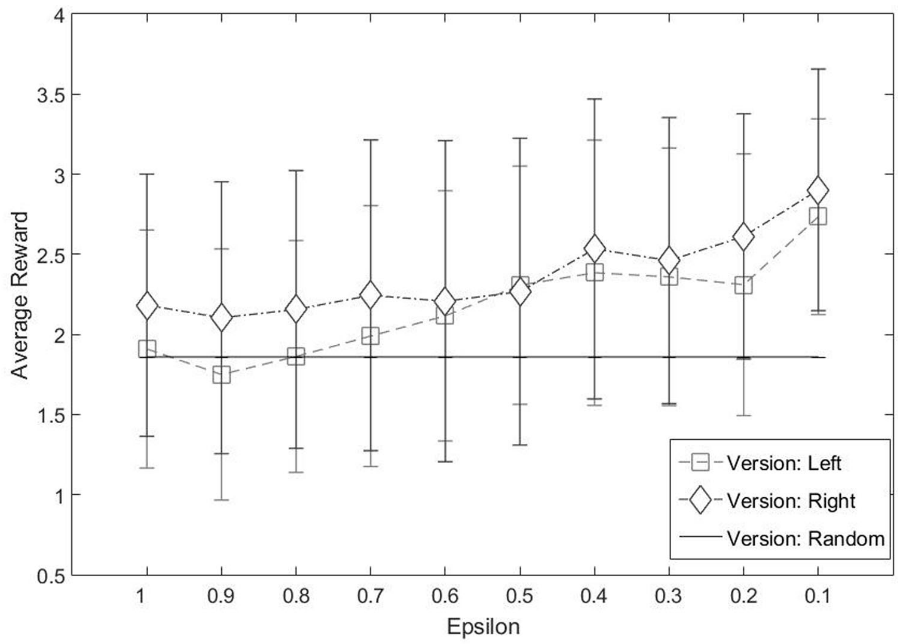
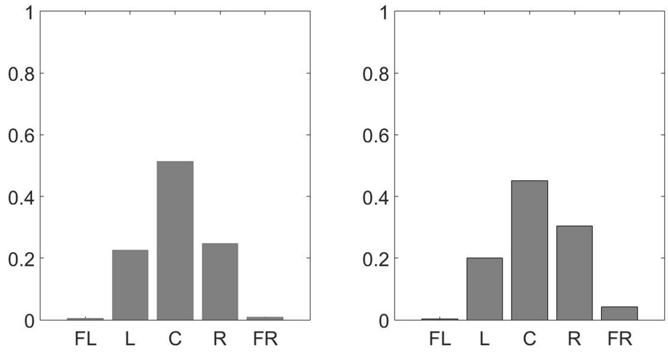


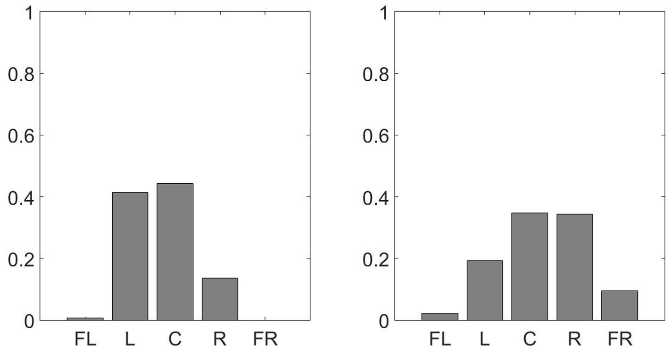
Figure 6.3: Mean and standard deviation of the reward for each ε grouped by experiment version.

(Fig. 6.4b) and the last stage where the experience was used in 90% of the actions taken (Fig. 6.4c). The tendency of the participants to spend less time in the centre of the scenario as ε decreased makes the histograms skew towards the goal position.

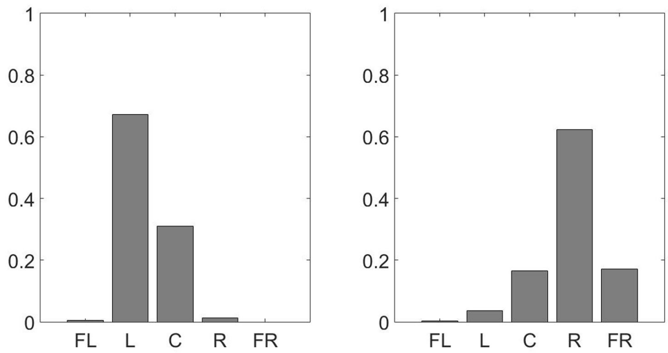
The significance levels of Kolmogorov-Smirnov tests the hypotheses that the Left and Right samples collected for each ε value are from the same distribution as shown in Table 6.2. The histograms obtained for $1.0 \leq \varepsilon \leq 0.8$ values are not significantly different, but, as ε decreases further, the histograms for Left and Right rapidly move away from one another. Examining the evolution of the skewness as a measure of asymmetry in the distribution functions of the time spent on each area, both Left and Right start close to 0 for $\varepsilon = 1.0$. As ε approaches the low values, the skewness values reach higher magnitudes. In the Left version, although not in constant progression, the level of skewness tends to increase over time, while in Right the result is the opposite and moves towards negative values (Fig. 6.5).



(a) $\varepsilon = 1.0$



(b) $\varepsilon = 0.5$



(c) $\varepsilon = 0.1$

Figure 6.4: Percentages of time spent on each area for ε values 1.0, 0.5 and 0.1. Left plots are from the Left version of the experiment, right plots are from the Right version. (FL=far left area, L=left, C=centre, R=right, FR=far right).

Epsilon	Left #samples	Left skewness	Right #samples	Right skewness	2-way KS test p-value
1.0	560	-0.06	559	0.10	0.16
0.9	292	-0.40	298	0.14	0.18
0.8	298	-0.07	295	0.19	0.51
0.7	298	-0.17	295	0.13	0.001
0.6	293	-0.04	299	0.14	< 0.001
0.5	596	0.35	592	-0.12	< 0.001
0.4	296	0.22	298	-0.20	< 0.001
0.3	593	0.18	592	-0.21	< 0.001
0.2	593	0.53	593	-0.47	< 0.001
0.1	294	0.24	297	-0.72	< 0.001

Table 6.2: Number of samples and skewness for each epsilon and experiment condition. KS test p-values show a progressive difference between Left and Right distributions as ε decreases.

6.2.5 Discussion

The results show that the RL agent generally learned to guide participants towards the goal. In Left and Right conditions, the values obtained differ substantially from the ones in the version where the spacecraft was shooting randomly throughout the game. Despite the tendency for people to move towards the goal, the time spent at the goal area was still small. This is due to the fact that the goal was to make them stay at the corner and people thought it was a weak spot where the options to escape are reduced. Our goal was to override this natural feeling but the number of actions in each game might have needed to be higher to achieve this. The main goal of this experiment was to see whether a RL agent would be able to learn, and the results show that the tendency was to make the participant stay closer to the goal position.

It is also interesting to note that RL was used to influence the movements of the people. This is different from typical applications, such as in board games or

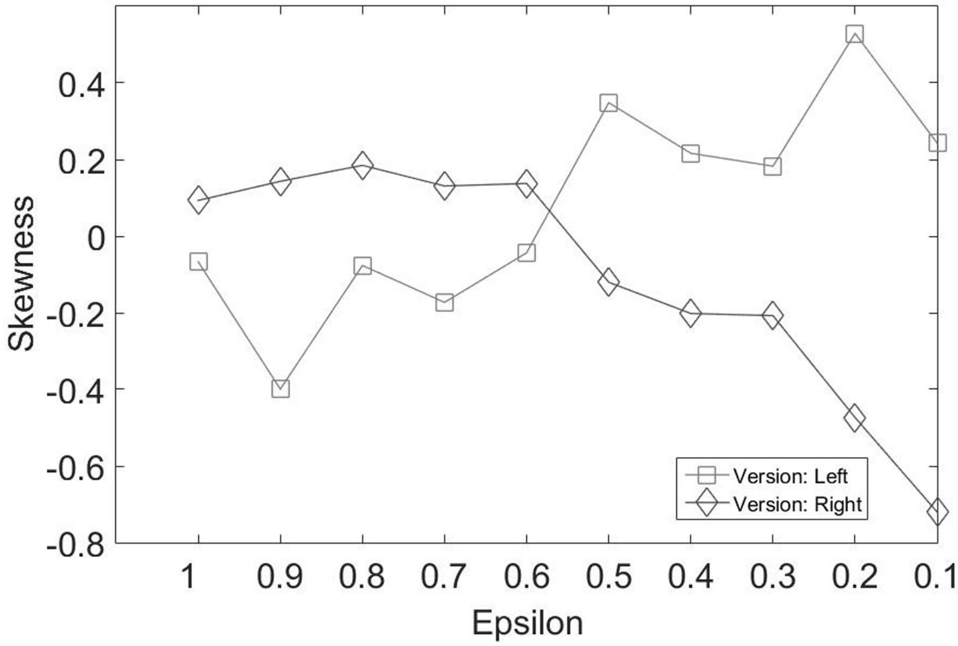


Figure 6.5: Skewness values of the histogram functions of the time spent on each area per ε for experiment versions Left and Right.

in Robotics. This experiment aimed at influencing people's behaviour rather than virtual or robotic actors. The results show that RL can perform well in dynamic environments, since each person's strategy can be different from the others based on their personality. Furthermore, a person might change his strategy over time and a RL agent is able to adjust its strategy by observing the outcome of the actions taken.

An accurate design of the RL problem is essential to make the agent solve it successfully. The number of tries that the agent needs to complete is directly related to the number of possible state-actions pairs to ideally make sure that each pair has been tried a minimum number of times. But this is not always feasible due to the lack of time or because the environment changes too rapidly to test all of the pairs in an ideal frequency. In our experiment, the number of states and actions were reduced from the initial idea based on the observation of the pilot study with 17 people, whose results have not been included in the analysis. The game length was also extended in order to increase the number of actions.

Some techniques have tried to mitigate the problem of having a large state-action space by adding a training session before the RL agent starts to solve the problem. This would allow the agent to start with some prior knowledge without having to try actions naïvely. In the context of our research, this could be applied to teach the RL agent how an average person behaves in a specific situation and use this as a starting point. This would enable the RL agent to exploit this knowledge to make people move towards the goal in less time. Although it is possible to discover patterns of behaviour across participants, each individual has a different personality. This could lead the system to not converge to an optimal solution if the policy is based on a model created from other people. However, RL can be programmed to adjust its policy based on recent observations. In this experiment, the RL agent learned for each participant with no accumulated experience, but it was not difficult to observe common behaviour. Examples of this are the difficulties in making people stay in a corner, the tendency to move to the left when the projectile was shot very close to the right of the person and vice versa, and projectiles that were shot far away from the person were likely to make them stay idle.

This experiment provided the ground to design a more elaborate scenario in IVR where RL is used to elicit certain responses from people. The scenario used in this experiment was rather simple, the next step is to use RL in the bar scenario.

6.3 Experiment. Using RL in a Violent Emergency in IVR

This section contains the description and findings of the second experiment using RL in IVR. This experiment was designed to achieve two goals. Firstly, to use RL in order to collect data about what makes a bystander more likely to intervene in a violent emergency, and secondly to use these data to try to increase their number of interventions. Its aim was to encourage people to respond in IVR towards fulfilling a predetermined goal, intervening in the confrontation in order to stop it, a goal of which they were unaware.

The RL capabilities were incorporated in the bar scenario. The main difference compared to the experiments described in previous chapters was the setup – the inclusion of a RL agent acting as a puppeteer of the virtual characters. They performed actions, such as the victim looking at the participant or the bystanders saying out loud some utterances. Additionally, these actions were tried multiple times while a participant was experiencing the scenario, instead of defining these actions as experimental conditions and trying them separately for different participants. In addition to this, the data collected from their responses was used as soon as it was available in order to try to increase their number of interventions. Despite each participant being a person with a different personality, the idea was to create a map of probabilities about what actions the virtual characters performed that increased the likelihood of intervention taking into account the distance between the participant and the people having an argument.

6.3.1 The scenario

The bar scenario was used as described in Section 3.2. It also included the three virtual bystanders introduced in the experiment about the bystander effect (Section 5.3). The initial dialogue was identical as in all previous experiments. The difference was in the second half of the scenario, when the confrontation takes place. Instead of having scripted times for the virtual characters to perform certain actions, the RL agent decided what action to perform each time, according to the RL policy.

6.3.2 Experiment Variables and Hypothesis

The experiment was designed as a single factor, epsilon (ε), with three levels which defined the probability of taking a random action or exploiting the best one depending on the distance between the participant and the virtual characters that were arguing. Experimental groups were completed sequentially, the participants experienced the same version of the scenario until the group was completed, and then moved on to the next one. The first group was All Random, ($\varepsilon = 1.0$), in which all the actions tried were exploratory. The initial Q values were reset for all participants, which means that all the participants in the first group started without the RL agent using the knowledge that had been collected from previous participants. The second group was Middle Random ($\varepsilon = 0.66$), two thirds of the actions were exploratory, and only one third exploited the experience accumulated from the participants in the All Random group. The initial Q values were the average final Q values from the participants in All Random, and experience from previous participants in Middle Random was not used at this stage. The third and last group was Least Random ($\varepsilon = 0.33$), in which only one third of the actions were exploratory. The agent focused on exploiting the experience accumulated over the previous two groups. The initial Q values were computed as the average of the final Q values of the two previous groups. The main hypothesis was that the average number of interventions would increase over the groups, when the RL used the experience collected in previous groups. This would mean that the RL agent had learned from participants in previous groups and knew what actions the virtual characters could perform to make new participants more likely to intervene.

6.3.3 The Reinforcement Learning Setup

The current state was determined by the distance between the participant and the two people having the argument. A discrete design was adopted to keep the problem simple. The distance was calculated from the participant's head position and the middle point between the victim's head and the perpetrator's. The current state was determined when action was about to take place. The distance was classified in three different states:

- Distance = [Intervention | Active | Passive]

    Intervention: participant was in the range of being able to reach out to them with his hands without having to step towards them ($distance < 0.5m$).

    Active: participant was close to them but keeping a short safety distance ($0.5m < distance < 1.0m$).

    Passive: participant stayed away from the confrontation ($1.0m < distance$).

The actions referred to head turns to look directly at the participant or verbal utterances that the virtual characters could perform during the confrontation. The first action was performed 4 seconds after the confrontation started, and following actions were carried out one every 10 seconds. Considering the length of the scenario, 2 minutes and 10 seconds, 13 actions were tried in total for each participant. There were three possible actions, each one performed by a different character, or characters: one by the victim, another by the perpetrator and the last one by the bystanders.

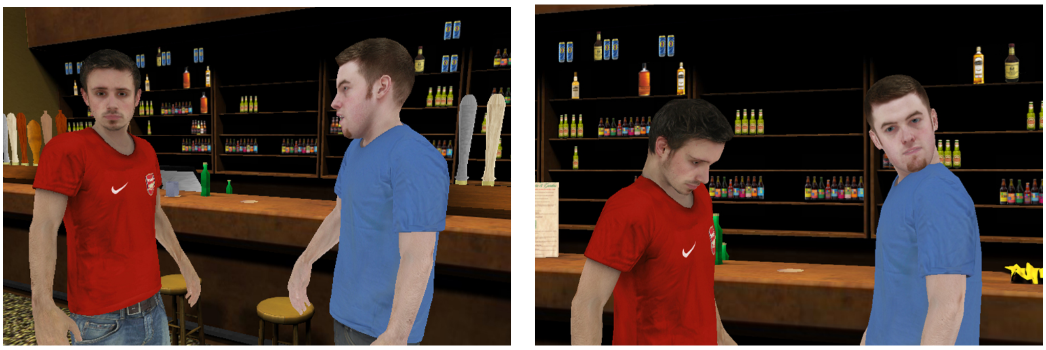
- Action = [VictimLookAt | PerpLookAt | BystandersUtter]

  VictimLookAt: the victim looks at participant. This was already tried in the experiment described in Section 4.3. The victim would turn his head towards the participant and stare at him for two seconds before going back to the original position and carrying on performing the scripted animation (Fig. 6.6a).

  PerpLookAt: the perpetrator looks at participant. This action had not been tried in previous experiments but it was implemented in the same style as the victim (Fig. 6.6b).

  BystandersUtter: one of the bystanders says something out loud. All the utterances were designed to encourage the participant to intervene and they were performed sequentially. The list of possible utterances (Table 6.3) performed by the bystanders was increased to 13, all of them encouraging intervention. This way it was guaranteed that, in the unlikely case that the chosen action was always the bystanders uttering something, they would not run out of utterances and none of them would have to be repeated. Even though some utterances sounded very similar, they were two different recordings that could have either been performed by a different person or the intonation changed.

The numbers of states and actions were kept small, otherwise the number of participants needed would have been much greater. Also, the number of actions that could be tried for each participant was rather low, due to the short length of the confrontation. Reducing the time interval between actions would make the



(a) Victim looks at participant. **(b)** Perpetrator looks at participant.

Figure 6.6: Physical actions that the virtual characters could perform. (a) The victim looks at the participant; (b) the perpetrator looks at the participant.

Character uttering	Utterance
Bystander A	“What is this guy doing?”
A	“Someone needs to do something about this!”
A	“This guy has lost it!”
Bystander B	“Tell him to calm down...”
A	“This guy is ridiculous!”
A	“Tell him to shut up!”
A	“Come on, who is going to tell him to stop?!”
B	“Someone needs to do something about this!”
A	“Who is going to tell him to stop?!”
A	“This guy has lost it...”
B	“Tell him to shut up!”
B	“This guy is ridiculous!”

Table 6.3: Sequence of utterances that virtual bystanders potentially said out loud during the confrontation.

scenario look unrealistic, as an action could be repeated multiple times and this could compromise the plausibility thus making people not respond realistically. The outcome was logged once the following action was carried out. The reward obtained by the agent derived from whether the participant had intervened during the 10 second window between actions. A participant's action was considered an intervention following the same criteria described in Section 3.6. An operator indicated manually to the agent when the participant intervened by pressing keys on a keyboard, one for each type of intervention. The reward was set to 1 if the participant intervened, either physically or verbally, making a maximum total of 2 if he intervened in both ways. They were binary indicators, which means that even if a participant intervened multiple times before the next action, the reward obtained for each type of intervention would still be 1. The reward returned was -0.1 in case an action did not lead to an intervention. This small negative reward was assigned to increase the chance of trying other actions that had not been tried before.

The experiment versions refer to the value of the randomness, ε parameter of the policy taken, and used the values described above. ε was not updated throughout the scenario, it was set when the scenario started and remained constant for that participant. The algorithm used was Watkins's $Q(\lambda)$ as in the previous experiment described earlier in this chapter. This algorithm is the variation of the standard Q-learning algorithm that also includes eligibility traces. The other RL parameter values used were the learning rate $\alpha = 0.2$, the discount factor $\gamma = 1.0$ (therefore all interventions had the same value, independently of the moment they were carried out) and the decay rate of the eligibility traces parameter $\lambda = 0.2$ to assign a small percentage of the reward to previous actions that led to the one carried out immediately before an intervention took place. Some simulations were carried out to help decide the optimal parameters values. Further details of the simulations are explained in App.E.2.

6.3.4 Experimental Procedures

45 male participants were recruited using the same method as the earlier experiments. All were Arsenal F.C. supporters who had scored 4 or higher in a scale from 1 (not at all) to 7 (very much so) on the question "How much do you support your team?", as explained in Section 3.4.1. There were three experimental groups that were carried out sequentially, so a new group was started once all 15 participants from the previous group had experienced the scenario. All participants

went through the scenario during nine calendar days, also making sure that Arsenal F.C. had not played any important game during that period that could influence the Arsenal F.C. supporters' level of optimism. The remaining procedures were similar to previous experiments (Section 3.4) with a few variations. Before the VR experience, participants also had to fill out the 44-items Neo Big Five Inventory questionnaire [John and Srivastava, 1999]. Four new questions were added to the post-experience questionnaire (App. D.9). These new questions were related to the actions that the virtual characters performed (Table 6.4). Participants were not interviewed; in compensation two additional questions were added to the questionnaire to elicit the level of authenticity of their responses with a numerical value, and a text box was added for them to give their opinion about anything that was not covered in the previous questions.

The overall mean age was 22.65 ± 3.95 with no significant differences between experimental groups. The 44 item Neo Big Five questionnaire was filled out before the VR experience and showed no differences between groups on either of the five traits – extraversion (mean±standard deviation, 23.8 ± 5.7), agreeableness (30.1 ± 5), conscientiousness (27.4 ± 6.2), neuroticism (17.5 ± 5.4), and openness (35.1 ± 4.1).

6.3.5 Results

The response variables were the total reward (Reward) obtained and the number of interventions, either physical (nPhys), verbal (nVerb), or both (AllInterventions = nPhys + nVerb). There is an increase on the reward mean value of the successive groups (All Random 7.57 ± 8.17 ; Middle Random 11.5 ± 8.44; Least Random 12.07 ± 8.82). The ANOVA on Reward shows that these differences are not statistically significant ($P = 0.297$), but the residuals are not compatible with normality (SW $P = 0.026$). Even transforming rewards to $\sqrt{Reward + 1.3}$ (-1.3 was the total reward obtained by somebody that did not intervene after any of the 13 actions taken), SW returns that the data is not normally distributed (SW $P = 0.015$). Kruskal-Wallis test results show that there are no significant differences on Reward per Group ($\chi^2 = 0.94$, df=2, $P = 0.19$). AllInterventions is highly

Character uttering	Utterance
PresenceBytandersEncouraged	I felt more determined to intervene after hearing the other people in the bar shouting out
VictimLookedEncouraged	After the argument started, the victim looking at me made me more likely to intervene
PerpLooked	After the argument started, the aggressor looked at me.
PerpLookedEncouraged	After the argument started, the aggressor looking at me increased the likelihood of me intervening.
ReactionAuthentic	To what extent you would say your reaction authentic?
ScenarioRealistic	Despite knowing that it was a simulation, how realistic do you think the scenario was?

Table 6.4: Questions added in the post-experience questionnaire that participant had to answer on a scale from 1 (not at all, at no time) to 7 (very much so, almost all the time). The first four questions referred to the presence of the virtual characters performed and the actions they performed. The last two were added from the interview.

positively correlated with the reward ($r = 0.83$, $P < 0.00005$), as shown in Fig. 6.7. This was the expected result, as the reward is obtained when participants intervened. The interventions were signalled to the RL agent as binary indicators on whether a verbal, physical, or both types of interventions had occurred since the last action had been performed. The actual total number of interventions was computed by coding the participants' responses once they had left the laboratory using the standard criteria described in Section 3.6.

The main hypothesis was that the number of interventions would increase once the experience collected was sufficient and used on subsequent participants. But rather than only looking at the groups established by the ε value and the initial Q values, it is also important to account for the actual number of exploratory actions (PercentageRandom) taken for each participant, as ε only determined the

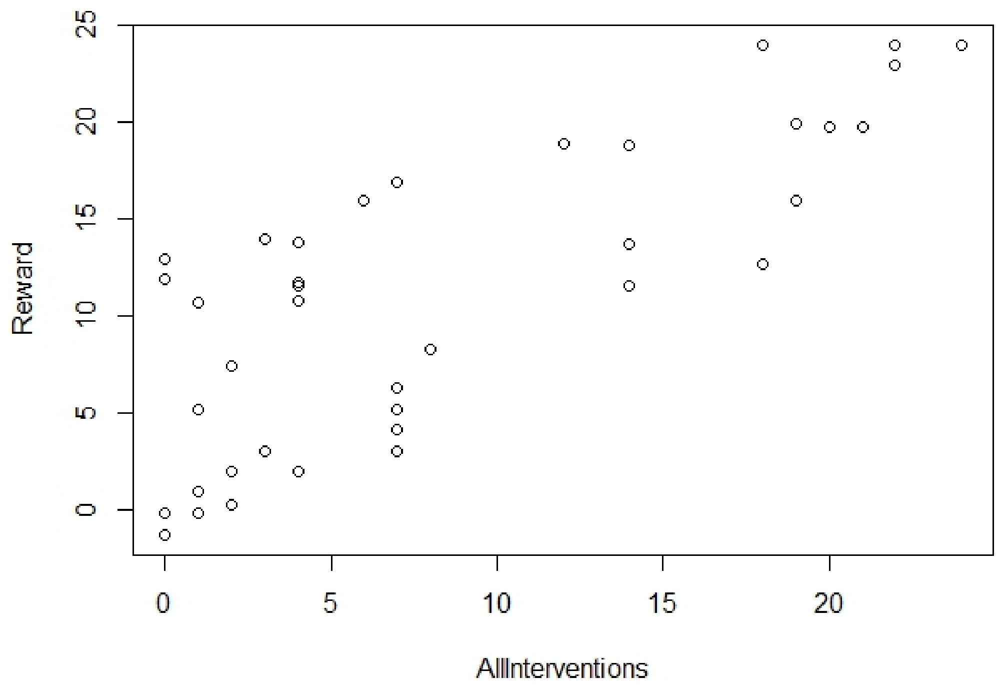
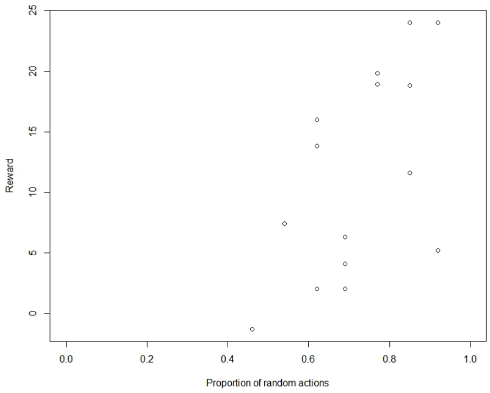
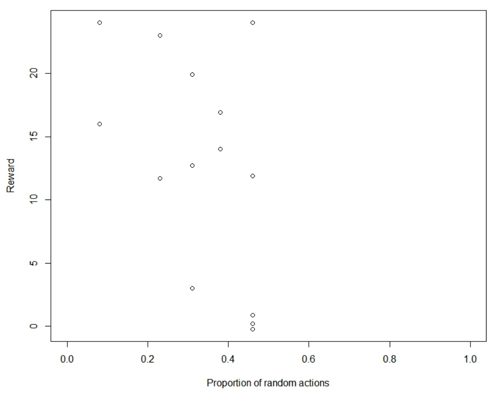


Figure 6.7: Scatter plot of Reward and AllInterventions.

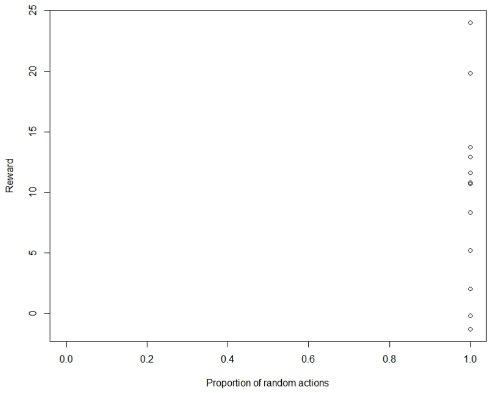
probability that each action would be exploratory. The scatter plots (Fig. 6.8) show that the reward is positively correlated with the number of random actions in the Middle Random condition (Fig. 6.8a), and it is inversely proportional in the Least Random (Fig. 6.8). The Random group is not considered in this part of the analysis, as PercentageRandom=1.0 for all the participants in the group (Fig. 6.8c). A regression analysis on the model $AllInterventions = Group + PercentageRandom + Group \bullet PercentageRandom$ (table 6.5) shows that the main contributor is the interaction factor. This supports the initial hypothesis that the reward would increase over successive groups, if we also take into account the percentage of random actions. Sufficient data had to be collected before being in the position to provide an optimal solution. The experience accumulated prior to starting the Middle Random group was not sufficient to know which action made participants more likely to intervene. In that group, people intervened more when random actions were tried. Conversely, in the last group, Least Random, the



(a) Middle Random ($\varepsilon = 0.6$).



(b) Least Random ($\varepsilon = 0.3$).



(c) All Random ($\varepsilon = 1.0$).

Figure 6.8: Scatter plots of reward on the actual proportion of random actions for each experimental group.

higher rewards were obtained when exploiting the experience accumulated rather than exploring other non-optimal actions. The results show that the experience accumulated from earlier groups was enough to have a sufficiently accurate model of human behaviour to try to increase the number of times they intervened. This is in spite of individual differences among the participants which may have made them more (or less) likely to intervene when witnessing a social situation that involved violence.

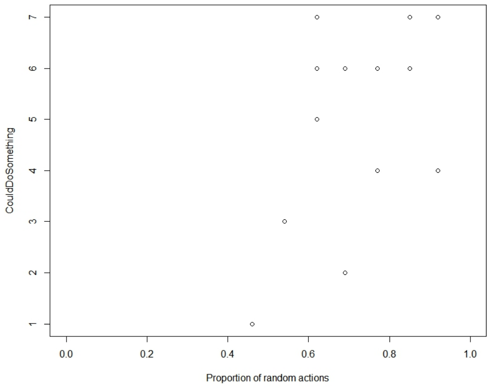
We also looked at the question "After the argument started, I felt I could do something to stop it" (CouldDoSomething) from the post-experience questionnaire as a response variable. Despite the fact that the confrontation was scripted except for the actions that the virtual characters performed, these questions referred to the

	Coef.	Std. Err.	t	P	95% Conf. Interval
(Intercept)	-15.27	9.51	-1.61	0.1205	-34.83 to 4.28
Least Random	39.91	10.67	3.74	0.0009	17.98 to 61.85
PercentageRandom	32.79	12.92	2.54	0.0175	6.23 to 59.35
Group:Least Random● PercentageRandom	-77.84	18.89	-4.12	0.0003	-116.66 to -39.02

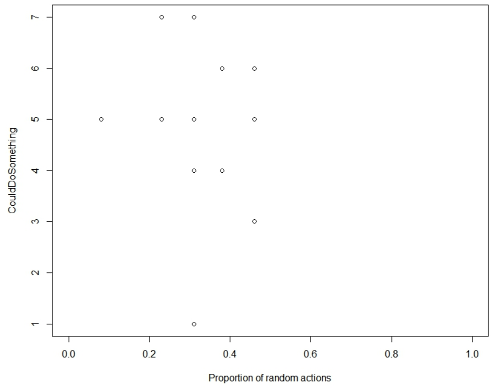
Table 6.5: Regression of AllInterventions on Group and PercentageRandom. $F(3,26) = 4.44$, $P = 0.003$, $R^2 = 0.4$

extent they thought they could change the course of events. The scatter plots (Fig. 6.9) show a clear positive slope for CouldDoSomething on reward in the Middle Random group (Fig. 6.9a), while the slope is negative in the Least Random group (Fig. 6.9b). CouldDoSomething is an ordinal variable with seven possible values. This type of variable can be analysed with an ordered logistic regression. As in the regression analysis of the Reward, the initial group All Random was not included, as all the actions were random. The results on CouldDoSomething by Group and PercentageRandom show that the interaction term Group●PercentageRandom is significant ($z = -2.06$, $P = 0.039$). This analysis shows that people had a stronger feeling that something could be done about the confrontation when fewer random actions were taken in the last group, in which sufficient experience had been already collected.

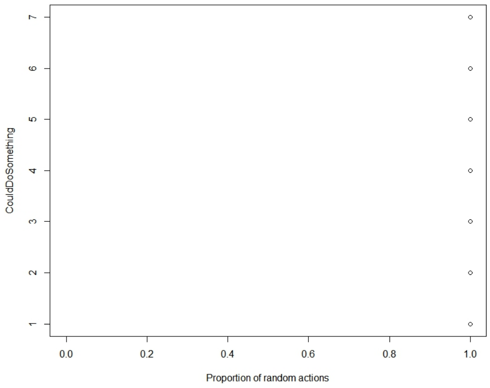
The best action per state (Table 6.7) referred to the action in each state that returned to highest reward in previous trials (i.e. it had the highest chance of leading to participant's intervention) thus making it the most likely to elicit an intervention in future trials. The percentage of participants with the same best action increased over the groups. In the last one, Least Random, the results were almost unanimous. The results in the first group, All Random, are not conclusive, as the percentage of people choosing the same best action is due to the fact that not all participants



(a) Middle Random ($\varepsilon = 0.6$).



(b) Least Random ($\varepsilon = 0.3$).



(c) All Random ($\varepsilon = 1.0$).

Figure 6.9: Scatter plots of CouldDoSomething on the actual proportion of random actions for each experimental group.

	Coef.	Std. Err.	z	$P > \|z\|$	95% Conf. Interval
Least Random	6.80	3.19	2.13	0.033	0.56 to 13.05
PercentageRandom	9.71	4.15	2.34	0.019	1.59 to 17.84
Group:Least Random$\bullet$ PercentageRandom	-10.97	5.31	-2.06	0.039	-21.38 to -0.55

Table 6.6: Ordered logistic regression analysis of CouldDoSomething on Group and PercentageRandom.

moved to all three states, therefore no data is available for these states that were not visited. It was very unlikely that a participant moved to all three areas during the confrontation, only 1 did so, out of 45 participants in total. In the Least Group, the best action per state was computed using the Q values of the next-to-last action instead of the last one. This was to avoid an anomaly in the data that made the Q value of the last action drop significantly for some participants, even if they intervened. This was caused by the design of the scenario. In the last seconds of the confrontation, the perpetrator started pushing the victim towards the wall in the front part of the bar, and moving away from the participant. The increase in the distance between the participant and the virtual characters was interpreted by the RL agent as the participant moving away from them, falling to a state where an intervention was less likely. This unforeseen matter was likely to confuse the RL by punishing the last action with a negative reward even if the participant had intervened, as moving to a state where interventions are less frequent makes an action be rewarded negatively. This also slightly affected the previous groups that could have affected the computation of the average Q values. Despite this, the RL agent was able to collect enough good information to prevent a negative effect of this anomaly.

The study of the best action per state, is that the perpetrator turning the head to look at the participant was the action that made an intervention more likely when the participant was within intervention distance ($< 0.5m$). A bit further away, in the active distance ($0.5m < d < 1.0m$), V looking at the participant was the action that led to more interventions. However, the results are not conclusive for the passive distance ($> 1.0m$), the furthest from the virtual characters, as this state was visited only by one participant on the Least Random group. The number of participants who visited the passive distance progressively decreased for each group (6 participants in the All Random group, 3 in the Middle Random, and 1 in the Least Random). This is also an interesting result; the more the experience was collected and used, the closer the participant stayed to the virtual characters throughout the confrontation.

	Intervention dist. ($d < 0.5m$)	Active dist. ($0.5m < d < 1.0m$)	Passive dist. ($d > 1.0m$)
All Random	P look at (20%)	Bystanders utter (33%)	V look at (20%)
Middle Random	P look at (73%)	V look at (87%)	P look at (20%)
Least Random	P look at (100%)	V look at (93%)	P look at (100%)

Table 6.7: Best action per state and group. Between brackets, the percentage of participants with the specified best action. The distance indicated how far the participant was from the middle point between the victim and the perpetrator.

6.3.6 Discussion

Here we have shown that RL can provide learning capabilities that, with the help of experience collected from previous trials, learns to predict people's behaviour and use this knowledge to make them respond in a pre-specified way to a violent emergency. This scenario is more complex than the one in the previous experiment, explained in Section 6.2. In the previous one, people had to move around to avoid being hit by virtual projectors. The bar scenario involves more complex interactions of the participants with the virtual characters in the scene. The RL agent created a statistical model to understand what actions the virtual characters could do in order to maximize the likelihood of intervention in the violent emergency, despite the differences between participants' personality.

The results need to be put in the perspective of not only the experimental groups, but also the actual number of random actions taken for each participant. Taking a low number of random actions too early means that it will try to exploit information that is not sufficiently accurate. On the other hand, when the information is collected and too many random actions are taken, the agent will be failing to maximise the total reward obtained. This is shown in the results obtained in this experiment. Participants who intervened more in the Middle Random group were those who experienced the scenario with more random actions taken, while the opposite happened in the last group, Least Random.

Looking at the best action depending on the distance between the participant and the virtual characters, the results showed that the perpetrator turning his head to look at the participant was the most effective way to make them intervene when the participant was either very close to them or far away. If the distance was between 0.5m and 1.0m, then the best action was to make the victim look at the participant. We put these results in the perspective of Psi. A participant perceiving the virtual characters looking directly at him, can make him feel acknowledged thus he thinks he is part of the scenario and enhances the belief that his actions could influence the outcome of the scenario. Nevertheless, both the virtual characters' animations and the dialogue between them in the confrontation were scripted. Only the action of making one of them look at the participant or the virtual bystanders saying something out loud were selected dynamically. It is also interesting to point out that the participants felt a stronger feeling that their actions could make a difference in the scenario when enough experience was available and used.

The setup of a RL problem is a critical step for convergence to a solution. The size of the state-action space needs to be adjusted to guarantee that all the possible state-action pairs will be tried a reasonable number of times. Additionally, it also depends on whether the environment is deterministic or the outcome of each state-action pair can be different every time it is tried. In the case of studying human behaviour, the result of each action is highly unpredictable, as it also depends on the person's personality, making the experience collected from previous participants not valid for everyone. The model of human behaviour that the method creates needs to be constantly adjusted based on recent observations. Future experiments could include the scores of the different personality traits obtained from a questionnaire before the experience in order to predict whether someone has a higher predisposition to intervene and adjust the strategy before the scenario starts.

6.4 Chapter Summary

The results of the first experiment described in this chapter showed that RL can be used to make people perform simple tasks in IVR. That experiment was focused on making people move to a target position and making them stay there the longest time possible. The RL agent learned how to make them move without having any prior experience for any participant. It could only partially override the feeling of participants that staying in the centre of the scene is safer than moving to a corner when their task is to avoid virtual projectiles thrown at them. Despite this, the results show a convergence towards the expected results, and we speculate that this could be achieved if the scenario was longer, allowing further experience to be collected. However, there was a limitation in the length of the scenario that depended on participants getting tired after 7 minutes moving around and performing sharp movements some times. The RL problem needs to be designed carefully, adjusting the size of the state-action space depending on the number of trials that will be carried out and the uncertainty of the outcome of each state-action pair. RL offers the possibility of adjusting the policy depending on recent observations, and changing its strategy accordingly to maximise the chances of reaching the goal.

The second experiment used a RL agent in a more complex scenario – the bar scenario. The RL initially had to learn how participants responded to a reduced set of actions that the virtual characters in the scene performed, and whether these actions could lead to the participants intervening in the confrontation. Afterwards, in subsequent experimental groups, the information collected previously was used to increase the number of interventions. The confrontation was short and it only allowed a reduced number of actions for each participant, therefore the agent focused on learning how an average person behaves, considering that not all participants respond to an emergency the same way. The main finding of that experiment is that the number of interventions is increased over the experimental groups if we take into account the actual number of random actions and the amount of experience collected before the trial. These results are promising and show evidence that RL can be used to learn rules to influence human behaviour.

In the last experiment, we also showed how RL was used to learn human behaviour with a reduced set of participants, compared to the number of participants that would be needed in a full factorial study with same number of experimental variables and factors. Trying all permutations of the three actions, considering 10 participants per experimental condition as in previous experiments, would have required 80 participants. However, this is an inexact estimation, as the distance between the participant and the two virtual characters arguing is not being considered when giving this estimation. Our setup also allowed the RL agent to adjust the strategy taking into account the distance between them. When the participant kept a distance from the confrontation considered to be 'safer', meaning that participant took a passive role, certain actions did not increase the likelihood of intervention directly, but made people move closer into distances where interventions were more likely to happen. Additionally, bystanders' utterances did not seem to have a great impact on the participants' responses in this particular scenario, therefore this action was carried out less often in the last experimental group. Knowing a priori that bystanders' utterances would not make an impact on the results could have made us rethink the design of the experiment about the bystander effect, described in Section 5.3. This would have meant reducing the the number of participants and the time needed, or investing these resources on other possible variations, such as making P look at the participant.

Virtual environments are built to place people in a specific situation and expose them to an experience – whether it is just entertainment, therapy, training, or some other goal. Usually the goal is to let them explore the environment freely and, in some cases, observe their responses. But what if the goal is to make them respond in a specific way? This could be the starting point to implement scenarios in which the goal is to learn how to, for example, teach something to people. This chapter described two examples of this and how to influence their behaviour in a systematic way, using a system that adapts the strategy to each participant. Future applications need to test this novel experimental framework in more complex scenarios where different outcomes are possible and where a larger set of actions can be tried. The use of RL in IVR is a promising field that could lead to new ways of performing research in behavioural sciences in the future.

Chapter 7

Conclusions

There is evidence in the literature that people can have realistic responses in immersive virtual reality (IVR) when the system used meets certain technical requirements [Sanchez-Vives and Slater, 2005], including a low-latency [Meehan et al., 2003] stereoscopic display with a minimum field of view [IJsselsteijn et al., 2001] and a 6 DoF head tracking system [Barfield et al., 1999] to adjust the imagery to the user's perspective. When this happens, a person has the illusion of 'being there', in the simulated environment. This illusion is referred in the literature as the sense of presence [Zahorik and Jenison, 1998, Witmer and Singer, 1998, Sanchez-Vives and Slater, 2005] and is associated with how similar the sensorimotor contingencies (SCs) afforded by the system are to those in real life. Additionally, a person can have the illusion that the events that occur in the IVE are actually happening when he thinks he can interact with the scene and the entities in the scene react to his actions [Slater, 2009]. This allows the use of this technology to expose people to situations and observe their behavioural responses to them in a controlled laboratory environment. It has been argued that IVR can be useful in the study of people's behaviour in social situations [Loomis et al., 1999, Blascovich et al., 2002]. Although this research does not provide further evidence on this direction due to ethical reasons not allowing to set up the same scenario in real life to compare the results, people reported high levels of authenticity on their responses and this can help to test theories in order to explain bystander responses in real life emergencies. In addition to this, IVR can also help to overcome some ethical issues, as participants know that the environment is a simulation and the virtual characters neither will get hurt nor try to physically harm them.

In the scenario, participants had to decide how to respond to a violent emergency in a pub. In the pub, two virtual characters start an argument about football in which one of them, the perpetrator, becomes increasingly aggressive towards the other, the victim, who tries to avoid the confrontation. Each participant had to decide if they want to intervene in the argument or step back and observe how the events unfold without their intervention. This scenario provided a way to manipulate the ingroup-outgroup social identity between participants and the other characters in the scene by changing the shirt the virtual characters wore. It is easy to encourage rapport between the participant and a virtual character by presenting the latter as a football supporter of the same team the participant supports. IVR also provides the possibility of easily manipulating specific details of the scenario keeping the rest of elements constant.

Chapter 4 explored the changes in people's responses when manipulating the victim's social identity as well as whether the victim looking at the participant would make the latter more likely to intervene. Chapter 5 described an experiment that was carried out to measure the impact of a change in the display resolution and luminance in the VR system on people's responses to the violent emergency. A second experiment focused on the bystander effect. Three virtual bystanders were added into the scene and we observed how their presence, their social identity and their position with respect to the argument influenced the participant's responses. Chapter 6 contains two experiments that aimed to use a reinforcement learning (RL) algorithm to learn people's behaviour and subsequently exploit this knowledge to elicit a specific response from them. The first experiment was aimed at making the participants move to a specific location in the IVE and making them stay there as long as possible. In the second experiment, the learning capabilities were incorporated into the violence scenario to study which actions that the virtual characters carried out made participants more likely to intervene. The remainder of this chapter is dedicated to enumerating the findings obtained in the experiments, a summary of the contributions that this thesis provides, both methodological and substantive, and lastly proposing future directions of this research.

7.1 Victim's Affiliation Experiment

The volunteers that helped during the piloting rated their responses as highly authentic during the violent incident, even though they knew the scenario was only a computer generated simulation. This provided the starting point to study what made a person more likely to intervene in an emergency of a violent nature. The interventions were classified into two different types, physical and verbal, as the data collected showed that these two types of interventions followed different distributions. Overall, the number of verbal interventions was higher than the physical ones and physical interventions were usually combined with verbal utterances.

Social identity between the bystander and the victim of an emergency is an important factor that influenced the number of interventions, both physical and verbal. The results showed that participants who underwent the Ingroup version intervened more than those in the Outgroup, both verbally and physically. In the Ingroup version, a common feeling was the sense of discomfort and the thought that they had to do something about it. On the other hand, the participants who experienced the Outgroup version described the situation as silly and felt less attached to the victim. These results are in the same direction as other experiments on affiliation and social identity, for example [Levine and Manning, 2013].

The other experimental variable determined whether the victim looked at the participant five times in total during the confrontation. The participant's belief that the victim looked at him rather than simply that the victim turned his head to look at the participants was associated with an increase in the number of physical interventions, but only in the Ingroup version. Other factors that influenced the likelihood of intervention are related to the feelings they had during the confrontation. The participants' feeling that they had to stop it was positively correlated to the number of interventions. Likewise, those who were concerned about the victim's safety also intervened more.

7.2 Display Characteristics Experiment

An experiment was carried out to test how a single upgrade to the VR system could have an impact on the results of the violence scenario. The displays in the IVR system were upgraded with higher luminance and pixel resolution, keeping the rest of the system specifications identical. The results showed a significant difference in the number of interventions and therefore, special attention must be paid to keeping the system specifications constant throughout an experiment, as this may be a source of extraneous variables.

7.3 Bystander Effect Experiment

Three virtual bystanders were added to the scene. They were all either ingroup or outgroup depending on the experimental version, while the victim was ingroup with the participant in all versions. The bystander effect states that the likelihood of intervention is inversely proportional to the number of bystanders present [Darley and Latané, 1968]. This phenomenon was observed in the Ingroup version, where the virtual bystanders were depicted as supporters of the same football team as the victim and the participant. The results in the Outgroup version were similar to those obtained in the previous experiment with the new projector configuration, which was an identical setup except for the presence of the virtual bystanders. Therefore, they intervened as much as if they were the only bystander in the scene. The second experimental variable was whether the virtual bystanders encouraged or tried to dissuade anyone from intervening by saying out loud three utterances, even though they did not intervene. We did not find support for the results described in [Levine et al., 2011] that stated that an individual's responses are influenced by ingroup bystanders.

7.4 Reinforcement Learning in Immersive Virtual Reality Experiments

RL was used in two different experiments. The first one aimed to learn how people move in an IVE and how to guide them towards a specific location. The results confirmed that people end up staying in the target area or nearby once sufficient experience was collected, considering that the RL agent learned with no previous experience and without using data from previous participants. The experimental versions that used the experience collected throughout the scenario scored higher rewards than the version where the experience was not used at all. However, special attention needs to be paid to the design of the RL problem; it needs to allow for a sufficient number of tries to ensure that enough data will be collected in order to converge to a solution, taking into account the size of the state-action space.

The second experiment's goal was to test the learning capabilities in the violence scenario to elicit a more complex outcome: the participants intervening. In this case, experience was collected throughout the participants and, despite differences in their personality, the agent built a map with the probability of the people's responses after different actions were performed by the virtual characters. The results showed that the agent was able to learn how people respond to the violent emergency and use this experience to maximise the likelihood of participants intervening in the confrontation. It is very important to know when the data collected is sufficient to have an accurate idea of how the environment changes, otherwise exploiting an incomplete map of information can lead to an unpredictable outcome.

7.5 Contributions

This thesis has presented an experimental framework that uses IVR to expose people to extreme emergencies and observe their responses. We have provided the example of exposing participants to a violent emergency and studied what parameters increased the likelihood of intervention. The experimental setup provides a higher degree of internal validity as the scenario can be played as many times as necessary. As it is a computer generated simulation, the risk of introducing extraneous variables due to repetition is significantly reduced. Moreover, it also provides the possibility of carrying out experiments with high ecological validity, as these technologies can be programmed to preserve sensorimotor contingencies in perception and allow users to interact with their environment with natural movements of their body, similar as they would do in real life, thus enabling IVR to better understand how people would respond to extreme social emergencies in the real world. Additionally, RL contributed to define a new experimental methodology aimed at reducing the number of participants needed for an experiment with various experimental variables with possible interactions between them. Secondly, this technology was used to provide substantive results on how people responded to a violent incident.

7.5.1 Methodological Contributions

This thesis has provided further evidence that IVR can be used as an experimental framework to carry out behavioural studies in which participants are placed in social situations, more specifically extreme emergencies in which a person can be exposed to stressful situations. We have described how this setup helps to overcome some ethical issues derived by the deceptive nature of experiments using confederate actors, without having the experimental validity compromised. IVR has the advantage of higher internal and ecological validity than studies based only on questionnaires or observations in the real world.

A new research methodology has been outlined with the use of IVR and RL. This methodology differs substantially from traditional methods that investigate the different permutations of experimental variables when interactions among the variables can also explain the results. The number of participants needed for full-factorial experimental designs grows exponentially with the number of variables to the point that makes many studies infeasible. The idea behind the new methodology is the use of RL as a heuristic allowing us to try different options to understand what combinations of variables have higher impact on the response variables. As the data about people's responses is being collected, the agent focuses more on those that seem important in detriment to others that have a higher chance to be significant.

7.5.2 Substantive Contributions

We have presented a study in which people reported having realistic responses to a computer simulation. We were able to use these technologies to study the behaviour of people in a situation that could not be studied in real life for ethical reasons. This thesis has provided further evidence that social psychology is a research area where this new methodology can be applied. Looking back at the research questions (Section 1.1), the experiment about the victim's affiliation showed that a bystander is more likely to help when there is a shared identity between the victim of an emergency and him. These results are similar to those that have been obtained in studies about emergencies using a real world setup. The novelty is that we have provided evidence that this also happens in an IVE. The experiment about the display characteristics (Section 5.2) showed that keeping the technical specifications of a virtual reality system constant throughout a study is very important in order to prevent introducing extraneous variables in experiments about presence. Despite the pixel resolution and the luminance levels in the Pre-upgrade version being sufficient for this, our experiment showed that a modification to the display characteristics led to different results in the number of interventions. The experiment about bystander effect (Section 5.3) provided evidence that this phenomenon also occurs in IVR, although it is conditioned to whether the bystanders share a social identity with the victim. All these findings can contribute to build theories about how people respond to a violent emergency in real life.

Using the RL capabilities in IVR, an agent can learn to influence people's behaviour, not only to make them perform simple tasks such as making them move to a target location in the virtual environment, as the first experiment using RL shows, but also using this technique in more complex scenarios where the agent needs to learn how to elicit a specific response from participants in a social situation. The last experiment presented in this thesis showed that, with enough experience collected from earlier participants, a statistical model of human behaviour can be built and later be used to maximise the likelihood of a bystander intervening in a violent emergency, despite the differences in personality among participants.

7.6 Future Work

One of the most important aspects that participants pointed out that made the scenario less realistic was the lack of responsiveness of the virtual characters to the actions that participants performed during the confrontation. The absence of interaction dissuaded them from intervening as they realised they could not do anything about it, which made them feel they were not part of the scene and became spectators. However, implementing artificial intelligence to create convincing interactions between people and virtual characters is not straightforward, as human behaviour is highly unpredictable. A computer-based system that is able to deliver plausible interactions should include speech recognition capabilities and non-verbal language interpretation. Algorithms that detect and process voices in noisy environments is ongoing research and there is not a robust implementation yet. Our design was based on triggering the virtual characters' responses manually by an operator, but implementing these interactions automatically and without breaking on the plausibility illusion is a task that entails a high level of complexity. A starting point would be to implement generic responses that can be triggered manually, such as making the virtual characters turn their head towards the participant a moment after they intervened using a voice detection algorithm. These types of basic actions are not difficult to implement and could increase the plausibility, making them preserve the illusion that they can influence the outcome of the scenario. An effective system should also include a way to store information (memories) and process it to be used in future interactions. There is a lot of work to be done in this field, and the use of RL is a step forward towards this direction.

Another technical aspect is that, in violent emergencies, physical contact is a very important factor. Providing haptic feedback would definitely be a major upgrade, as participants could touch other people with their hands and also induce the fear of being in physical danger. However, bulky haptic devices might not be the best choice for this type of study, as they could hinder the freedom of movements and affect negatively the authenticity of their responses.

This research used a violent emergency as an example to show how these technologies can be used for behavioural studies. Other scenarios can be studied to understand violence in a different context and perspective, for instance making the participant be the victim or even the perpetrator. Furthermore, this thesis is not limited to emergencies with a violent nature. The study of other types of extreme emergencies can also benefit from using IVR as an experimental framework. The findings reported in the experiments can be of great value to the social psychology community as well, who can see a lot of potential in using IVR. These technologies are not limited to observational studies only; they can also be used, for example, to foster pro-social behaviour and encourage helping other people.

Further research needs to be done to understand the advantages of using RL. We have described two experiments that used RL, but other more sophisticated setups with larger sets of actions need to be tried. In the experiments included in this thesis, the number of actions was kept small to ensure the RL algorithm would converge to a solution. Longer scenarios with larger sets of actions and state variables can be tried. Moreover, the idea of creating an average model of people's responses to a specific situation should be more flexible, so the data could be combined with results obtained in similar emergencies to predict their responses. When the agent tries a scenario for the first time, if it is a violence emergency, it can search for data about similar violence emergencies studied in the past. If there are no data available about violent situations, make some initial assumptions based on the responses observed from an emergency of a similar nature. For example, although the strength of the bystander effect can be diminished depending on the perceived level of danger of the emergency [Fischer et al., 2006], a RL agent could know in advance that a person is less likely to intervene in any type of emergency if he is not the only one who witnesses it.

At the time of writing, IVR is entering a new stage with several low price

HMDs about to be released at affordable prices targeting at end-consumers. Different types of applications will be released in the coming years, starting from video games and other options in entertainment. Among the most popular ones are the Oculus Rift[1], the HTC Vive[2], the Samsung Gear VR[3], and the Project Morpheus[4]. These prototypes define a new generation of high pixel density, low latency head tracking and also aim to keep the sales price in the range of a few hundreds dollars to make them affordable to end-consumers. Although currently the devices are mainly designed for entertainment, it is not difficult to foresee that the scientific community will also use them in different research fields, as has already happened with the released prototypes in previous years. These upcoming models enable to carry out the type of studies presented in this thesis at a much reduce cost compared to when our research was carried out.

Today's citizens have been described sometimes as a nation of onlookers that will not offer help to other people in emergencies. News reports cases of failure to assist people who need assistance too often, even to help the most vulnerable people in society, such as children hit by a car (http://www.bbc.co.uk/news/world-asia-pacific-15398332) or being abducted (http://ed.ted.com/on/LfrtkfEN). Nevertheless, delivering help successfully could not be possible in other cases without the presence a large number of bystanders (http://www.bbc.co.uk/news/magazine-32993891). From the 'safety in numbers' to the diffusion of responsibility, the social identity, and the nature of the emergency, there are multiple factors that can influence helping behaviour in extreme situations, but the lack of a safe and valid experimental framework to study these types of situations has hindered research on these topics for decades. This thesis has addressed this issue by showing how immersive virtual reality and reinforcement learning can be combined to depict social situations, obtain realistic responses, and test different versions of a scene reducing the overhead of participants and time that this usually implies in other traditional experimental methodologies.

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[1] https://www.oculus.com/
[2] http://www.htcvr.com/
[3] http://www.samsung.com/global/microsite/gearvr/gearvr_features.html
[4] https://www.playstation.com/en-gb/explore/ps4/features/project-morpheus/

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Appendix A

List of Published Papers

A.1 Papers Related to the Thesis

The use of virtual reality in the study of people's responses to violent incidents.paper:Rovira2009

Aitor Rovira, David Swapp, Bernhard Spanlang, and Mel Slater, 2009.

Frontiers in Behavioural Neuroscience

Bystander responses to a violent incident in an immersive virtual environment.

Mel Slater, Aitor Rovira, Richard Southern, Jian J. Zhang, Claire Campbell, and Mark Levine, 2013.

PLoS One

```
@article{Slater2013,
  title = {Bystander responses to a violent incident in an immersive virtual environment},
  author = {Slater, Mel and Rovira, Aitor and Southern, Richard and Swapp, David and Zhang, Jian J. and Campbell, Claire and Levine, Mark},
  journal = {PLoS One},
  keywords = {Avatars, violence, virtual environments},
  number = {1},
  url = {http://dx.plos.org/10.1371/journal.pone.0052766},
  volume = {8},
  year = {2013}
}
```

The impact of enhanced projector display on the responses of people to a violent scenario in immersive virtual reality.

Aitor Rovira, David Swapp, Richard Southern, Jian J. Zhang, and Mel Slater, 2013.

Virtual Reality (VR), 2013 IEEE

```
@inproceedings{Rovira2013,
  title = {The impact of enhanced projector display on the responses of people to a violent scenario in immersive virtual reality},
  author = {Rovira, Aitor and Swapp, David and Southern, Richard and Zhang, Jian J. and Slater, Mel},
  booktitle = {Proc. 20th IEEE Virtual Real. Conf.},
  editor = {Coquillart, Sabine and LaViola, Joseph J and Schmalstieg, Dieter},
  keywords = {avatars, bystander behavior, cave system, computer graphics, graphics and realism, presence, projectors, user studies, violence, virtual environments, virtual reality},
  pages = {15–18},
  publisher = {IEEE},
  url = {http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6549350},
  year = {2013}
}
```

Bystander Affiliation Influences Intervention Behaviour – An Immersive Virtual Reality Study

Aitor Rovira, Richard Southern, David Swapp, Jian J. Zhang, Claire Campbell, Mark Levine, and Mel Slater.

In review.

```
@article{Rovira2015a,
  title = {{Bystander Affiliation Influences Intervention Behaviour âĂŞ An
  Immersive Virtual Reality Study},
  author = {Rovira, Aitor and Southern, Richard and Swapp, David and Zhang,
  Jian J. and Campbell, Claire and Levine, Mark and Slater, Mel},
  journal = {Frontiers in Psychology},
  keywords = {Bystander intervention, virtual reality, ingroup, outgroup, diffusion
  of responsibility},
  url = {}
  year = {}
}
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Reinforcement Learning as a tool to make people move to a specific location in Immersive Virtual Reality

Aitor Rovira, Mel Slater.

Submitted to International Journal of Human-Computer Studies

```
@article{Rovira2015b,
  title = {Reinforcement Learning as a tool to make people move to a specific
  location in Immersive Virtual Reality},
  author = {Rovira, Aitor and Slater, Mel},
  journal = {International Journal of Human-Computer Studies},
  keywords = {Immersive Virtual Reality, Reinforcement Learning},
  url = {}
  year = {}
}
```

A.2 Other Papers

Lie tracking: social presence, truth and deception in avatar-mediated telecommunication

William Steptoe, Anthony Steed, Aitor Rovira, and John Rae, 2010.

Proceedings of the SIGCHI Conference on Human Factors in Computing Systems

```
@inproceedings{steptoe:2010,
    title = {Lie tracking: social presence, truth and deception in avatar-mediated
    telecommunication},
    author = {Steptoe, William and Steed, Anthony and Rovira, Aitor and Rae,
    John},
    booktitle = {Proc. SIGCHI Conf. Hum. Factors Comput. Syst.},
    keywords = {Avatars,avatar-mediated communication,deception,eye tracking,gaze,social
    presence,trust,video-mediated communication,virtual environments},
    pages = {1039–1048},
    publisher = {ACM},
    url = {http://dl.acm.org/citation.cfm?id=1753481},
    year = {2010}
}
```

Embodying Compassion: A Virtual Reality Paradigm for Overcoming Excessive Self-Criticism

Caroline J. Falconer, Mel Slater, Aitor Rovira, John A. King, Paul Gilbert, Angus Antley, and Chris R. Brewin, 2014.

PLoS One

```
@article{Falconer2014,
    title = {Embodying Compassion: A Virtual Reality Paradigm for Overcoming
    Excessive Self-Criticism},
    author = {Falconer, Caroline J. and Slater, Mel and Rovira, Aitor and King,
    John A. and Gilbert, Paul and Antley, Angus and Brewin, Chris R.},
    editor = {Avenanti, Alessio},
    journal = {PLoS One},
    keywords = {Attitudes (psychology),Biology and life sciences,Clinical
    psychology,Compassion,Computer and information sciences,Computer architecture,Medicine
    and health sciences,Mental health and psychiatry,Mental health therapies,Psychology,Research
    Article,Social sciences,User interfaces,Virtual reality},
    number = {11},
    publisher = {Public Library of Science},
    url = {http://dx.plos.org/10.1371/journal.pone.0111933},
    volume = {9},
    year = {2014}
}
```

Effects of Embodying Self-Compassion within Virtual Reality on Depressed Patients

Caroline J. Falconer, Aitor Rovira, John A. King, Paul Gilbert, Angus Antley, Pasco Fearon, Neil Ralph, Mel Slater, and Chris R. Brewin, 2016.

British Journal of Psychiatry Open submission

```
@article{Falconer2015,
    title = {Effects of Embodying Self-Compassion within Virtual Reality on
    Depressed Patients},
    author = {Falconer, Caroline J. and Rovira, Aitor and King, John A. and Gilbert,
    Paul and Antley, Angus and Fearon, P. and Ralph, N. and Mel Slater and Brewin,
    Chris R.},
    year = {}
}
```

A collaborative process of creating local memory though augmented reality

Ana Moutinho, Ana Javornik, Petros Koutsolampros, Aitor Rovira, Phil Blume, Ava Fatah gen. Schieck, and Simon Julier, 2015.

Media City Conference

```
@inproceedings{Moutinho2015,
    title = {A collaborative process of creating local memory though augmented
    reality},
    author = {Moutinho, A. and Javornik, A. and Koutsolampros, P. and Rovira,
    Aitor and Blume, P. and Fatah gen. Schieck, A. and Julier, S.},
    conference = {MEDIACITY 5 International Conference: reflecting on social
    smart city},
    year = {2015}
}
```

Hypersensitivity to contingent behaviour in paranoia: a new virtual reality paradigm

Miriam Fornells-Ambrojo, Maaike Elenbaas, Chris Barker, David Swapp, Xavier Navarro, Aitor Rovira, Josep Maria Sanahuja, and Mel Slater, 2016.

Journal of Nervous and Mental Disease.

```
@article{Ambrojo2015,
  title = {Hypersensitivity to contingent behaviour in paranoia: a new virtual reality paradigm},
  author = {Miriam Fornells-Ambrojo and Maaike Elenbaas and Chris Barker and David Swapp and Xavier Navarro and Aitor Rovira and Josep Maria Sanahuja and Mel Slater},
  journal = {Journal of Nervous and Mental Disease},
  url = {}
  year = {2016}
}
```

Appendix B

Bar Scenario Script

This is the basic script of the bar scenario. It has two versions, the Ingroup version, which was used in all experiments, and the Outgroup version, only used as part of the first experiment described in chapter 4. The script was modified depending on the goals of each experiment, the changes are explained in detail in the corresponding chapters. The experiment about the victim's affiliation (section 4.3) used the basic script, both ingroup and outgroup versions. The experiment about the upgrade of the display characteristics (section 5.2) used the ingroup version with no further changes either. The experiment about the bystander effect (section 5.3) used the ingroup version with the addition of three new virtual characters as bystanders. The last experiment that used this scenario combining it with RL capabilities (section 6.3) also used the virtual bystanders. In addition, in this experiment the virtual characters performed extra actions that were not scripted. A video of the Ingroup version of the scenario can be visualized in https://www.youtube.com/watch?v=lq-uxFnotHc.

B.1 Characters

- Participant. The person recruited for the experiment. Participants were all male, 18 years old at least, and considered themselves strong Arsenal F.C. supporters.

- V. The victim is the virtual character that is being bullied and tries to avoid the confrontation.

- P. The perpetrator is the other virtual character that shows a belligerent attitude towards V.

B.2 Script - ingroup version

The participant enters the Cave and finds himself in a virtual bar. The bar has some chairs on the left and the bar with tall stools on the right. In the beginning, there is no one in the bar except for him. After about 60 seconds, a male virtual character (V) wearing a red Arsenal F.C. shirt enters the bar through the door on the front. He approaches the participant and engages him or her in a conversation about football. V particularly discusses the Arsenal team asking the participant questions. In the Ingroup version, V tries to be friendly when asking the questions very enthusiastically.

V: You alright mate?

Participant - (...) (Note: the researcher operator waited until the participant had finished before triggering the following expression)

V: Where are you from?

Participant - (...)

V: You're Arsenal, yeah?

Participant - (...)

V: What do you think of the team last year?

P enters the bar and sits down on a stool. He drinks from his glass from time to time and turn the head to look at the two characters chatting. Participant - (...)

V: When did you last go to see a match?

Participant - (...)

V: Who is your favourite player?

Participant - (...)

V: I love Fàbregas, see, I got him on my shirt, so... (while turning around, showing his back to the participant, where it displays the name 'Fàbregas' and the number

4).

V: What do you think our chances are this season?

Participant - (...)

V: We definitely gotta get something, like 5 years ago, Henry, Vieira, Pires ... That was a hell of a team! Do you think we were right to get rid of Henry?

Participant - (...)

V: Anyway, sure, we've got other good players, but do you think we can get a better goalkeeper?

Participant - (...)

A set of utterances was also available in order to a better sense of the conversation and also showing, in the case of the Ingroup version, great optimism. They were played in any order and combination. The outgroup utterances were also available but the following had priority in this version.

V: Good!

V: Not too bad.

V: Get yu!

V: Yeah!

V: I totally agree with you.

V: I'm sure about it.

V: I'll pray for that.

P stands up and approaches the other two but he looks to V all the time, ignoring the participant.

P: Hey, you got a problem?

V: sorry?

P: I said, have you got a problem?

V: no mate.

P: but I saw you looking at me.

V: I didn’t look at you.

P: but I saw ya... I saw ya staring.

V: no, I wasn’t.. I wasn’t staring even.

P: something to get off your chest?

V: no.

P: you sure about that?

V: There’s nothing wrong mate, there’s no trouble, I’m just trying to enjoy a quiet pint.

P: yeah, that’s was I was doing, enjoy a quiet pint

V: get back to your table and enjoy your quiet pint

P: don’t fucking tell me to go back to my table.

V: I’m not telling you what to do mate.

P: I think you was.

V: Just leave it out.

P: Leave it out?

V: There is no need for any hassle, ok?

P: I’m not causing any hassle. I come in here for a quiet drink and you are staring at me.

V: I wasn’t staring at you. I wasn’t even looking at that direction.

P: so are you saying I’m wrong?

V: I’m just saying there’s no trouble here, just...

P: what’s that? (pointing at V’s shirt)

V: what?

P: What the fuck is that?

V: what?

P: Is that a fucking Arsenal shirt?

V: yes.

P: You actually go out of the house wearing a fucking Arsenal shirt?

V: yes.

P: Fucking take it off

V: what?

P: I hate Arsenal, take it off.

V: I'm sorry to hear that. I'm Arsenal fan...

P: Take the fucking shirt off. It offends me, it offends me.

V: I'm not taking my shirt off.

P: you actually walk out of the house with a fucking Arsenal top on?

V: this is ridiculous.

P: it's sick! You actually support Arsenal?

V: yes, I'm an Arsenal fan.

P: What was the last thing they won?

V: It doesn't matter.

P: What was the fucking last thing the won?

V: It doesn't matter, I'm not looking for any trouble...

P: yeah, nothing, nothing! No fucking cups - they're shit!

V: Just leave it out. Just leave it alone, I don't want any hassle.

P: Yeah, well neither did I, but, you know, you come in here with your Arsenal top, giving me grief, staring at me.

V: I didn't realize it was illegal, just let me sit down and have my pint.

P: (Don't) you fucking tell me what to do... I'm not your mate, I don't know you...

V: I'm sorry.

P: your bloody Arsenal shirt...

V: I'm sorry

P: Don't be sorry - what, sorry because you support a shit team?

V: I'm... I'm sorry... wha.. what more can I do? Just... I'm sorry, I'll finish my pint and then I'll go, ok?

P: Why don't you fuck off now? Why don't you leave now?

V: but.. but...

P: Take your pint and fuck off!

V: Why?

P: Because you offend me, that shirt offends me. I told ya, take it off and you can stay here.

V: I'm not gonna take it off.

P: Take it off and you may have a drink.

V: I'm not going...

P: TAKE THE FUCKING SHIRT OFF.

V: Leave it alone... What's going on here?

P: DON'T FUCKING TELL ME TO LEAVE IT OUT! (starts pushing V)

V: What have I done?

P: YOU FUCKING TELL ME TO LEAVE IT OUT? (keeps pushing V)

The image fades out to black and the scenario ends.

B.3 Script - outgroup version

The participant enters the Cave and finds himself in a virtual bar. The bar has some chairs on the left and the bar with tall stools on the right. In the beginning, there is no one in the bar except for him. After about 60 seconds, a male virtual character (V) wearing an unbranded shirt enters the bar through the door on the front. He approaches the participant and engages him or her in a conversation about football. V particularly discusses the Arsenal team asking the participant questions. In the Outgroup version, V shows more neutrality on his interventions, he is very sceptical about Arsenal chances to win trophies and even showing some apathy about the topic.

V: Hi, how is it going?

Participant - (...) (Note: the researcher operator waited until the participant had finished before triggering the following expression)

V: Where are you from?

Participant - (...)

V: You Arsenal, yeah?

Participant - (...)

V: How did they do last season in the Premier League?

P enters the bar and sits down on a stool. He drinks from his glass from time to time and turn the head to look at the two characters chatting. Participant - (...)

V: Do you think they've got any chance of winning anything in the next couple of years?

Participant - (...)

V: Well, the current team doesn't seem to be as good as it used to be: Henry, Vieira, Pires... do you think they were right to get rid of Henry?

Participant - (...)

V: Don't you think they can find a better goalkeeper?

Participant - (...)

V: How many times did the win the Champions League so far?

Participant - (...)

The following set of utterances was also available in order to make a better sense of the conversation and also showing, in the case of the Outgroup version, some lack of interest. They were played in any order and combination. The Ingroup responses were also available but the following had priority in this version. The answers in the Outgroup condition also have a more neutral tone than the Ingroup ones.

V: I see.

V: I don't know, let's see.

V: I don't know mate

V: We'll see.

V: Come on mate, really?

V: Are you sure?

V: You kidding me, right?

V: If you say so.

V: No problem.

V: Nevermind.

P stands up and approaches the other two but he stares at V all the time, ignoring the participant.

P: hey

V: sorry?

P: you want something?

V: no mate.

P: you wanna say something?

V: I don't know what you are talking about mate, just...

P: I just saw you looking?

V: I wasn't looking

P: yeah, but I saw you staring. Are you saying I'm wrong?

V: I didn't...

P: Are you saying I'm wrong?

V: I didn't...

P: I saw you looking over

V: I wasn't looking over at all mate

P: what were you looking at?

V: nothing.

P: but you were looking at something, was it me?

V: I don't want any trouble, I'm just...

P: Is something funny?

V: no.. errr, I'm just trying to enjoy a quiet pint.

P: so was I, and then I saw you staring at me.

V: I wasn't staring at you, so go back to your pint and we'll both have a...

P: don't fucking tell me to go back to my pint... you go back to your fucking pint.

V: I'm at my pint, you've come over here, I don't...

P: This is my pub, you come in here, you tell me to go back in... you tell me what to do!

V: I didn't realize this is your pub.

P: yeah, but it is!

V: alright, sorry mate.

P: Sorry? I'm not your mate. Don't call me your mate, don't call me your fucking mate.

V: sorry.

P: What's that, is that an Arsenal shirt? (pointing at V's shirt)

V: no.

P: you support Arsenal?

V: no..

P: I heard you talking about Arsenal.

V: Just having a conversation about Ars...

P: yeah, well they're shit! I fucking hate Arsenal.

V: I'm not an Arsenal fan.

P: You better not be!

V: I'm not...

P: I fucking hate Gooners. They're shit!

V: Is that a problem?

P: yeah it is a fucking problem, cuz I think you support Arsenal.

V: I'm telling you, I'm not an Arsenal supporter.

P: so why are you talking about them? What were you saying about them?

V: We were just talking about the team

P: Were you talking about what they've won over the last five years? Yeah, fuck all - nothing!

V: Just leave it alone.

P: do you reckon they'll win this season?

V: Just leave it ...

P: do you reckon they'll win this season?

V: I don't... I don't know mate.

P: well, I bet you do. I bet you want them to fucking win. I bet you wear your red shirt and I bet you want them to win.

V: well, they've got a good squad... I don't know...

P: they've got... a what?? A good squad?

V: I'm not an Arsenal fan.

P: you are telling me they've got a fucking good squad?

V: I'm sorry mate, there are a lot of good teams. I don't know...

P: Good team?? They're not a fucking good team. You come in here and tell me Arsenal are a good fucking team? You come down this end and talk about Arsenal? You have the fucking cheek to come into my pub and talk about Arsenal?

V: I'm sorry. Just, let's... Let's leave it alone.

P: Leave what??

V: I'm sorry

P: I was having a fucking drink, I was having a quiet drink, till you started with your...

V: Leave it out.

P: Leave it? You telling me to leave it?

V: I'm just saying there's no need...

P: you don't fucking tell me to fucking leave it!

V: why can't leave it out...

The image fades out to black and the scenario ends.

Appendix C

Experimental Procedures

This is the detailed list of steps that was followed in each experiment, for each participant. This is the generic list, it enumerates all the basic steps, but some modification were introduced in each experiment.

- When the day starts, check that all is working in the lab.

  All four projectors are on.

  Tracking system is up an running.

  Shutter glasses have a working battery and infra-red emitters are not moved.

  Speakers are on and audio level is the same as previous sessions.

  Video camera is in place and plugged to the computer.

  Microphone has good battery level.

  Put the 'Do not disturb, experiment in progress' sign on the VR laboratory door.

- The participant comes, before the experiment starts:

  Ask him to read the information sheet (app. D.5).

  Ask him to read, fill out and sign the consent form (app. D.6).

  Ask him fill out the pre-experience questionnaire (app. D.7).

- When the participant moves into the Cave:

Ask him to take the shoes off.

Give a brief explanation about how VR system works. Show him the head tracking device and explain that this allows him to move anywhere inside the tracking space. Ask him to be careful not to bump onto the physical Cave walls.

Explain how the goggles provide stereoscopic vision and tell each participant they can wear them over their spectacles in case they wear them.

Help him to put the goggles on making sure the cable is over his left shoulder. Ask him to be careful with the cable and to not step on it.

Explain him that his task is to look for objects related to football and make sure that he understands it is not a memory test.

Warn him about there would be bad language, tell him again that he can withdraw at any time without giving any explanation.

Answer any question he could have.

Close the Cave curtain and switch the lights off.

Select the scenario version according to the experimental version.

- The experiment starts and the participant experiences the VR scenario.

  Start audio and video recording.

  At least 1 minute after the curtain was closed, find the best moment to make the first character enter the bar, trying to avoid physical collision with the participant.

  Carry out the dialogue of V with the participant.

  When the confrontation starts, observe participant's responses from behind the curtain.

- The scenario ends:

  Switch the lights back on and open the curtain.

  Ask him to put the shoes back on.

Ask him to fill out the post-experience questionnaire (app. D.8).

Ask him to if we could ask him some questions about the experience he just had (app. D.10).

Ask him to fill out the Payment form (app. D.11) in order to receive the monetary compensation.

Pay him the amount stipulated in the recruitment announcement.

Debrief the nature of the experiment in case the participant wants to know more about this research.

Ask them not to discuss this experiment for the next few months, as this is an on-going experiment and forthcoming participants must not know anything about the scenario.

- After the participant leaves:

  Save all the data generated for the participant in one folder:

  Video file.

  Audio file.

  Interview audio file.

  Log file.

- At the end of the day, switch all the equipment off.

The experiments that used the bar scenario were behavioural studies and their validity was based on the assumption that participants were naïve about what they were about to experience. They were asked if they knew anything about what they were about to witness. Before the VR exposure, they were warned about any ethical issue they needed to know, as explained in Section 3.3. They also knew they could ask any question at any time, although the ones about the nature of the experiment or questions that could compromise the element of surprise, they were told that they would be addressed in the end of the session.

Appendix D

Documents and Forms for Experiments

D.1 Recruitment Board Announcement

VR Experiment

@ UCL CAVE Lab

Payment **£7.00**

We are seeking football supporters to participate in a VR study.

The experiment will involve one short session in a virtual reality simulation, followed by a brief interview.

email:

a.rovira@cs.ucl.ac.uk

VR expt: a.rovira@cs.ucl.ac.uk	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**	**VR expt: a.rovira@cs.ucl.ac.uk**

D.2 Recruitment Email

Virtual Reality Study for Football Supporters

We invite you to take part in a virtual reality experience that has to do with attitudes towards football.

In order to take part in this study you must be a supporter of a football team, for example, someone who attends matches.

You must be over 18 years old.

If you are someone who would be put off by witnessing realistic scenes that might include bad language or aggressive behaviour then you should not take part in this experience.

This will involve one short (10 minute) experience in a virtual reality simulation followed by a brief interview. Participants will receive £7, and the experiment will take about 50 minutes per participant in total.

The experiment will take place in the Malet Place Engineering Building, ground floor. Click on the following link to the see a map:
http://tiny.cc/MPEB

If you are interested in taking part, please fill out a brief questionnaire by following the link below.

Prof. Mel Slater, melslater@cs.ucl.ac.uk

Dr David Swapp, d.swapp@cs.ucl.ac.uk

Mr Aitor Rovira, a.rovira@cs.ucl.ac.uk

Department of Computer Science, University College London, Malet Place Engineering Building, London WC1E 6BT.

D.3 Recruitment Online Announcement

UCL

Virtual Reality Study for Football Supporters

We invite you to take part in a virtual reality experience that has to do with attitudes towards football.

In order to take part in this study you must be a supporter of a football team, for example, someone who attends matches.

You must be over 18 years old.

If you are someone who would be put off by witnessing realistic scenes that might include bad language or aggressive behaviour then you should not take part in this experience.

This will involve one short (10 minute) experience in a virtual reality simulation followed by a brief interview. Participants will receive £7, and the experiment will take about 45 minutes per participant in total.

The experiment will take place in the Malet Place Engineering Building, ground floor. Click here to the see a map.

NEW DAYS SCHEDULED: Tuesday 9th, Monday 15th, Tuesday 16th of February 2010.

If you are interested on participate in this experiment, please fill up the following form: click here to go to the form

Prof. Mel Slater, melslater@cs.ucl.ac.uk

Dr David Swapp, d.swapp@cs.ucl.ac.uk

Mr Aitor Rovira, a.rovira@cs.ucl.ac.uk

Department of Computer Science, University College London, Malet Place Engineering Building, London WC1E 6BT.

D.4 Recruitment Online Form

Virtual Reality study for Arsenal F.C. supporters

*Required

First name

Age *

e-mail address *
Please, provide us e-mail address and telephone number so it will be easy to contact you

Telephone number *

Your gender *

- Male
- Female

Which day of the following could you come to UCL for the experiment?
Have in mind that the experiment is 40 minutes long in total. It will take place during these days from 10am until 5pm

- Monday 9th of June
- Tuesday 10th of June
- Wednesday 11th of June
- I cannot make any of these dates, but I would like to participate. Please keep me informed when you open new dates

What time is best for you?
The more hours you provide, the easier will be to make the schedule, but you only will be asked to come once.

Continue »

Virtual Reality study for Arsenal F.C. supporters

*Required

First name

Age *

e-mail address *

Please, provide us e-mail address and telephone number so it will be easy to contact you

Telephone number *

Your gender *

- ◯ Male
- ◯ Female

Which day of the following could you come to UCL for the experiment?

Have in mind that the experiment is 40 minutes long in total. It will take place during these days from 10am until 5pm

- ☐ Monday 9th of June
- ☐ Tuesday 10th of June
- ☐ Wednesday 11th of June
- ☐ I cannot make any of these dates, but I would like to participate. Please keep me informed when you open new dates

What time is best for you?

The more hours you provide, the easier will be to make the schedule, but you only will be asked to come once.

Continue »

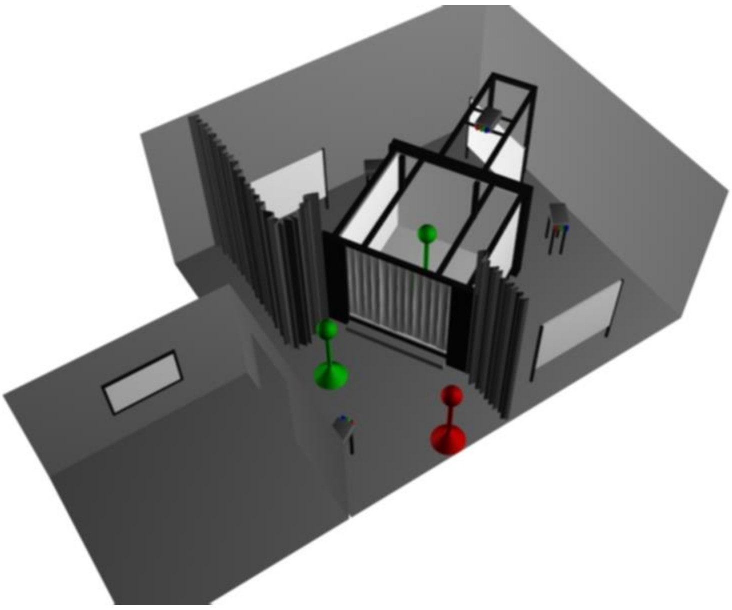
D.5 Information Sheet

UCL DEPARTMENT OF COMPUTER SCIENCE

INFORMATION SHEET FOR PARTICIPANTS

Thank you for participating in our study. This is one of a long series of studies into understanding the responses of people within virtual environments. This study has been approved by *The UCL Research Ethics Committee.* Please read through this information sheet and feel free to ask any questions. The experimenters will answer any general questions; however the specific aspects regarding this study cannot be discussed with you until the end of the session. The whole study will take about *40 minutes*

You will be using the Cave system. See figure below. The Cave is a Virtual Reality system made up of 3 walls measuring roughly 3m x 3m x 2.2m. You will wear VR glasses. The virtual reality viewing equipment can be worn over eyeglasses. You may be asked to take off your shoes in order to protect the virtual reality equipment.



In this experiment you will visit a bar where something is going to take place. There will be more people involved, so feel free to interact with them. Afterwards you will be asked some questions.

Please ask any questions that come to mind.

Information that we collect will never be reported in a way that specific individuals can be identified. Information will be reported in a statistical and aggregated manner, and any verbal comments that you make, if written about in subsequent papers, will be presented anonymously.

PLEASE TURN OVER

IMPORTANT

When people use virtual reality systems, some people sometimes experience some degree of nausea. If at any time you wish to stop taking part in the study due to this or any other reason, please just say so and we will stop.

There has been some research, which suggests that people using head-mounted displays might experience some disturbances in vision afterwards. No long term studies are known to us, but the studies which have been carried out do testing after about 30 minutes, and find the effect is still sometimes there.

There have been various reported side effects of using virtual reality equipment, such as 'flashbacks'.

With any type of video equipment there is a possibility that an epileptic episode may be generated. This, for example, has been reported for computer video games.

PROCEDURES

- You will be asked to read, understand and sign a **Consent Form**. If you agree to take part in this experiment then we will ask you sign it, and the study will continue with your participation. Otherwise your involvement will cease at that point. **Note that in any case you can withdraw at any later time without giving any reasons.**
- You may be asked to remove your shoes and switch off mobile phones before using the VR equipment.
- You will be asked to complete a number of questionnaires, so that we can try to understand your responses during the study.
- You will move into the virtual reality Cave system.
- You will be in a virtual reality simulation of a bar, where you will see other people, some of whom may talk with you. This will continue for about 7 minutes during which you will be videotaped.
- After the visit to the room you will complete a questionnaire about your experience.
- Finally there will be a short discussion with the experimenters about your experiences while reviewing your experience in the virtual environment on video. During this time, you might be audio or video taped.
- You will be paid 7 pounds for your participation.
- **Thank you** for your participation. Please do not discuss this study with others for about **three months**, since the study is continuing.
- Any other questions?

Note that this experience is concerned with discussions about football. The language and the situation depicted is realistic. If you are someone who would be put off by witnessing realistic scenes that might include bad language or aggressive behaviour, then you should not take part in this experience.

Remember, if at any time you do not wish to continue participating in the experiment, you are free to withdraw without being required to give reasons.

In case you have any enquiries regarding this study in the future, please contact:

Prof. Mel Slater, Department of Computer Science, UCL. m.slater@cs.ucl.ac.uk
Dr David Swapp, Department of Computer Science, UCL, d.swapp@cs.ucl.ac.uk
Aitor Rovira, Department of Computer Science, UCL, a.rovira@cs.ucl.ac.uk

Telephone:

020 7679 3709

D.6 Consent Form

UCL DEPARTMENT OF COMPUTER SCIENCE

ID

PROJECT: BYSTANDER
Investigators: Mel Slater, David Swapp, Aitor Rovira

To be completed by volunteers:
We would like you to read the following questions carefully.

Have you read the information sheet about this study?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all your questions?	YES/NO
Have you received enough information about this study?	YES/NO
Which investigator have you spoken to about this study?	…………
Do you understand that you are free to withdraw from this study?	
• At any time	YES/NO
• Without giving a reason for withdrawing	YES/NO

Do you understand and accept the risks associated with the use of virtual reality equipment?
YES/NO

Do you agree to take part in this study?	YES/NO
Do you agree to be video taped?	YES/NO
Do you agree to be audio taped?	YES/NO
Do you agree to be physiological monitored?	YES/NO

I certify that I do not have epilepsy.

I certify that I will not be driving a car, motorcycle, bicycle, or use other types of complex machinery that could be a danger to myself or others, within 3 hours after the termination of the study.

Signed……………………………………...…………**Date**……………………………...

Name in block letters……………………………..…………………………………...

Investigator…………………………………………………...……………………….

In case you have any enquiries regarding this study in the future, please contact:

Mel Slater

Department of Computer Science
University College London
Gower Street
London WC1E 6BT

Tel +44 (0) 20 7679 3709
Fax +44 (0) 20 7387 1397

m.slater@cs.ucl.ac.uk

Information that we collect will never be reported in a way that individuals can be identified. Information will be reported in aggregate, and any verbal comments that you make, if written about in subsequent papers, will be presented anonymously.

UCL Department of Computer Science
University College London Gower Street London WC1E 6BT
Tel: +44 (0)20 7679 3709 Fax: +44 (0)20 7387 1397
m.slater@cs.ucl.ac.uk
www.cs.ucl.ac.uk/staff/m.slater

D.7 Pre-experience Questionnaire

Please make sure that you answer each question.

*Required

your given ID *

How fluent is your english? *

- Basic
- Proficient
- Native

Are you taking any medication? *

- Yes
- No

Did you consume more than 2 units of alcohol within the last 6 hours? *
(2 units of alcohol = 1 pint of beer or 2 glasses of wine)

- Yes
- No

State your level of computer literacy *

- 1 (Novice)
- 2
- 3
- 4
- 5
- 6
- 7 (Expert)

Have you ever experienced 'virtual reality' before? *

- 1 (No experience)
- 2
- 3
- 4
- 5
- 6
- 7 (Extensive experience)

How many times did you play video games (at home, work, school, or arcades) in the last year? *

- Never
- 1-5
- 6-10
- 11-15
- 16-20
- 21-25
- 25+

How many hours per week do you spend playing video games? *

- Never
- Less than 2
- 3-5
- 6-15
- more than 25

D.8 Post-experience Questionnaire

Please make sure that you answer each question. If you have any queries ask the experimenters who will be nearby.

All the questions relate to the time after the argument started.

Even though you knew that the situation not real, and that there were no real people there, did you sometimes finding yourself automatically experiencing any of the following thoughts and feelings?

*Required

Your given ID *

After the argument started, I was feeling uncomfortable with the situation *

○ 1 (not at all) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (very much)

After the argument started I was sometimes concerned for the safety of the man being threatened *

○ 1 (not at all) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (very much so)

After the argument started I was sometimes concerned for my own safety. *

○ 1 (not at all) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (very much so)

After the argument started I looked around for help *

○ 1 (at no time) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (almost all the time)

After the argument started I looked around to check in case the other people might come to make situation worse *

○ 1 (at no time) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (almost all the time)

After the argument started, the victim looked at me wanting help *

○ 1 (not a single time) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (almost all the time)

After the argument started I felt I should move away from those people *

○ 1 (at no time) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (almost all the time)

After the argument started, the aggressor was aware of me looking at him *

○ 1 (not at all) ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 (very much)

After the argument started, I felt I should do something to stop it *

- 1 (not at all) 2 3 4 5 6 7 (very much so)

After the argument started, I felt I could do something to stop it *

- 1 (at no time) 2 3 4 5 6 7 (almost all the time)

The presence of other people in the bar encouraged (or dissuaded) me to intervene *

- 1 (Dissuaded me, I expected them to do something instead of me)
- 2
- 3
- 4 (neither encouraged nor dissuaded me)
- 5
- 6
- 7 (Encouraged me, I felt I had backup)

The other people in the bar tried to persuade me... *

- 1 (... not to intervene) 2 3 4 5 6 7 (... to intervene)

The other people´s utterances had an impact on my behaviour *

- 1 (not at all, that is what I would have done anyway)
- 2
- 3
- 4
- 5
- 6
- 7 (very much so, I would have done the opposite)

After the argument started I felt that I needed to get out *

- 1 (not at all) 2 3 4 5 6 7 (very much so)

My mind started wandering and thinking about other things during the argument *

- 1 (not at all) 2 3 4 5 6 7 (very much)

D.9 Post-experience Questionnaire Bystander RL

Please make sure that you answer each question. If you have any queries ask the researchers.

All the questions relate to the time after the argument started. Before you reply each question, please try to put yourself back in the experience you just had in the Virtual Reality system.
Even though you knew that the situation not real, and that there were no real people there, did you sometimes finding yourself automatically experiencing any of the following thoughts and feelings?

Your given ID *

After the argument started, I was feeling uncomfortable with the situation *
(1=not at all, 7=very much so)
1 2 3 4 5 6 7

After the argument started I was sometimes concerned for the safety of the man being threatened *
(1=not at all, 7=very much so)
1 2 3 4 5 6 7

After the argument started I was sometimes concerned for my own safety. *
(1=not at all, 7=very much so)
1 2 3 4 5 6 7

After the argument started I felt I wanted to move away from those people *
(1=not a single time, 7=almost all the time)
1 2 3 4 5 6 7

After the argument started I looked around to see what the rest of the people were doing *
(1=not a single time, 7=almost all the time)
1 2 3 4 5 6 7

I felt more determined to intervene after hearing the other people in the bar shouting out *
(regardless of whether I intervened or not. 1=not at all, 7=very much so)
1 2 3 4 5 6 7

After the argument started, the victim looked at me... *
(1=not a single time, 7=almost all the time)
1 2 3 4 5 6 7

After the argument started, the victim looking at me made me more likely to intervene *
(regardless of whether I intervened or not. 1=not at all, 7=very much so)
1 2 3 4 5 6 7

After the argument started, the aggressor looked at me... *
(1=not a single time, 7=almost all the time)
1 2 3 4 5 6 7

After the argument started, the aggressor looking at me increased the likelihood of me intervening.*
(regardless of whether I intervened or not). 1=not at all, 7=very much so

1 2 3 4 5 6 7

During the argument, I felt I could do something to stop it *
(1=not at all, 7=very much so)

1 2 3 4 5 6 7

During the argument, I felt I had to do something to stop it *
(1=not at all, 7=very much so)

1 2 3 4 5 6 7

My mind started wandering and thinking about other things during the argument *
(1=not at all, I was totally focused on the confrontation, 7=I didn't pay attention to them at all)

1 2 3 4 5 6 7

To what extent you would say your reaction authentic? *
(1=not much, I felt like I was watching a film, 7=Very much so, I would have done the same in real life)

1 2 3 4 5 6 7

Despite knowing that it was a simulation, how realistic do you think the scenario was? *
(1=not more than watching a movie on TV, 7=almost as realistic as in real life)

1 2 3 4 5 6 7

Talking about technical aspects, was there any specific detail that you would highlight that made the scenario less plausible?

(Anything related to the characters, the virtual bar, the audio, the script, the equipment, the lab, etc...)

Please add here any comments you might want to share with us

D.10 Interview Questionnaire

UCL DEPARTMENT OF COMPUTER SCIENCE

Bystander responses to violence

in

Immersive Virtual Reality

INTERVIEW

m.slater@cs.ucl.ac.uk
a.rovira@cs.ucl.ac.uk
d.swapp@cs.ucl.ac.uk

1. Can you briefly describe what you think was happening?

2. How realistic were the unfolding events in the experience that you have just had?

3. What feelings did you have while this was happening?

4. What were your responses?

5. Did you feel at any time you wanted to do something about what was happening? If so, why did you not do it (assuming that they did not do anything).

6. Did you at any time look for other people there other than the two people in the argument?
   If yes, why?

7. To what extent was your reaction authentic? Would you do the same if the situation happened in real life?

8. (If they did not intervene) What would have made it more likely that you would have personally intervened (even though you knew it was virtual reality)?
   (If they intervened) What would have made it more likely that you would have personally intervened again (even though you knew it was virtual reality)?

9. What elements reduced the plausibility of the situation?

10. Did you at any time want to leave?
    (If yes) Why?

D.11 Payment Form

UCL DEPARTMENT OF COMPUTER SCIENCE

EXPERIMENT TITLE: **Bystander Responses to violence in Immersive Virtual Reality**

No.	NAME	ADDRESS	AMOUNT RECEIVED £	SIGNATURE
1				
2				
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I certify that the above persons have taken part in the aforenamed experiment in accordance with the College Financial Terms and Conditions .

Signed...
Department of Computer Science

Payments approved in accordance with College regulations

Signed...
Department of Computer Science

Appendix E

Reinforcement Learning Simulations

A number of simulations was carried out to learn how RL works and help decide the most suitable values for the set of RL parameters for the experiments described in Chapter 6. The simulations included setting up hypothetical behaviour of how the environment would work and real data taken from volunteers to create a map of probability of the transitions that was later used to run the simulation with different parameters values.

E.1 First RL Experiment Simulations and Piloting

A pilot study was carried out before the first experiment using RL. The idea behind the testing was to find a setup to ensure that the problem would converge to a solution. Taking the idea from the model-based RL, the strategy was to do a reverse engineering process in which the first step included running a piloting to collect data about how people behave in the scenario. These data was used to build up a map of transitions and compute the probability of these transitions. The map of the probabilities was useful to run as many simulations as necessary. The simulation stage was composed several runs with large number of episodes and tries in each episode where all the permutations of the RL parameters values were tried.

The initial design of the game-like scenario consisted of splitting the environment surface into 6 lanes lengthwise to the depth dimension, leading to have six possible states and six actions. The state was the lane the person was in when an action took place. The six possible states are the leftmost lane (FL), second from the left (SL), middle left (ML), middle right (MR), second from the right (SR), and the rightmost (FR). The number of states was chosen splitting the width of the Cave between the average width of a person approximately. The action was the lane in which the spacecraft would shoot from, and a projectile would travel along that lane. The expected behaviour form volunteers was that they would move to one side when a projectile was shot to them, and the goal of the RL agent was to guide them to the leftmost lane, FL. Each volunteer experienced the scenario where several projectiles were shot during that time. The average number of projectiles was 280 with standard deviation 18.6. Ten volunteers underwent the scenario and a log file was created for each one of them, storing all the transitions that took place. After reading the log file, an early conclusion was that the number of tries for each volunteer was too small, as, despite the theoretically large number of tries compared to the dimensions of the state-action space, there were different state-action pairs that were tried very few times, or even not tried a single time, for any of the ten volunteers. To mitigate this problem, we took advantage of the symmetry of the scenario. For example, being in the leftmost lane and shooting on the closest lane to the right should have the same effect than being in the rightmost lane and shooting on the next lane to the left. Therefore, the number of actions of symmetric state-action pairs were added. Table E.1 shows the transitions for each state-action pair and the number of times each following state was visited. The probability of each transition was computed as the percentage of times a following state, state1, was reached from each initial state-action pair, (state0, a). The transitions probabilities are shown in Table E.2, including the best action, computed as the maximum value of the summation of the product of the probability of each possible following state and the reward associated to that state for each initial state-action pair. The results show that the best action is either shooting on FR or SR, except when the person was in FL, where there is a tie between SL and FR. These results are not concluding, and different from our initial hypothesis that the best action would be to shoot on the next lane on the right from the current lane. This is itself a hint that the number of tries was too small to make the RL problem converge to a solution. Furthermore, the furthest lanes on each side, FL and FR, were rarely visited, so information collected in these states was insufficient.

Using the map of transition probabilities, a simulation was run to test all the possible permutations of the RL parameters values. In a triple for loop statement, each value of α, γ, and δ was tried from 0.9 to 0.1 in steps of 0.1, making ε decrease over the time to encourage exploration during the initial stage of an episode and gradually increase the chance of exploiting the experience accumulated. For each permutation, the simulation process ran 1000 episodes with 250 tries each, and the resulting total reward and best action per state were the average of all episodes. The results showed that all combinations converged to the same solution. The best actions, from leftmost lane to the rightmost one, were: second to the left, middle left, middle right, middle left, middle right, second to the right. These results are not exactly the results expected in the hypothesis, but they are very similar, the best action was further to the right, the more to the right the person was. Considering that the map of transitions showed not only cells were transition was not possible (e.g. a person was not able to move to the leftmost lane from the rightmost one), due to the short time interval between actions, the RL was able to learn a policy in order to make people move towards the left part of the scenario. The simulation was repeated changing the number of episodes and how many tries were carried out in each episode, and the results were very similar. The total reward obtained was not important, as its absolute value is based on the magnitude of the learning rate and the discount factor. It is more important to remark that all the combinations of parameters returned the same set of best actions per each state, so it seemed that the values given to them were not as critical as initially thought, at least for this scenario. We can argue that the best action set is not ideal due to a small sample size when building up the map of transitions, but nevertheless it allowed us to test the RL library and confirm that, with a minimum number of tries, the RL was able to converge to a solution.

The conclusion from the first piloting and simulation was that the number of actions tried was too small. Some state-action pairs were not tried, despite having

2806 samples in total. Furthest lanes on each side were barely visited, as people reported to feel less safe when staying in a corner due to having less options when trying to avoid a projectile. Some volunteers also mentioned that they felt the game was too long, there was not a clear goal to achieve besides trying to avoid being hit and it became boring towards then end of the scenario.

		state1					
		FL	SL	ML	MR	SR	FR
state0	action						
FL	FL	0	2	6	0	0	0
FL	SL	6	0	0	0	0	0
FL	ML	23	7	1	0	0	0
FL	MR	3	1	0	0	0	0
FL	SR	3	0	0	0	0	0
FL	FR	3	1	2	0	0	0
SL	FL	4	49	94	20	2	0
SL	FL	0	19	42	22	0	0
SL	FL	3	38	20	5	0	0
SL	FL	3	72	11	0	1	0
SL	FL	4	57	6	0	0	0
SL	FL	5	144	29	6	0	0
ML	FL	0	3	106	164	11	0
ML	FL	0	8	149	192	15	0
ML	FL	0	18	115	138	8	0
ML	FL	0	55	194	33	7	0
ML	FL	0	85	333	55	3	0
ML	FL	0	57	257	70	6	0
MR	FL	0	6	70	257	57	0
MR	FL	0	3	55	333	85	0
MR	FL	0	7	33	194	55	0
MR	FL	0	8	138	115	18	0
MR	FL	0	15	192	149	8	0
MR	FL	0	11	164	106	3	0
SR	FL	0	0	6	29	144	5
SR	FL	0	0	0	6	57	4
SR	FL	0	1	0	11	72	3
SR	FL	0	0	5	20	38	3
SR	FL	0	0	22	42	19	0
SR	FL	0	2	20	94	49	4
FR	FL	0	0	0	2	1	3
FR	FL	0	0	0	0	0	3
FR	FL	0	0	0	0	1	3
FR	FL	0	0	0	1	7	23
FR	FL	0	0	0	0	0	6
FR	FL	0	0	0	6	2	0

Table E.1: Number of transitions to following states for each state-action pair observed during the piloting, with 10 volunteers, sample size = 2806, number of states = 6, number of actions = 6. s0=initial state, s1=state reached after the action was taken. FL=Far Left, SL=Second to the Left, ML=Middle Left, MR=Middle Right, SR=Second to the Right, FR=Far Right.

state0	action	state1 FL	SL	ML	MR	SR	FR	$\sum p(s1)*r$	Max. value	Best action
FL	FL	0.00	0.25	0.75	0.00	0.00	0.00	3.25	5.00	FL,MR
FL	SL	1.00	0.00	0.00	0.00	0.00	0.00	5.00		
FL	ML	0.74	0.23	0.03	0.00	0.00	0.00	4.71		
FL	MR	0.75	0.25	0.00	0.00	0.00	0.00	4.75		
FL	SR	1.00	0.00	0.00	0.00	0.00	0.00	5.00		
FL	FR	0.50	0.17	0.33	0.00	0.00	0.00	4.17		
SL	FL	0.02	0.29	0.56	0.12	0.01	0.00	3.20	3.97	SR
SL	SL	0.00	0.23	0.51	0.27	0.00	0.00	2.96		
SL	ML	0.05	0.58	0.30	0.08	0.00	0.00	3.59		
SL	MR	0.03	0.83	0.13	0.00	0.01	0.00	3.87		
SL	SR	0.06	0.85	0.09	0.00	0.00	0.00	3.97		
SL	FR	0.03	0.78	0.16	0.03	0.00	0.00	3.80		
ML	FL	0.00	0.01	0.37	0.58	0.04	0.00	2.36	3.05	SR
ML	SL	0.00	0.02	0.41	0.53	0.04	0.00	2.41		
ML	ML	0.00	0.06	0.41	0.49	0.03	0.00	2.51		
ML	MR	0.00	0.19	0.67	0.11	0.02	0.00	3.03		
ML	SR	0.00	0.18	0.70	0.12	0.01	0.00	3.05		
ML	FR	0.00	0.15	0.66	0.18	0.02	0.00	2.94		
MR	FL	0.00	0.02	0.18	0.66	0.15	0.00	2.06	2.64	FR
MR	SL	0.00	0.01	0.12	0.70	0.18	0.00	1.95		
MR	ML	0.00	0.02	0.11	0.67	0.19	0.00	1.97		
MR	MR	0.00	0.03	0.49	0.41	0.06	0.00	2.49		
MR	SR	0.00	0.04	0.53	0.41	0.02	0.00	2.59		
MR	FR	0.00	0.04	0.58	0.37	0.01	0.00	2.64		
SR	FL	0.00	0.00	0.03	0.16	0.78	0.03	1.20	2.04	SR
SR	SL	0.00	0.00	0.00	0.09	0.85	0.06	1.03		
SR	ML	0.00	0.01	0.00	0.13	0.83	0.03	1.13		
SR	MR	0.00	0.00	0.08	0.30	0.58	0.05	1.41		
SR	SR	0.00	0.00	0.27	0.51	0.23	0.00	2.04		
SR	FR	0.00	0.01	0.12	0.56	0.29	0.02	1.80		
FR	FL	0.00	0.00	0.00	0.33	0.17	0.50	0.83	1.75	FR
FR	SL	0.00	0.00	0.00	0.00	0.00	1.00	0.00		
FR	ML	0.00	0.00	0.00	0.00	0.25	0.75	0.25		
FR	MR	0.00	0.00	0.00	0.03	0.23	0.74	0.29		
FR	SR	0.00	0.00	0.00	0.00	0.00	1.00	0.00		
FR	FR	0.00	0.00	0.00	0.75	0.25	0.00	1.75		

Table E.2: Probability of reaching every state for each state-action pair in a 6×6 state-action space. $\sum p(s1)*r$ is the summation of the product between the probability to move to a state and the reward obtained in it. The best action is determined by the maximum value in the previous column. States and actions are FL=Leftmost, SL=Second to the Left, ML=Middle Left, MR=Middle Right, SR=Second to the Right, FR=Rightmost.

A second round of pilot studies was carried out using a new setup. Based on the results obtained previously, the state-action space was reduced to 5×5. Additionally, as suggested by one volunteer, a scoreboard was added to the game.

The score displayed on the scoreboard would be increased by 1 each time a projectile was avoided and it was reset to 0 in case they were hit. This score was not related to the rewards and the values stored in the Q values, it was merely to have participants engaged and it was not included in any data analysis. The possible states were leftmost (FL), second from the left (ML), middle (M), second from the right (MR), and rightmost (FR). The game length was increased to allow 420 actions approximately for each person. Another seven volunteers were asked to experience the scenario. The procedure was similar to the one used in the 6×6 setup, and the goal was again to guide people to the leftmost lane. Symmetric state-action pairs values were added (Table E.3) and the resulting transition probabilities are shown in Table E.4. The results obtained from running 1000 episodes for each permutation of the RL parameters values and 420 tries for each episodes showed that the best action was shooting at FR in all possible states, but the values from the rest of candidates were not far from the winner action. As we had observed it the previous configuration, the values of the RL parameters do not seem to have a big impact on the results. The highest total reward obtained was 795 the lowest was 763. The maximum difference on the score obtained only differed by 4%.

It is important to understand what each parameter represents. α is the learning rate and it depends on the absolute values of the rewards obtained and the frequency in which they are obtained. γ is the discount-rate parameter that can reduce the amount of reward obtained as a function of the time elapsed since the beginning of the episode. In our experiment, there should not be discount, as it is not important to reach the goal as soon as possible. In other words, if two different people reached the goal the same number of times, the RL agent should get the same reward, regardless if one reached the goal earlier than the other. δ is the parameter that determines how far back in time the actions are rewarded when a reward is obtained. This parameter needs to be greater than zero, but its value does not seem to have a great impact on the results. In the experiment, we wanted to reward previous actions, as the goal can be reached thanks not only to the last action, but the sequence that preceded the person moving to the goal position.

		state1				
		FL	SL	M	MR	FR
state0	action					
FL	FL	13	13	0	0	0
FL	ML	17	7	2	0	0
FL	M	20	13	1	0	0
FL	MR	20	4	1	1	0
FL	FR	45	17	0	1	0
ML	FL	14	191	171	6	0
ML	ML	10	131	79	1	0
ML	M	11	165	57	3	0
ML	MR	7	161	40	2	0
ML	FR	16	239	53	4	0
M	FL	0	9	131	74	0
M	ML	0	7	146	57	0
M	M	0	21	177	59	1
M	MR	0	18	224	63	0
M	FR	0	25	277	46	2
MR	FL	0	4	53	239	16
MR	ML	0	2	40	161	7
MR	M	0	3	57	165	11
MR	MR	0	1	79	131	10
MR	FR	0	6	171	191	14
FR	FL	0	1	0	17	45
FR	ML	0	1	1	4	20
FR	M	0	0	1	13	20
FR	MR	0	0	2	7	17
FR	FR	0	0	0	13	13

Table E.3: Number of transitions to following states for each state-action pair observed during the piloting, with 7 volunteers, sample size = 2880, number of states = 5, number of actions = 5. FL=Leftmost, ML=Second to the Left, MR=Second to the Right, FR=Rightmost.

E.2 Simulating a Violence Emergency

In initial stages of development of the bar scenario, a simulation was carried out how RL could be used to understand people's responses to a violent emergency. The first milestone was to simulate a scenario where people respond to certain virtual characters' actions. In this initial stage, we designed a deterministic environment, i.e. a person who witnesses a confrontation between two other people will always respond the same way to the other people's actions. This is not the case in reality, but this helped us to do some initial testing. In the scenario, a person (bystander) is in a bar and witnesses two people arguing. One is clearly the aggressor, while the other tries to avoid the confrontation trying to calm the other one down and looking around to find somebody who can help to defuse the confrontation. The

state0	action	state1 FL	SL	M	SR	FR	$\sum p(s1) * r$	Max. value	Best action
FL	FL	0.50	0.50	0.00	0.00	0.00	3.50	3.68	FR
FL	ML	0.65	0.27	0.08	0.00	0.00	3.58		
FL	M	0.59	0.38	0.03	0.00	0.00	3.56		
FL	MR	0.77	0.15	0.04	0.04	0.00	3.65		
FL	FR	0.71	0.27	0.00	0.02	0.00	3.68		
ML	FL	0.04	0.50	0.45	0.02	0.00	2.56	2.86	FR
ML	ML	0.05	0.59	0.36	0.00	0.00	2.68		
ML	M	0.05	0.70	0.24	0.01	0.00	2.78		
ML	MR	0.03	0.77	0.19	0.01	0.00	2.82		
ML	FR	0.05	0.77	0.17	0.01	0.00	2.86		
M	FL	0.00	0.04	0.61	0.35	0.00	1.70	1.93	FR
M	ML	0.00	0.03	0.70	0.27	0.00	1.76		
M	M	0.00	0.08	0.69	0.23	0.00	1.84		
M	MR	0.00	0.06	0.73	0.21	0.00	1.85		
M	FR	0.00	0.07	0.79	0.13	0.01	1.93		
MR	FL	0.00	0.01	0.17	0.77	0.05	1.14	1.44	FR
MR	ML	0.00	0.01	0.19	0.77	0.03	1.18		
MR	M	0.00	0.01	0.24	0.70	0.05	1.22		
MR	MR	0.00	0.00	0.36	0.59	0.05	1.32		
MR	FR	0.00	0.02	0.45	0.50	0.04	1.44		
FR	FL	0.00	0.02	0.00	0.27	0.71	0.32	0.50	FR
FR	ML	0.00	0.04	0.04	0.15	0.77	0.35		
FR	M	0.00	0.00	0.03	0.38	0.59	0.44		
FR	MR	0.00	0.00	0.08	0.27	0.65	0.42		
FR	FR	0.00	0.00	0.00	0.50	0.50	0.50		

Table E.4: Probability of reaching every state for each state-action pair in a 5×5 state-action space. $\sum p(s1) * r$ is the summation of the product between the probability to move to a state and the reward obtained in it. The best action is determined by the maximum value in the previous column. States and actions are FL=Leftmost, SL=Second to the Left, M=Middle, SR=Second to the Right, FR=Rightmost.

bystander must decide whether to intervene to try to defend the victim, but trying the perpetrator not to turn into him.

The RL design was composed of six discrete state variables, each one with a default value:

- v1. Level of violence: the degree of violence that the perpetrator uses at a certain time. 3 levels (1-least violent (default), 2-violent, 3-very violent).
- v2. Victim's discomfort: Amount of discomfort that the victim shows. 3 levels (1-less discomfort (default), 2-discomfort, 3-high discomfort)
- v3. Victim's gaze: whether the victim looks at the bystander. Binary (1-looks

at perpetrator (default), 2-looks at bystander)

- v4. Perpetrator's gaze: whether the aggressor looks at the bystander. Binary (1-looks at victim (default), 2-looks at bystander)
- v5. Distance: distance between the bystander and the other two. 5 levels (1-very close, 2-close, 3-mid distance (default), 4-far away, 5-furthest away)
- v6. Bystander intervention: bystander trying to intervene by saying something to them. Binary (1-no intervention (default), 2-bystander).

The combination of the state variables makes the scenario to have 360 possible states, and the current state was computed as:

$$s = v6 - 1 + (v5 - 1) \cdot 2 + (v4 - 1) \cdot 2 \cdot 5 + (v3 - 1) \cdot 2 \cdot 5 \cdot 2 + \\ + (v2 - 1) \cdot 2 \cdot 5 \cdot 2 \cdot 2 + (v1 - 1) \cdot 2 \cdot 5 \cdot 2 \cdot 2 \cdot 3 + 1; \quad \text{(E.1)}$$

There were 4 possible primitive actions:

- Change the level of violence.
- Change the feeling of discomfort of the victim.
- Make the victim look at the bystander.
- Make the perpetrator look at the bystander.

The environment was programmed that all four actions or any combination of them could take place at the same time, therefore making the actual number of possible RL actions was 60. Each one of the actions, depending on the value, would lead to a change on the value of the state variables. The environment changed according to whether any of the primitive actions occurred:

- If the victim looks at the bystander, the bystander moves 1 step forward (he understands the victim is asking for help).

- If the perpetrator looks at him makes bystander move 1 step back (as he is afraid of the perpetrator).
- If level of violence=least violent, victim's discomfort decreases.
- If level of violence=discomfort, bystander moves 1 step closer (he wants to help).
- If level of violence=very violent, bystander moves one step back (he is scared).
- If level of discomfort=3 makes bystander moves 1 step closer (he sees that victim needs help).
- If bystander is in the closest position and level of violence = 2, then makes bystander to say something (he is close enough and he is not scared of the perpetrator).

If level of violence was 'very violent' and level of discomfort was 'high discomfort', then bystander stayed at the same place. The best reward was obtained if the bystander intervened. Other partial rewards could be granted, depending on the distance between the bystander and the other two, assuming that the bystander was more likely to intervene if he was close to the people having the argument. The list of possible rewards were:

- Bystander tries to intervene by saying something: reward = 10.
- Bystander moves closer, reward = 3.
- If bystander is at the closest position and stays there, reward = 1.
- Bystander moves back = -3.
- If bystander stays far away, reward = -1

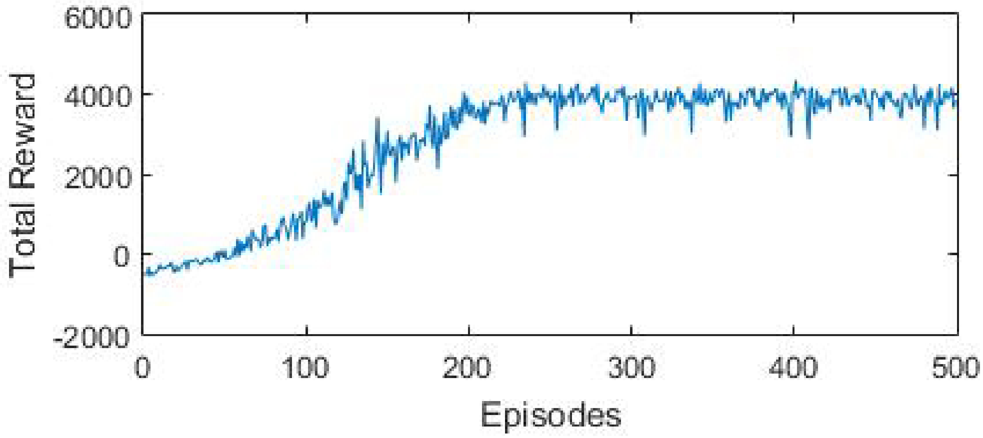
Using this scenario, the simulation was carried out for different number of episodes and steps in each episode, with RL parameters $\alpha = 0.1$, $\gamma = 1.0$, and

$\delta = 0.0$. The experience was accumulated over the episodes, while the epsilon was reduced in each one. Fig. E.1b shows the total reward obtained during 1000 episodes with 500 steps. The total reward increased over the episodes and, depending on the values of ε, the optimal solution was reached after about 400 episodes. The problem was that ε reaches very low values earlier, therefore it still needed to learn more about the environment. In Fig. E.1a, ε minimum value was set to 0.1, therefore it encouraged more exploration than in the previous simulation. This allowed the RL agent to reach to the optimal solution earlier, although in the long run the total reward obtained was lower when exploration was also done in later episodes. It was important to start exploring the environment and not use the experience accumulated, as it is scarce, thus not reliable. In deterministic environments, i.e. the outcome of every state-action pair is always the same, it is possible to reach the optimal solution once enough episodes have been tried, and epsilon can be reduced to 0 and exploit the knowledge. However, in our experiment, where the rewards will be based on people's responses to certain virtual characters' behaviour, the outcome can be different for each participant.

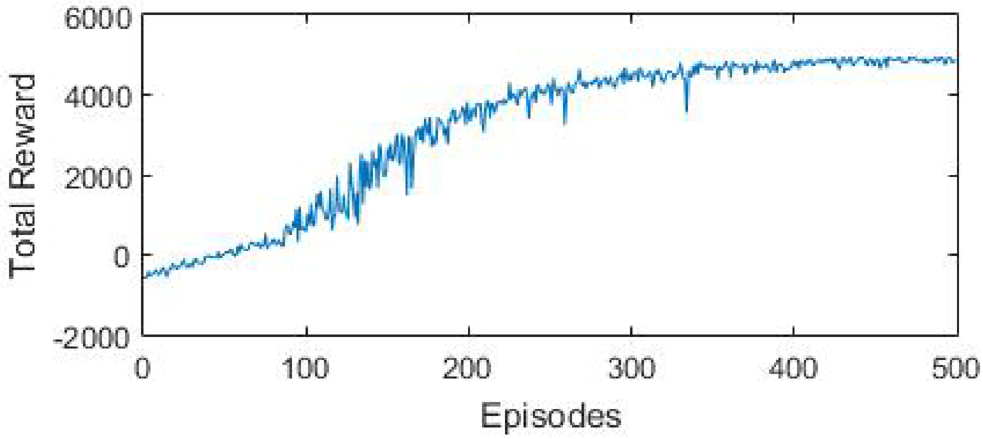
An early conclusion from this simulation is the large number of episodes needed to achieve the optimal solution. 400 episodes means that we would need at least 400 participants to learn how the environment changes to the actions taken. The number of state and actions needs to be drastically reduced. Considering that participants will go through a scenario where the confrontation lasts for 2 minutes and 10 seconds, it seems reasonable to think that actions will be tried in an interval of about 10 seconds, otherwise it can make the experience not realistic, if, for example, a virtual character turns the head to look at the participant too often. That means that not more than 13 actions will be tried for each participant.

With this knowledge, we build up a new simulation environment, closer to what the real experiment would be. The number of states was reduced to 3, and the number of actions also to 3. The state was computed based on the distance between the participant and the two virtual characters having the argument. This were:

- Intervention space: the closest range to the characters, the participant is close



(a) $0.1 < \varepsilon < 1.0$. The optimal solution is found after about 300 episodes, but the 10% of random actions makes the total reward show some variance throughout the episodes.



(b) $\varepsilon, 0 < \varepsilon < 1.0$. The optimal solution is found slower, after about 400 episodes, but the results afterwards do not show much variation.

Figure E.1: Evolution of the total reward obtained over the episodes in the first design of the bar scenario simulation.

enough to be able to reach out to them by extending one arm.

- Active space: The participant is close to them, his attention is on the confrontation, but he cannot reach them with his hands.

- Passive space: The participant tries to stay away from them and not willing to intervene.

The possible actions referred to specific behaviour that any of the virtual characters could have:

- Victim looks at participant. The victim of the confrontation turns his head towards the participant and glances at him for about 1 second.

- Perpetrator looks at participant. Similar to the previous action, but this time is the perpetrator who turns the head towards the participant.

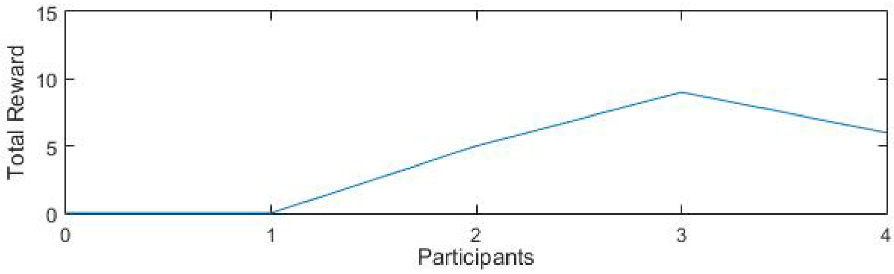
- Bystanders utter something to encourage intervention.

At this point it was difficult to predict how people would respond, therefore, to set up a quick simulation, we decided to use again a deterministic environment. The outcome for each state-action pair are shown in table E.5. A reward of 1 can only be obtained in the participant intervenes. The intervention only happens when the participant is in close range and the victim looks at him. The rest of actions only make the participant moves forward, backwards, or do nothing.

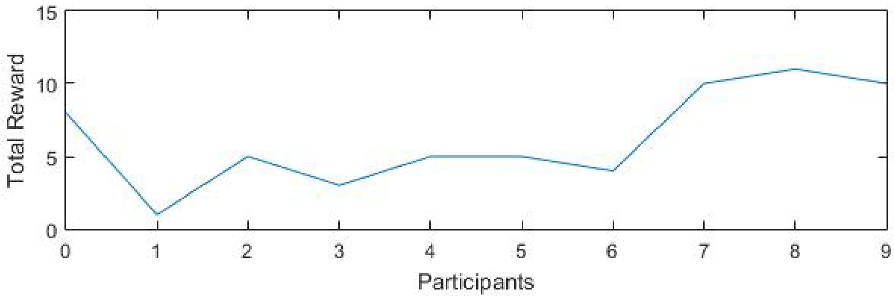
	Intervention space	Active space	Passive space
V looks at participant	Participant intervenes	Participant moves closer	Nothing
P looks at participant	Participant moves back	Participant moves back	Nothing
Bystanders utter	Nothing	Nothing	Participant moves closer

Table E.5: RL bar scenario simulation. state-action pairs outcomes.

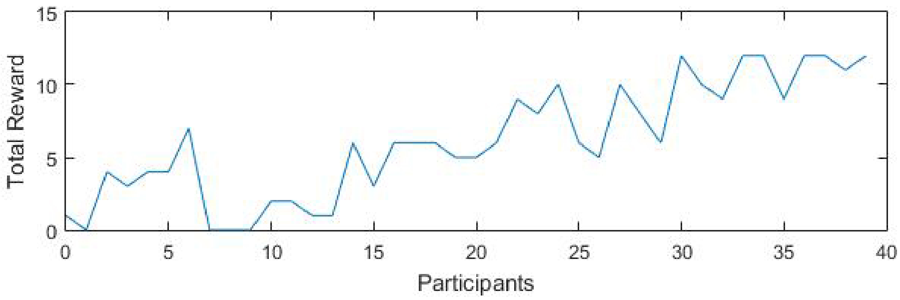
The simulation was carried out with RL parameters $\alpha = 0.1$, $\gamma = 1.0$, $\delta = 0.0$, and ε was linearly decreased until it reached 0. This means that, all the actions were exploratory in the first participant, and all actions exploited the knowledge in the last one. The plots in Fig. E.2 show examples of the evolution of the total reward obtained, depending on the total number of participants. In the simulation we created, the experience was accumulated over the participants, and the maximum reward that a participant could get was 12. The participants started in the Active distance, and then, in the optimal case, the first action was taken to make them move closer, and then the rest of the actions were eliciting an intervention. In the case of having 5 participants only, the experience accumulated was not enough to make sure that the optimal solution was reached (Fig. E.2a). When using 10 participants, the optimal solution could be reached, but sometimes it did not, as shown in the plot (Fig. E.2b). When using a pool of 40 participants, however, the optimal solution was reached every time the simulation was run, the reward obtained for each participant does not increase linearly. In the end, the last participants always scored the maximum value. Despite environment is not deterministic when observing real people respond to a social situation, the simulations carried out were not only useful to understand how a RL problem is designed, but also to have a approximate idea of the number of participants will be needed in an experiment depending on the number of states and the possible actions.



(a) Number of participants = 5



(b) Number of participants = 10



(c) Number of participants = 40

Figure E.2: Total reward obtained accumulating the experience over participants, 13 actions tried for each one of them. ε starts at 1.0 and it is decreased linearly until it reaches 0 in the last participant.

Appendix F

List of Acronyms

3D Three-dimensional.

ANCOVA Analysis of Covariance.

ANOVA Analysis of Variance.

Cal3D Character Animation Library 3D.

Cave Cave Automatic Virtual Environment.

CCTV Closed-circuit Television.

CRT Cathode Ray Tube.

DLP Digital Light Processing.

DoF Degrees of Freedom.

HALCA Hardware Accelerated Library for Character Animation.

HMD Head-mounted Display.

IDE Integrated Development Environment.

IVE Immersive Virtual Environment.

IVR Immersive Virtual Reality.

MANOVA Multivariate Analysis of Variance.

MDP Markov Decision Process.

ML Machine Learning.

nPhys Number of Physical Interventions.

nVerb Number of Verbal Interventions.

P Perpetrator.

PC Personal Computer.

PI Place Illusion.

Psi Plausibility Illusion.

RAIR Response as if Real.

RL Reinforcement Learning.

SCs Sensorimotor Contingencies.

SD Standard Deviation.

SW Shapiro-Wilk test.

UCL University College London.

UI User Interface.

V Victim.

VR Virtual Reality.

XVR Extreme VR.