Emotional Responses in Virtual Reality Environments

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Contents

List of Tables

List of Figures

Abstract

The use of virtual reality (VR) technology to induce emotional responses has recently become more common in psychological studies. The majority of these studies have been restricted to seated VR experiences where the participant remains in a sedentary position. The purpose of the current thesis is to utilise room-scale VR to increase presence, agency and potency of virtual environments (VE) designed to induce embodied emotional responses. The Evaluative Space Model (ESM) [Cacciopio et. al 2012] was used as the theoretical basis for this programme of research, which was particularly concerned with avoidance responses to negative stimuli, perception of threat and negativity bias. A number of unique VEs were created using Unreal Engine 4 designed to create an illusion of height and the potential for a virtual fall as a source of threat. These scenarios were supplemented by additional tracking sensors and an integrated approach to data collection wherein behavioural interactions and movements in the VE were synchronised with ambulatory methods from psychophysiology, e.g. facial electromyography (fEMG), skin conductance level (SCL). The first study (N=20) utilised a VE that requires participants to walk on a wooden plank between the rooftops of two buildings, two versions of the VE were created: sedentary version operated via gamepad controller and a room scale version with natural sensorimotor mappings. The study revealed greater psychophysiological reactivity for the room-scale version of the environment. The second study (N=34) introduced an elaborated room-scale VE where participants must traverse a grid of translucent ice blocks suspended at height in order to reach an end-goal within a physical space of $9m^2$. This grid contained three types of ice block: solid (low-threat), crack (mid-threat) or fall (high threat). The number of crack and fall blocks were increased over three levels of the VE in order to manipulate threat. The foot movements of participants were tracked as the primary mode of interaction with the VE. The study revealed: (i) higher incidence of risk-averse behaviours as threat increased, (ii) this pattern of behaviour was enhanced for participants with higher levels of trait neuroticism, and (iii) greater reactivity from the corrugator muscle in the period following a two-feet movement. The third study (N=20) represented an extension of study two where a significantly larger version of the ice block VE was created in a physical space of $27m^2$. In this experiment, the level of threat (i.e. number of crack and fall blocks) was increased, sustained and decreased in order to observe behavioural adaptation to reduced threat level. In addition, a 'ground level' version of the VE was utilised as a control to study the effect of virtual height in isolation. The results of this study revealed: (i) participants adjusted behaviour to increased threat and decreased threat, but only in the presence of virtual height, and (ii) increased activation of zygomaticus during interactions with crack blocks, which suggests this muscle may be associated with a 'grimace' response in this context. The final experimental chapter represents a re-analyses of the data from studies 2 and 3 designed to explore individual differences as predictors of risk averse behaviour in response to the threat. These analyses identified trait neuroticism and age as traits that significantly influenced the magnitude of the negative gradient in response to threat. The implications of the research for studying emotional experiences in VR are discussed.

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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Publications

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Chapter 1

Introduction

1.1 Psychophysiological Analysis of Emotion

Human emotional responses have a basis in behavioural responses which are driven by physical reaction to positive and negative stimuli [Cacioppo et al., 1997, Cacioppo and Berntson, 1999]. The general view from the latter half of the 19th century to the mid 20th was that reasoning and emotion response were functionally separable and that emotional response generally inhibited cogent reasoning in individuals. Research has indicated that these responses are interpreted by more complex higher order brain functions [LeDoux, 2012]. Enhanced cognition of positive and negative stimuli and more nuanced regulation of approach and avoidance response would logically lead to a survival advantage for that organism. It would then follow that comprehension and expression of such situations would have an enhanced benefit to a group. Such expressions, if interpreted by higher cognitive mechanisms, could give rise to more complex social structures. Such structures would then behave in both individualistic ways; approach, avoidance, and in ways which would add additional nuance to the behaviour of the individual, the group, and alter the previously imperative nature of survival based stimuli in the form of a consistent feed-back loop [Damasio, 1996]. Researchers have attempted to apply more refined and nuanced interpretations of the neurological mechanisms at play in this survival circuit [LeDoux, 1996] and to reconcile such responses into logical laws [Wundt, 1980, Frijda, 2007]. Interpretation of complex behavioural patterns began with analysis of the underlying survival mechanisms that give context to latter models of emotion expression.

In 1872 Charles Darwin published The Expression of the Emotions in Man and Animals. Darwin's work was one of the primary texts to attempt to categorise the physical expression of emotions and ascribe their causes. Darwin's primary shift away from prior thinking in The Expression was to ignore inanimate facial morphology and to focus on temporary changes in appearance, a shift away from physiognomic thinking. In the text Darwin made five contributions to advance understanding of emotion at that time. The first, that Darwin treated emotions as discrete entities. The second was his focus on the face as a means of expression in both humans and animals. Third, that emotional expression was universal. For the fourth he suggests that emotions are not unique to humans, the final original statement, that emotions stem from basal functions of animal behaviour. In 1879 Wilhelm Max Wundt established the first experimental laboratory for psychological research. In 1890 William James classified four basic emotions of fear, grief, love, and rage [James, 1981]. He stipulated that these emotions were products of specific physical stimuli. "Instinctive reactions and emotional expressions thus shade imperceptibly into each other. Every object that excites an instinct excites an emotion as well" [James, 1981, Ch. 15, pg. 395]. James and Carl Lange proposed their own theory of emotions at around the same time, this became known as the James-Lange theory of emotion. This theory emphasised autonomic response to stimuli as the cause of emotional response and diverged from the Darwinian viewpoint of emotion as a means of communication.

Antonio Damasio updated this theory of emotion as an autonomic response to stimuli. Damasio studied the effects of brain lesions on cognition. Patients with frontal lobe damage demonstrated impaired decision-making capabilities without any impaired cognitive effects in working memory, comprehension etc. [Adolphs et al., 1994]. He demonstrated experimentally that cortical and subcortical sites in the brain play a key role in the creation of emotional responses and that these responses are necessary in reasoning and decision-making tasks. This led him to propose the "Somatic Marker Theory" [Damasio, 1996]. This theory proposed that emotions play a central role in decision making and his work with patients with neurological damage showed how the ventromedial areas of the brain regulated this decision making process. According to this theory when faced with complex situations decisions are made only after weighing up short and long term outcomes, a key hypothesis of the theory is that when the outcomes of the decision making stage remain ambiguous emotions then strongly affect this decision making process. Damasio's theory provides a link between higher and lower cognitive function; a "bottom-up" representation of the brain suggests that autonomic responses and subconscious survival circuits shape emotional responses, and these responses then feedback into the behavioural reasoning capabilities of individuals [Damasio, 2004]. Furthermore this approach provides a link between emotion theory and approach vs. avoidance responses and their effects on complex behavioural responses and individual differences in response to stimuli.

In 1988 Nico Frijda published The Laws of Emotion [Frijda, 1988]. Frijda sought to emphasise the idiosyncratic nature of emotional expression, allowing the regularity and patterns of emotions to be studied without undermining the individual differences in behavioural response and that emotions form an input to action preparation [Frijda, 2007]. Frijda's work formally emphasisied the role of emotions as preparation for action. Joseph LeDoux was to build on this line of reasoning, working modelling fearful responses to stimuli in rodents, and linking these responses to the amygdala in the human brain. LeDoux primarily worked with the threat response, studying how organisms avoid threatening stimuli as opposed to approaching a positive stimulus stating that there were two separate processing functions of stimuli e.g. threat. A "Low" road in which the brain acts upon processed stimuli and a "High" road which involved higher order brain functions and was a direct result of the processing of the the responses to stimuli as they were occurring. Emotional response being the term used to describe the byproduct of this mechanism [LeDoux, 1996]. LeDoux and Brown's Model of emotions [LeDoux and Brown, 2017] suggests that the brains of vertebrates have integral survival circuits, the purpose of these mechanisms is to process information fundamental to survival and that they are not directly concerned with producing emotional responses. He suggests that emotion theories have a tendency to group and omit detail in the processing of emotional responses for the sake of categorising them under a single word, fear, love, hate, that dismisses the interaction of many complex and interacting neural pathways [Debiec et al., 2014, LeDoux, 1996].

The ability of an organism to distinguish between different stimuli is critically important to its survival and or ability to thrive in an environment. Research has shown that survival circuits in the brain influence an organism's reflex actions when presented with external stimuli and influence the organism's predisposition to approach avoidance behavior (See Lang and Bradley [2010]; Saraiva et al. [2013] for experimental evidence of approach avoidance survival mechanisms). The patterns of behavioural response driven by survival circuits are not simple reflex actions but can be nuanced, flexible and sensitive to context [Feldman Barrett and Finlay, 2018] and personality idiosyncrasies [Elliot and Thrash [2010]; Elliot [2006]; Querengässer and Schindler [2014]; feldman_barrett_concepts_2018].

In summary, modern research has attempted to underpin behavioural responses to stimuli with links to survival mechanisms by demonstrating that functionally separable neural systems generate approach vs. avoidance responses to positive and negative stimuli. Lower order neurological circuitry directly influences higher order responses to categorical stimuli which may or may not change over time and be influenced by individual differences [Frijda, 1989]. Generalised responses to positive and negative stimuli inform approach and avoidance responses in a nuanced contextual fashion revealing higher order personality traits through observed affective disposition to enticing or threatening environmental factors.

1.2 Models of Emotional Experience

The ease at which humans interpret emotional responses in others has led to discussion as to whether there are a range of basic emotions that are universally recognisable and that these emotions can be interpreted without higher cognition, an automatic response. This theory of Basic Emotions (BET) [Ekman, 1992] suggests that knowledge of what stimulus has provoked an emotional state should not be required as the emotion can be interpreted from the physical response alone. It suggests that emotional responses are discrete entities which are functionally separate that these separate emotional states have evolved to enable an organism to deal with fundamental “life-tasks” [Ekman, 1992] and that these separate emotional states can be observed through facial expression. The BET approach is challenged by the ‘appraisal’ group which suggests that emotions are adaptive responses which reflect appraisals of features of the environment that are significant for the organism’s well-being [Moors et al., 2013]. Gendron and Barret put forward a third ‘constructionist’ viewpoint [Barrett, 2011]. The constructionist viewpoint seeks to reintroduce prior work in the field and re-establish a theory that basic reactions to stimuli are not themselves emotions but form the building blocks to the more complex reactions we then call emotional responses [Stearns et al.]. These three central viewpoints in modern psychology form an opposing viewpoint to the group which supports a dimensional model system for the appraisal of emotional responses.

In 1879 Wilhelm Max Wundt established the first experimental laboratory for psychological research. Wundt theorized that emotional experiences followed a strict continuum of positive or negative valences [Wundt, 1980]. Wundt experimented directly with emotional stimuli in formal laboratory conditions which allowed him to construct a formal psychological model which added to the theories of William James [James, 1981] and attempted to map emotional states onto three orthogonal dimensions. It suggested that emotions were not simply perceptions of raw bodily sensations and that the mental processing of these sensations led to the complex patterns of emotional responses. Wundt described these responses on a three separate scales of pleasantness or unpleasantness, arousing or subduing and strain vs. relaxation (valence, arousal and intensity) suggesting that no individual is entirely devoid of emotion at any one time and that all these sensations activate and fluctuate together to form emotional responses.

In 1985 the PANA model of emotion was proposed by Watson and Tellegen. This model of positive and negative activation (PANA) suggests that positive affect and negative affect are two separate systems. States of higher arousal tend to be defined by their valence, and states of lower arousal tend to be more neutral in terms of valence. The vertical axis of this model represents low to high positive affect and the horizontal axis represents low to high negative affect [Watson and Tellegen, 1985]. The Vector model was proposed in 1992 by Bradley and Greenwald [Rubin and Talarico, 2009]. This model builds on Wundt’s theories of continual emotional assuming that there is always an underlying arousal dimension, and that valence determines the direction in which a particular emotion lies (See Fig. 1.1). This two-dimensional model consists of paired vectors, high arousal states are differentiated by their valence, whereas low arousal states are more neutral and are represented near the meeting point of the vectors.

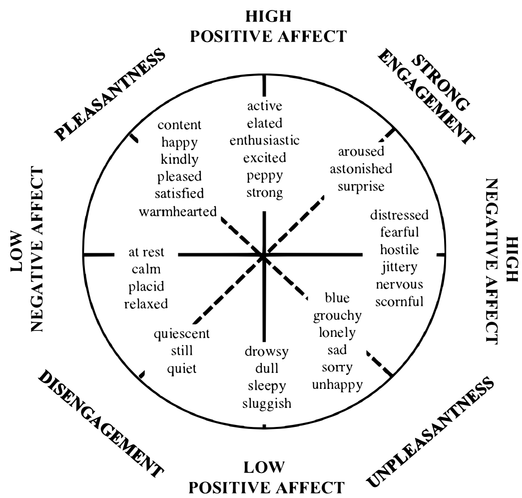

Figure 1.1: The Positive Affect Negative Affect (PANA) Model from Watson and Tellegen, 1985

Robert Plutchik proposed a model that incorporated a third dimension and hybridised the basic and complex emotional categories. It comprised of concentric circles the inner basic emotions formed overlapping circles with the outer more complex emotions. There are numerous emotions, which appear in several intensities and can be combined in various ways to form emotional 'dyads'. [Plutchik, 2001] (Fig. 1.2).

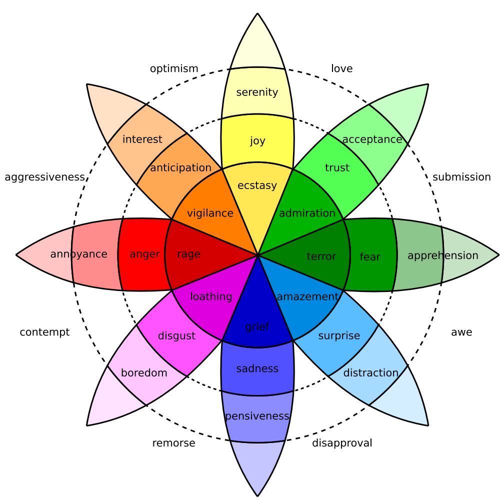

Figure 1.2: The Plutchik Model from Plutchik, Robert 1980

The Circumplex Model of emotional arousal was proposed by James Russell. It is commonly used to measure responses to emotional words, facial expressions and affective states [Remington et al., 2000]. It plots emotional responses around a two dimensional circular space configured with two axes of emotional arousal and valence (Fig. 1.3) Arousal is distributed across the vertical axis and valence across the horizontal, neutral states of arousal being located at the central convergence of both axes. In this model emotional states can be represented at any level of valence and arousal, or at a neutral level of one or both of these factors [Russell, 1980].

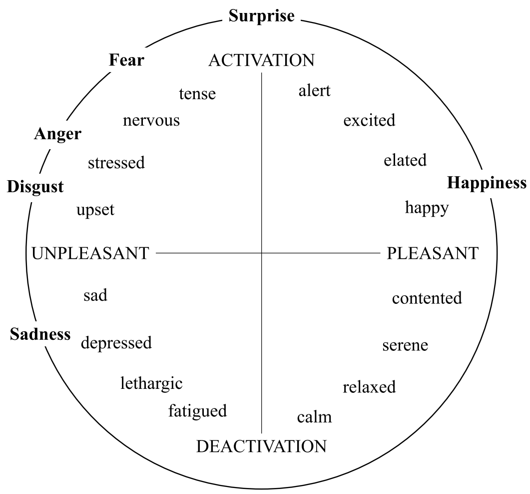

Figure 1.3: The Circumplex Model from Russell 1980

Categorical models of emotion such as BET set clearly defined boundaries between emotional states and placed emphasis on facial expression as a means of categorisation of emotional states further suggesting that facial expressions had evolved in pre-linguistic society as the primary means of communication [Ekman, 1992]. Facial expressions were hypothesised to be universally recognisable and their linked emotional states cross-culturally acknowledged. Several studies were conducted into the universality of facial expression of emotional states, Ekman initially suggested that studies of isolated amazonian tribes supported the universality of facial expression of emotion [Ekman and Friesen, 1971] but also conceded that there was evidence that context played a role [Ekman, 1972]. Constructivist arguments cite similar research to directly counter the basic emotion approach [Gendron et al., 2014]. The Constructionist view of emotions states that emotions such as fear, anger, sadness are the building blocks of emotion and are the result of complex basic responses that can differ in their resultant outcome based on individual differences. Secondarily regarding the classification of emotional states as subordinate to the assessment of causation. Dimensional models explicitly state that emotions coexist in two or in some cases three dimensions of valence, and that emotional arousal across one dimension can affect the susceptibility of an organism to other emotional responses. Commonly opposing states are situated at opposite ends of a dimensional model. Dimensional models can allow for greater nuance in emotional states vs. categorical models but their design can also affect their ability to categorize emotional states accurately. The Circumplex model (Fig. 1.3) allows for emotionally intense reactions to stimuli that are neither very positive or negative in terms of valence. The Plutchnik model (Fig. 1.2) does not incorporate low valence emotionally intense states. If emotion is an evolved means of preparing an organism for action within the context of its environment dimensional models allow the observer to categorise emotions which may be functionally similar whilst also allowing for individual differences to be observed. The addition of a third dimension in emotional models allowed for more complex nuances particularly in emotional states that are functionally similar. This third dimension of emotional response would be expanded and form the basis for a new model a decade later. The Evaluative Space Model was developed by Cacioppio, Bernston, Norris and Gollan and attempted to provide a more flexible and adaptable affect system of evaluative processes [Cacioppo et al., 2012].

1.3 Evaluative Space Model

The Evaluative Space Model (ESM) is a theory that describes a multidimensional space within which responses to positive and negative stimuli can be studied. It suggests that emotive responses are bipolar in nature, but such behaviour is partially segregated [Cacioppo et al., 2012]. Such that lower valences of stimuli overlap at the center of the model and can provoke a range of low affect positive and negative emotional responses. This equivocal separation of positivity and negativity results in behavioural plasticity enabling an adaptable and flexible range of responses to stimuli. A key feature of the ESM is that consideration of the affect system as a construct discrete emotions or abstract dimensional structures is irrelevant.

ESM suggests a clear differentiation between positive and negative emotional valences. Evidence for behavioural bipolarity dates back to Brehm who suggested that individuals will increase the perceived positives in their choice of a set of options and exaggerate the negative in any alternatives they reject [Brehm, 1956]. If the perceived difference between the options is greater the affect is greater. Contemporary emotion theories assume or place emphasis on reciprocal activation in approach and withdrawal behaviours. ESM does not posit a reciprocal activation dependency. ESM is best thought of as a three dimensional graph (Fig. 1.4). The X axis of the graph extending towards an increasing negative response to stimuli, The Z axis extending back from the origin towards a high positive stimulus response. The Y axis extends upwards. This Y valence being the Net Predisposition axis which represents the resultant affect based on the net results of the positive and negative valences. Thus the ESM model allows for the antagonistic nature of positive and negative stimuli to be reconciled and explain resultant behaviour.

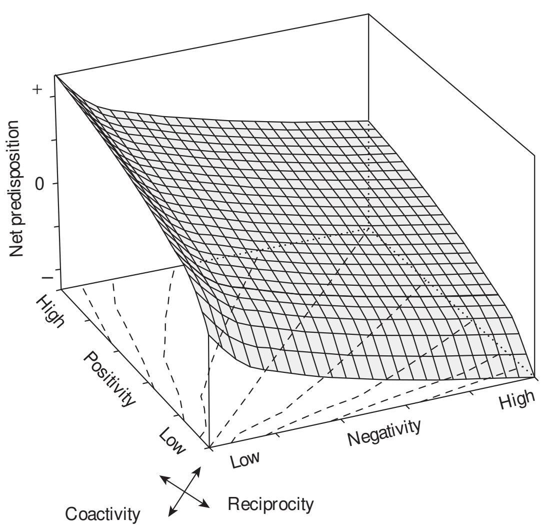

Figure 1.4: The Evaluative Space Model fom Cacioppo et al., 2012

The Affect System [Cacioppo and Berntson, 1999] is the basis for ESM and refers to the functional processing of appetitive and aversive information. It has at its core a basis in evolutionary theory. The evolutionary responses of organisms favour a high degree of temporal response in the initial stages of reaction to stimuli preserving 'tried and tested' evolutionary responses within an organism. The affect system has evolved to efficiently and effectively promote adaptive responses to stimuli, and to produce a broad range of emotional states and expressions [Norris et al., 2010]. Two postulates of the ESM (See Table 1.1) are central to its hypotheses on approach avoidance behaviour in organisms and link evolutionary responses with higher order emotional responses. The Negativity Bias and Positivity Offset posits of the ESM [Cacioppo and Berntson, 1999, Cacioppo et al., 2012] are adaptive responses to negative and positive stimuli driven by the extremity of the stimulus and its relative proximity to the organism. The ESM suggests that the affective cognition of positive and negative stimuli operates across a diametric scale convergent about an axis of valence, minimal activation on this scale provokes an approach response. Higher activations induce an overpowering desire to avoid the excitatory stimuli when it is negative [Cacioppo et al., 2012, pg. 54, Fig 3.3] (See Fig. 1.5).

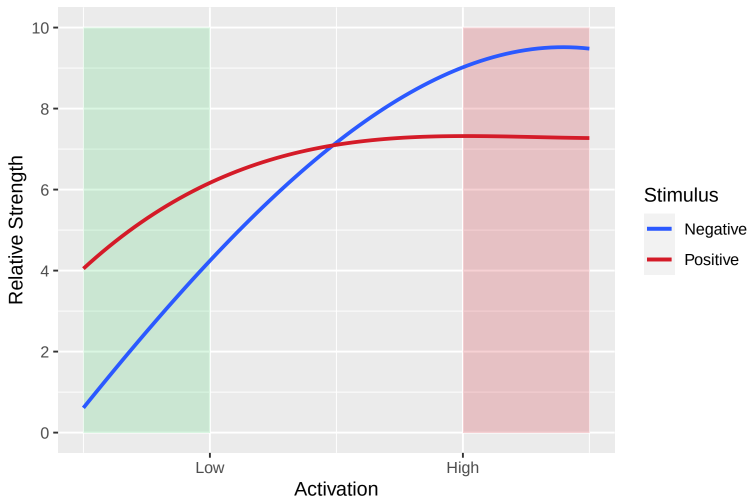

Figure 1.5: Negativity Bias, Positivity Offset

The ESM postulate of Heteroscedacity plays a regulatory role in approach avoidance responses. It suggests that adaptive avoidance behaviour is primarily affected by negative stimuli, in the absence of negative stimuli or the evocation of positive emotions 'staying the course' is a sufficient behavioural response. ESM includes a further variable within its scope. The recalibration postulate suggests that the activation functions for each valence are subject to change. An animal must have a dynamic range which provokes changes in sensitivity or it will be unable to adapt to changes to the environment. A response to a predators for instance is fundamental to an organism's survival and is counterbalanced by the animals energy expenditure in any avoidance measure. The measure of an organism's fitness depends on factors outside its control but any organism wishing to react to stimuli must display adaptability to circumstance or any stimuli falling outside its adaptive range would fail to induce responsive behaviour. Nature favours a degree of adaptability in organisms and their responses to stimuli.

Table 1.1: Table of ESM Postulates fom Cacioppo et al., 2012

Postulate	Definition	Additional Detail
Level of analysis	There are distinctions among both positive and negative emotions, but positive emotions are more similar to each other than they are to negative emotions, and vice versa.	A single valence continuum does not capture the structure and operating characteristics of affect system
Functional separabil-ity	The constellation of antecedents, emotions, expressions, and response is more diverse for negativity than positivity.	There is a superordinate dimensional structure representing appetitive predispositions, positive affects, and emotions, as well a superordinate dimensional structure representing defensive predispositions, negative affects, and emotions.
Heteroscedac	Positivity and negativity are not equivalent in their constitution, operations, or consequences.	When an event elicits a positive emotion, staying the course is sufficient; when negative emotion is elicited, an adaptive response may vary greatly across eliciting events.

Table 1.1: Table of ESM Postulates fom Cacioppo et al., 2012 *(continued)*

Postulate	Definition	Additional Detail
Energetic efficiency	Behavior in future encounters with target stimuli will tend to be more expected and stable when organized in terms of a bipolar evaluative dimension.	Behavioral and cognitive efficiency and a reduction in stress is served by mental representations of general action predispositions toward classes of stimuli.
Evaluative activation	Affect is a joint function of positively and negatively valent activation functions.	The resultant output disposition(s) is not necessarily the simple arithmetic mean of the separate functions. The net disposition, for example, may be comprised of ambivalence, vacillation, or active suppression of one or the other dispositions.
Monotonicity	Strength of the response varies as a function of the extremity of the stimulus.	The functions, however, appear to be negatively accelerating rather than linear across the full dynamic range.
Antagonistic effects	Directional response effects of positive affect (approach) are generally opposite to that of negative effect (withdrawal).	Exceptions exist, such as when aversive threat is met with aggressive defense, or when a pain stimulus (e.g., flu shot) is approached and solicited.
Functional separability	Activation of positivity and negativity are partially separable.	This separation confers additional adaptability and flexibility for learned dispositions.
Modes of evaluative activation	Positivity and negativity can be activated reciprocally, uncoupled, or nonreciprocally	At high levels of coactivation (which minimizes the dynamic range, reduces response lability, and maximizes directional flexibility), energy expenditure is taxing over long periods of time; eliciting circumstances tend to be avoided.The reciprocal activation postulate in prior models of affect and emotion is replaced by this postulate.Bivalent modes of evaluative action requires at least a three-dimensional approach: 1 for positivity; 1 for negativity; 1 representing the net behavioral predisposition or response orchestrated by the affect system.
Parallel evaluative processing	The ability to achieve coactivation of positivity and negativity by attending to positive and negative features of a stimulus simultaneously (e.g., bittersweet, disappointing wins).	Although there may be some reciprocal inhibition between the evaluative dimensions, they are at least partly independently expressed.
Low-pass filtering	The ability to achieve coactivation of positivity and negativity by oscillating between positive and negative stimuli with sufficient speed that results in the sustained activation of positivity and negativity.	Even though there can be an oscillation between positive and negative activation, if the speed of the presentation of the contrasting stimuli is faster than the low pass filter cutoff, the activation of each cannot follow the speed of the oscillations and coactivation results (ambivalence)From both a practical and theoretical perspective, a rapidly switching oscillation between positive and negative (or more generally, from the two ends of a bipolar system) is equivalent to a bivariate system in its formal properties.
Distinct activation functions	The partial segregation of the positive and negative evaluative channels allows for distinctive activation functions for positivity and negativity	The activation functions may be at least in part contextually dependent.
Positivity offset	The offset (intercept) for the positive activation function is higher than that of the negative activation function	Motivation to approach is stronger than the motivation to withdraw at very low levels of evaluative activation; this promotes exploratory behavior – without a positivity offset, a person in a neutral environment is unlikely to approach novel stimuli
Negativity bias	The gain for the negative activation function is higher than that of the positive activation function	Motivation to withdraw is stronger than the motivation to approach at very high levels of evaluative activation; it is more difficult to overcome a fatal (or near fatal) assault than to return to an opportunity unpursued.
Recalibration	The activation functions for positivity and negativity are capable of the same kind of recalibrations based on salient contextual and accessible stimuli as is seen in receptor mechanisms.	Both sensitivity to small variations among stimuli and a dynamic range suitable to detect a wide array of affective stimuli are preserved.

Table 1.1: Table of ESM Postulates fom Cacioppo et al., 2012 *(continued)*

Postulate	Definition	Additional Detail
Affective dispositions	There are measurable individual differences in the positivity offset and negativity bias.	These individual differences may have both a biological and an experiental/psychological basis.
Heterarchical organization	Evaluative processes are implemented at multiple, re-representative levels of the neuraxis	There is a continuum of neuraxial organization that extends throughout the central nervous system in a heterarchical structure, ranging from the spinal cord to the frontal lobes. Rostral, in contrast to caudal, neurobehavioral organizations are slower, more serial like; susceptible to more contextual control; potentiate greater response flexibility; and manifest multiple modes of appetitive and aversive activation, The multiple levels of processing can result in coordinated synergistic outcomes, or can lead to conflicts.

ESM assumes that positive affect is linked to appetitive attraction and negative affect linked to aversion but certain emotions such as anger appear to contradict this dichotomy with the negatively associated display of anger generating approach responses. This apparent discrepancy can be explained by the underlying motive of defensive reaction. Other complex emotional states with ambiguous or deeply personal affective predispositions such as humour can result in complex behaviour and modes of expression. This is most easily seen in the language used to describe highly co-activated states e.g. 'I'm so happy I should cry'. The principles of the ESM provide a roadmap for future investigations in multiple areas, such as testing the mechanisms underlying emotional disorders and examining the relationships between emotional states and physiological responses [Norris et al., 2010]. In summary, the postulates of the Evaluative Space Model have the ability to direct and guide future research on the structure of affective space, as well as its representation in the brain, body and its implications for affective disorders.

1.4 Emotional induction in psychology

The study of emotional states requires the means of reliably inducing changes in physical states and subjective feelings that are referred to as 'affect' and 'emotion'. Affect refers to a valence state between pleasant and unpleasant induced by a change in environmental factors [Russell and Barrett, 1999]. Emotion being complex responses to stimuli that can be influenced by primitive survival mechanisms and subject to differences in physical condition of the brain and interpersonal personality differences. Presentation of recorded media such as films or music can be selected to reliably induce emotional states and researchers have assessed and categorised libraries of emotionally arousing films [Gross and Levenson, 1995, Schaefer et al., 2010], imagery [Lang, 1995], emotionally aroused faces [Biehl et al., 1997], music [Eich and Metcalfe, 1989], recorded sounds and voices [Yang et al., 2018] and affective word comprehension [Bradley and Lang, 1999]. Standardised libraries can aid the researcher in inducing emotional states that can be subject to cultural differences in the interpretation of the stimulus on behalf of the participant, familiarity with the media and are usually scored via a manipulation check after the stimulus response has been viewed which can be subject to their own biases [Robinson and Clore, 2002]. Researchers also conduct experiments which employ the use of confederates [DeSteno et al., 2006] or the use of an audience to create a positively or negatively affective group response to a participant [Allen et al., 2017]. The use of confederates and social stressors can carry additional ethical issues for the researcher and will require the use of pre-screening such that candidates who may be undesirably affected by study participation are excluded from the experiment or in the case of confederates additional planning to ensure that participants do not suspect the role of the confederate. Changes in emotional arousal states can be measured implicitly using facial Electromyography (fEMG) [Golland et al., 2018, Lajante et al., 2017]. Activation of the corrugator supercilia and zygomaticus major can be used to measure positive and negative valence respectively [Cacioppo et al., 1986, Fridlund et al., 1984, Larsen et al., 2003] and are correlated with self-reported affective states [Brown and Schwartz, 1980, Golland et al., 2018]. In this case, increased activation of the negativity dimension enhances corrugator reactivity and suppresses activation of the zygomaticus. In addition, increased negativity would precipitate activation of the sympathetic branch of the autonomic nervous system, e.g., increased heart rate (ECG) and skin conductance level (SCL) are associated with arousal during emotional experiences [Bradley et al., 2001, Dawson et al., 2000, Gross, 1998, Felnhofer et al., 2014, Malińska et al., 2015, Peterson et al., 2018]. Negative responses to stimuli are more universal and less subject to interpersonal differences as they operate on an instinctive level as survival mechanisms triggering behaviours which require little conscious thought to process [Bradley, 1994]. There is evidence for a broad range of interpersonal interpretation on the affect generated by negative stimuli [Charles and Carstensen, 2008, Heinström, 2010, Soroka et al., 2019]. Heightened sensitivity to negative stimuli is a characteristic associated with increased trait neuroticism [Eysenck, 1963] and high neuroticism has also been associated with a 'harm avoidant' style of coping [Zelenski and Larsen, 1999], leading to exaggerated psychophysiological reactivity to increased threat [Drabant et al., 2011] and negative form of media stimuli [Norris et al., 2007, Reynaud et al., 2012].

1.5 VR as an Emotional Induction Method

VR technology allows a user to view a simulated environment that can be photorealistic or otherwise and choose to mimic naturalistic laws, e.g. gravity, or to deliberately establish its own contextual rules unique to that environment. Such environments are projected inside the headset binocularly allowing for accurate depth perception from a first person perspective. Tracking technology reorients the simulated camera perspective according to a users physical head movements increasing immersion, the same technology can also be applied to users limbs giving them added environmental agency and allowing for full body locomotion within the simulated environment. These mechanisms can create a convincing sense of presence and embodiment [Baños et al., 2004, Schultze, 2010, Slater et al., 2009b, Cummings and Bailenson, 2016] which can influence how individuals react to environmental stressors such as the threat of virtual height [Meehan et al., 2002]. VR can deliver potent affective scenarios which induce varied emotional states, provided those simulations can provide user agency via the use of interactive mechanics which mirror the agentic capacity of real world scenarios and the visual and mechanical representation of the users' avatar is sufficient to provide a sense of coherent presence [Skarbez et al., 2017]. VR environments designed to induce emotional responses in laboratory environments can also be designed to be interactive producing experiences which are influenced by an individuals choices in the environment enhancing the potential for display of individual differences. It could be argued that the schematic use of batteries of media [Quigley et al., 2013] provide a less ecologically valid solution to the researcher than the use of VR as an emotional induction method. Virtual Environments (VE) and VR technology can also circumvent some of the ethical issues in confederacy tasks through the illusion of threat displayed by virtual avatars and characters and can in general portray threatening scenarios that would be impossible to replicate in laboratory environments which place the researcher and participant at minimal personal risk.

A number of studies have been conducted which attempt to measure emotional responses via psychophysiology using the relatively new methods of emotion induction VR technology presents to research programmes. Riva et al studied how changes in the lighting, weather effects and scenery of virtual parks affected a participants sense of presence and elicited differing emotional responses [Riva et al., 2007]. Other studies have attempted to replicate well known psychological experiments in VR [Felnhofer et al. [2014]; Montero-López et al. [2016]; [Toet et al., 2009]. Biedermann et. al recreated an elevated plus maze designed for rodents [Biedermann et al., 2017]. The use of VR to study fear responses to virtual height has been a popular method of emotional induction [Slater et al., 2009a, Cleworth et al., 2012, Peterson et al., 2018, Seinfeld et al., 2016]. Some of these studies have used room-scale tracking technology to allow participants to physically explore their environment [Krupić et al., 2020, Meehan et al., 2002, Wuehr et al., 2019]. Room-scale VR can further enhance the immersive potential of VEs allowing a participant to freely to explore an environment. Participants can also naturalistically respond to stimuli, withdrawing from threatening stimuli either voluntarily or through activation of instinctive survival behaviour, allowing the researcher to observe approach vs. avoidance behaviour. Additionally the technology used to build the VE is inherently well disposed to tracking the exact time at which stimuli are presented and modulating their delivery, used in conjunction with the highly accurate tracking required by VR applications room-scale VR simulations offer a researcher unprecedented levels of accuracy in behavioural measures and increased flexibility in experimental design and stimulus delivery.

1.6 Aims and Objectives

The aim of this project is to create a series of VE which can reliably induce approach avoidance behaviour and emotional responses to environmental stimuli in order to further understand their role in human behaviour with reference to the Evaluative Space Model [Cacioppo et al., 2012]. These responses will be measured through Facial-electromyography, Electrocardiogram, Electrodermal activity and through behavioural tracking via the underlying engine used to create the virtual environment. In order to achieve this aim a number of design challenges and technical constraints must be developed and managed:

- Negative responses to stimuli are less subject to interpersonal and cultural differences and so it was decided from the outset of the project that the avoidance response to negative stimuli should be studied first. Whilst the ESM states that positive and negative valences are not functionally separated a design for a threatening, avoidance provoking scenario was required.
- A Negatively biased scenario must also fit within the real world constraints of the laboratory testing environment and its effects should be tested to ensure reproducible results on participants. The scope of this environment and the degree of interactivity must be set at a level which allows for the maximum amount of participant interaction and immersion without compromising the schedule of the overall project. The designed and tested VE should also be able to be easily expanded upon or modified for further studies during the project timeline.
- The use of room-scale VR presents several challenges to the reliable capture of psychophysiological measures. Ambulatory participants will naturally produce recorded measures with an increased level of signal noise which will vary depending on the degree of physical activity that is required of them during a task. The design of the study should consider this, test the effects of any VE and develop measures to accurately process signals which are captured from ambulatory room-scale VR experiments.
- A programmatic means of recording the time of stimulus delivery within a VE and accurately recording all the body positions of ambulatory participants must be developed to study the naturalistic approach and avoidance mechanisms during the ambulatory psychology procedures.
- Previous research has suggested what effects negative environmental stimuli may have on psychophysiological signals within a VE and to predict how approach avoidance responses may differ between personality types. Firstly we must focus experimental

design on reliable emotional induction and attempt to demonstrate differences in behaviour within personality groups. After this point the enhanced immersive effects of room-scale VR, improvements to accuracy in behavioural measures and flexibility of modern software techniques in VE design can be used to modulate the effects of an y induced emotional states.

1.7 Research Questions

1. Wearable sensors can deliver equivalent signal quality and sensitivity to independent variables as conventional wired psychophysiology.
2. Room-scale VR will enhance emotional reactivity because it induces an embodied emotional state.
3. Negative gradient from ESM is observed when potential source of negativity (threat) is increased.
4. Due to negativity bias, personality traits, such as neuroticism, lead to a more pronounced (i.e. steeper) negative gradient when faced with increased level of threat.
5. Corrugator activation will increase when participants perform high threat behaviour compared to low threat. Zygomaticus activation will decrease when participants perform high threat behaviour compared to low threat.

1.8 Novelty

To our knowledge no previous study has attempted to measure emotional responses in virtual reality with explicit regard to the Evaluative Space Model nor have they adapted the latest in VR sensor technology to facilitate full body interactions mechanics and to track these movements to the degree we believe possible with current VR technology. Although some studies have explored the use of room-scale VR and fear of heights these studies have restricted participant movement to a singular axis and not introduced nuanced interactive mechanics that modulate threat perception without compromising participant agency. To our knowledge no psychological study has developed a bespoke framework for the accurate delivery of stimulus responses and participant body tracking or used techniques within game engine development to modulate stimulus delivery. Overall the project aims to contribute to the available literature and to provide methods which others can choose to use to advance knowledge in the areas of emotion research and VR/VE experimental design.

1.9 Summary

This chapter has presented an introduction to the research project, aims and objectives. A literature review relating to emotion research and models of emotion, emotion induction in psychological research, and the use of VR technology to induce emotional responses. Chapter 1 serves to introduce the reader to the background and purpose of this research project, which will be the underlying focus of the remainder of this work.

Chapter 2

Methodology

2.1 Introduction

This chapter gives a background to the current state of virtual reality technology explaining how several important recent developments have realised the potential of the technology and how these advances were utilised for the purposes of this thesis. It also describes the methods and procedures used in each protocol combining technological innovation with established techniques used to record psychophysiological measurements to meet the objectives of the research programme.

VR technology can create a convincing illusion of a spatial location by presenting visual and auditory data to the eyes and ears that are isolated from the physical environment by a head-mounted display. In order to sustain this illusory effect, a number of key technological systems must function in unison. Almost all of these technologies have been widely available for many decades but it has not been possible to combine them into a technology package that is powerful enough to render virtual environments and be ergonomically acceptable until recently. Ivan Sutherland's 'Ultimate Display' [Sutherland, 1965] described the technology requirements and broad design for a head-mounted display device, and with the exception of accurate tracking, his 'Sword of Damocles' demonstrator proved that different technologies could be brought together relatively successfully. Recent advances in software, processing hardware, computer aided design, optical mass production and display panel technology have allowed these technologies to be integrated in a hard/software package light enough for sustained use and sufficiently advanced to minimise motion sickness for the wearer.

The key groups of technological hardware and software services can be aggregated into four main groups:

(1) VR display panels must be of a small enough size to function within the headset, deliver high definition content and have a high pixel density (DPI). Display resolution is vital due to the short distance between the users eyes and high DPI is required so that the individual display pixels cannot be observed.
(2) The position of the wearer's head and body movements must be accurately tracked by the system running the VE with accuracy and consistency, i.e., currently the main methods of tracking in VR systems are gyroscopic sensors, optical tracking or laser based designs.
(3) High CPU and GPU computing power in systems architecture, as accurate tracking, particularly for optically based systems, can increase CPU burden on any system running VR simulations. Recent advances in GPU architecture have led to the widespread adoption of graphics processors, which are required to process any VE

scene essentially twice, as every virtual environment presented in a VR headset is displayed from a naturalistically accurate shift in position to each eye. This binocular display doubles the burden on graphics processing but allows for accurate depth perception and three dimensional comprehension of the VE. Current software techniques and in-headset eye tracking can enable foveated rendering techniques whereby only the parts of the scene that are being directly observed by the eye are rendered at the highest quality, reducing rendering expense.

(4) General advances in manufacturing and demand for low power small die processors, high quality plastic optic manufacture and a general reduction in processor size combined with an increase in mobile device usage have enabled small, lightweight headsets to be mass produced. This development has reduced the technical burdens on VR research and lowered costs for research institutes wishing to use VR technology in psychophysiological experiments. At the onset of the project it was necessary to select a technological strategy and choose systems which would support the aims and objectives of the research project.

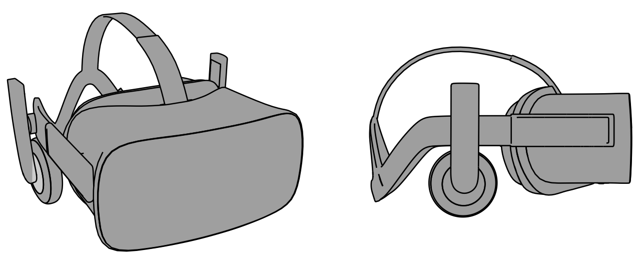

Figure 2.1: Oculus Rift HMD persepective and side view

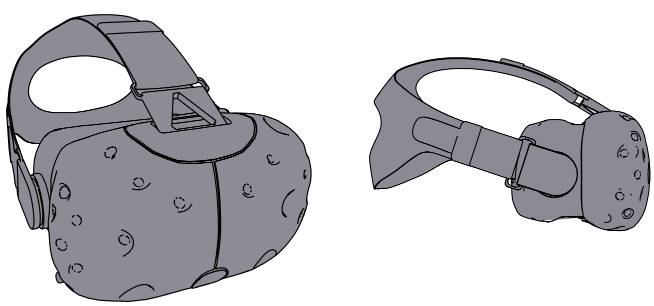

Figure 2.2: HTC Vive Headset HMD persepective and side view

2.1.1 VR Comparison and Solution

During the initial design and development phase of the project it was decided that a room-scale VR system should be chosen to maximise the level of immersion available

Table 2.1: Oculus Rift vs. HTC Vive comparison

Name	Release	Tracking	Display type	Resolution	PPD	Aspect Ratio	Refresh	FOV
Oculus Rift	2016-3-28	Optical	OLED	1080x1200	9.81	9:10	90Hz	94°
HTC Vive	2016-4-5	Laser	OLED	1080x1200	9.81	9:10	90Hz	110°

to any VE design chosen for experimental tests. An alternative approach to use other commercially available VR headsets in a sedentary or standing position for the user and restricting body movement to a fixed position. This decision would have reduced complexity of design and development, but it was, would reduce the potential for an interactive embodied experience which gave the user enhanced agency and also reduced the analysis potential of the behavioural measures. This decision narrowed the choices of commercially available VR systems to the Oculus Rift (Fig. 2.1) (Oculus Rift DK2, Oculus VR, Irvine, CA, USA) and the HTC Vive (Fig. 2.2) (HTC Corporation, Xindian, New Taipei, Taiwan). Any decision on hardware specification also necessitates a commitment to the software APIs (application programming interface) developed to work in conjunction with that specific hardware system, i.e., the Oculus Rift having its own software ecosystem and the HTC Vive system running on the Steam VR API (Valve Corporation, Bellevue, WA, USA). Specifications with respect to the rendering and room scale capabilities of both systems were examined that prioritised room-scale tracking scope. With respect to our research objectives, the lower hardware overhead and accuracy potential of the laser tracking in the Vive system vs. the optical solution used by the Rift device led to the HTC Vive/Steam VR solution being selected (See Tab. 2.1 for comparison). Two Vive hand controllers were used to manipulate virtual objects within the VE using the HTC Vive Steam VR system (Fig. 2.3). Another advantage of this system is the capacity to expand the area covered by the tracking devices beyond their 5x5m range by adding in two more Lighthouse devices for a possible 10x10m area. Also, this system has the facility to extend the control mechanic via additional Vive Trackers (Fig. 2.3) that can be used alongside conventional hand controllers. These devices can be attached to the body of a participant or to inanimate real world objects, which can subsequently be tracked and manipulated within the VE. This system was used to complete Studies One and Two after which it was replaced by a HTC Vive Pro Headset (Fig. 2.4), Valve Index hand controllers (Fig. 2.4) and a HTC Vive wireless transmission device for the study described in Chapter 5. This device ran on an updated Steam VR 2.0 API which allowed for 15x15m tracking areas and was compatible with the Valve Index hand controllers which were capable of detecting changes in hand grip strength and finger tracking.

2.1.2 Room-scale VR

Room-scale VR can have immersive benefits for psychophysiological experiments and the study of embodied emotional states, but adoption of this approach must be considered in the context of the research programme as it can place additional technical, logistical and design burdens on laboratory experimentation. Researchers may seek to reuse VR experiments which have previously been used in earlier studies. Those VEs ,which may have been designed for non-roomscale sedentary VR systems, will need to be adapted and redeveloped or they will be fundamentally unusable in room-scale applications. In the context of room-scale VR applications a researcher cannot predict the speed or direction with which a participant may travel within the VE,therefore it is more difficult to programmatically deliver stimuli at set times and locations as the participant is free to examine and “look behind” or around any obstacles or areas of the VE which are not designed for close examination. Researchers may also wish to repurpose assets that are freely available online as props or full environments for use in roomscale applications. These assets are also unlikely to have been designed for the level of unlimited and unpredictable scrutiny that can be exercised by the user of room-scale VR applications.

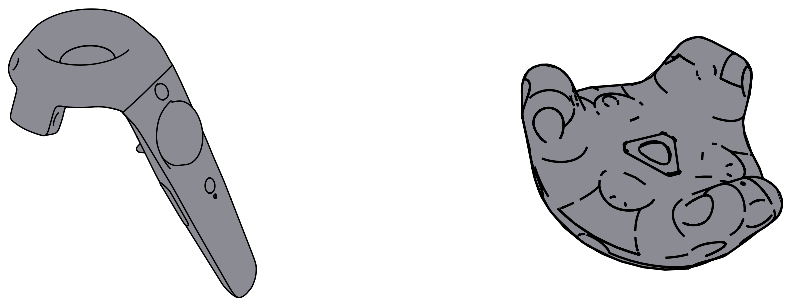

Figure 2.3: HTC Vive Controller and Tracker, used for hand manipulation and foot tracking

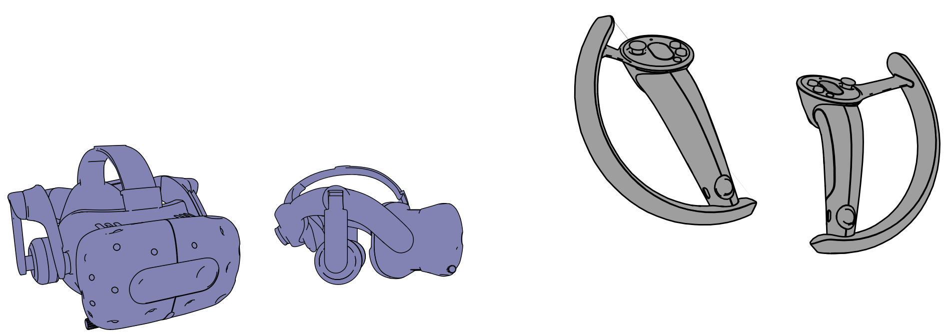

Figure 2.4: HTC Vive Pro Headset and Index controllers used for third VE experimental design

2.1.3 Software

Virtual environments were created via Unreal Engine 4 with custom C++ code added to facilitate behavioural tracking, see Section 2.1.4 for further detail. Unreal engine ran on a laboratory PC and interfaced with the VR hardware via the Steam VR API developed by Valve Corporation (versions 1.2-2.1). Psychophysiological data was recorded for Study One and Two via the AcqKnowledge version 5 data acquisition and analysis software. For Study Three fEMG data was recorded via the Emteq data capture software package. Data analysis for Study One and Two was performed via Matlab (v 9.3) and SPSS 11. For Study Three data analysis was performed via R (3.8) and SPSS 12 see Section 3.3.6.1 for further detail.

2.1.4 Unreal Engine

Initial piloting had proven the usefulness and speed of development time of the Unreal Engine 4.0 platform developed by Epic Games (Potomac, MA, USA) This engine had been trialed considered against the Unity game engine developed by Unity Technologies (San Francisco, CA, USA). Unreal was selected for its capacity to compile standard C++ code and its Blueprint scripting engine which eased the creation and iteration of VE mechanics.

2.1.5 Blueprint Scripting

Unreal Engine 4 BluePrint Scripting is a node based software system designed to expedite prototyping within the engine Development UI and functions as a wrapper around lower level C++ that forms the bulk of the engine codebase (Fig. 2.5). The developer of Unreal Engine projects can pick from a library of simple and complex functions to build multi-faceted environmental mechanics and interactions and often reuse base mechanics for their VE without rewriting complex object-orientated code. Changes to prototypes can also be made quickly and easily and complex custom BluePrint mechanics can be easily exported to additional projects.

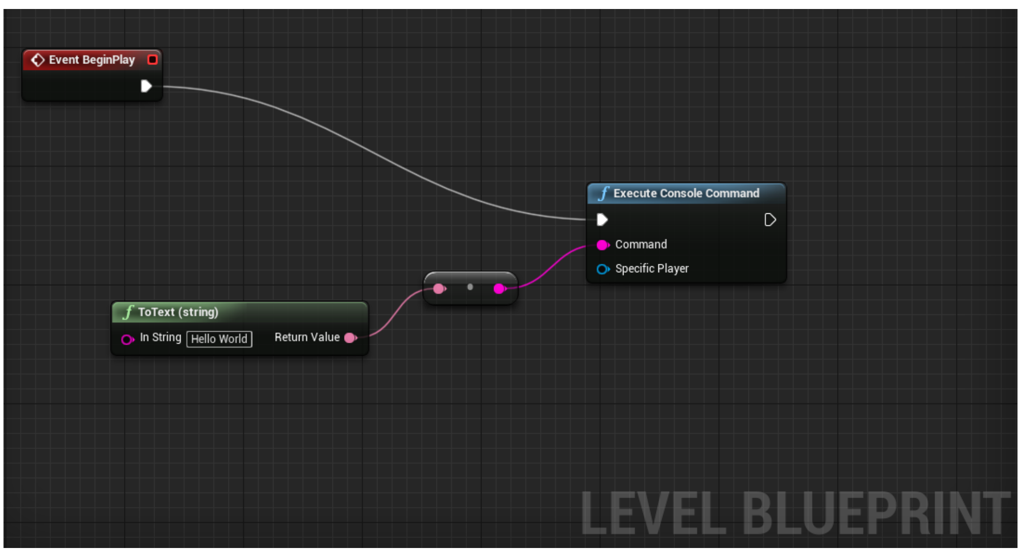

Figure 2.5: BluePrint Scripting, Event BeginPlay node triggered as VE starts > Execute console command triggered > String "Hello World" sent to execute console command as parameter = "Hello World" is visible inside headset

2.1.6 Custom C++

Unreal engine allows the developer to mix BluePrint scripting with their own C++ code. This custom code is then compiled alongside all other interactive mechanics and scripts a developer wishes to integrate into their VE. BluePrint scripting allowed for quick prototyping of pilot studies during design and development phases of this research project. Custom C++ code was utilised to deliver the behavioural data methods required to fulfill the projects aims and objectives.

2.1.7 Behavioural Data Capture

Novel Behavioural data capture techniques were combined with established methods of triggering and capturing events within an interactive VR application. Trigger volumes are three dimensional areas placed within an interactive application or VE which can detect when other objects within the VE enter and exit their perimeter. Trigger volumes are commonly used in video game development to trigger animations or transitions between states in the application. For example, a trigger volume will activate the animation for a door opening, perform a level transition or change the state of a player avatar based on an interaction with the VE.

This research project deployed trigger volumes to activate events in the virtual environment. Trigger volumes were registered when participants transitioned between experimental tasks, received stimuli, tracked the location of the VR headset, hand controllers and foot-mounted sensors, and registered interactions with threatening mechanics within the environment (Fig. 2.6); for specific details, see next section. C++ code was designed specifically for each of the VE environments for the research project. Trigger volumes were placed within the VE environment on key objects and locations and custom C++ code was used to precisely measure behavioural actions with these areas and objects. The C++ code produced a custom BluePrint object which when attached to these interactive components generated a master text file for each participant which recorded the precise time of interaction with a VE object and the ID tag of that object or area. This code generated a list of time values that allowed us to place event markers in the psychophysiological data to mark when participants started and ended an interaction with a specific area or object within the VE.

2.2 Virtual Environment Design

After review of relevant VR research it was decided to focus the initial design of the VE for Study One on the induction of negative emotional responses, in the ESM context stimulus responses that provoked an avoidance response. Previous research on emotion induction media libraries suggested that negative states were more easily provoked [Gross and Levenson, 1995, Lang et al., 1993]. Based on the review conducted in the previous chapter (1.4, Ch. 1), we have summarised the range of VEs developed by other researchers that were designed to induce negative emotional responses below (Table 2.2).

2.2.1 Piloting and Design Choices

An initial phase of piloting was planned after design discussion sessions prior to finalisation of experimental design for the first study. With respect to potential stimuli, consideration was given to research conducted on phobias, specifically fear of spiders, insects and reptiles. Representation of phobia-inducing fauna should provoke avoidance behaviour towards if participant was required to approach an area of a VE inhabited by a virtual facsimile of these stimuli. This approach was rejected before dedicated development time was used to produce a pilot study. It was felt that the animation and rendering of aversive animal character within the VE could be excessively time-consuming and require a photorealistic

Table 2.2: VR Emotion induction

Title	Author(s)	Affect	Method	Group
Physiological Measures of Presence in Stressful Virtual Environments	Meehan .et al (2002)	Fear	Precipice Exposure	Height
Affective Interactions Using Virtual Reality: The Link between Presence and Emotions	Riva .et al (2007)	Joy, Sadness, Anxiety	Environment	Environment
Anxiety and Presence during VR Immersion: A Comparative Study of the Reactions of Phobic and Non-phobic Participants in Therapeutic Virtual Environments Derived from Computer Games	Robillard .et al (2008)	Fear	Actors, Environment	Phobia
Anxiety Increases the Feeling of Presence in Virtual Reality	Bouchard .et al (2008)	Anger, Anxiety	Environment	Actors, Environment
Is a Dark Virtual Environment Scary?	Toet .et al (2009)	Fear	Environment	Height
A Randomized, Controlled Clinical Trial of In Virtuo and In Vivo Exposure for Spider Phobia	Michaliszyn .et al (2010)	Phobia, Fear	Spiders	Phobia
Influence of real and virtual heights on standing balance	Cleworth et. al (2012)	Fear	Heights	Height
A virtual reality approach to the Trier Social Stress Test: Contrasting two distinct protocols	Montero-Lopez .et al (2016)	Anxiety	Evaluative Audience	Social Stress
Introducing the Wunderkammer as a tool for emotion research: Unconstrained gaze and movement patterns in three emotionally evocative virtual worlds	McCall .et al (2016)	Approach, Avoidance, Anger, Anxiety	Environment, Actors	Environment
An elevated plus-maze in mixed reality for studying human anxiety-related behavior	Biedermann .et al (2017)	Fear	Elevated Plus Maze	Height

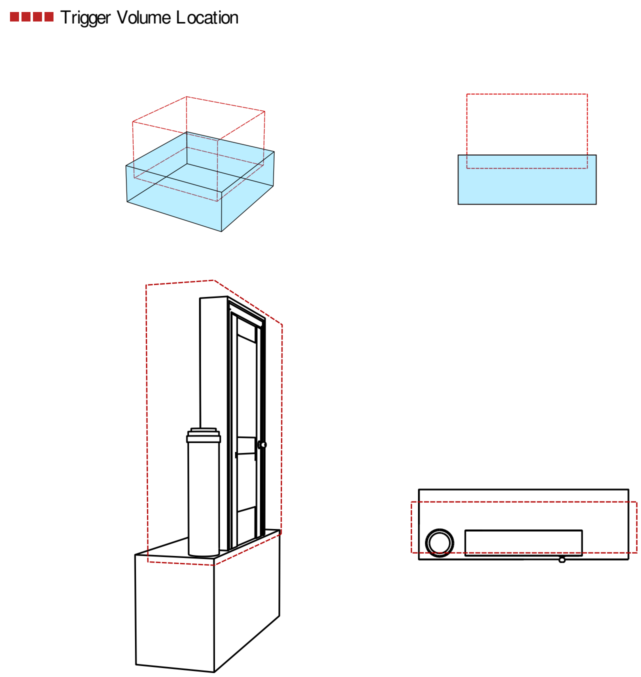

Figure 2.6: Red trigger volumes attached to key interactive elements, invisible to the user these volumes provide timestamps for interactions

approach. With respect to the research questions it was also doubtful that sufficient response would be found without pre-screening participants for specific phobias and calibrating the precise stimuli on a person-by-person basis.

A small room-scale VE was designed for a pilot study in a 4m x 3.2m laboratory, which consisted of a stark virtual room within which a participant was able to view an approximation of their hands and interact with the environment using the VR controllers. After a short period, an area of the VE would begin to be consumed by a virtual fire effect (Fig. 2.7) and participants were required to approach the virtual flames and move their virtual hands into this virtual flame. This pilot study was unsuccessful, participants reported a desire to approach the flames and some reported a degree of enjoyment when they placed their hands through the flames. Therefore, this method of inducing negative emotion and threat was ruled out.

The next version of the VE was based on a Subsequent design consultation suggested using a fear of heights mechanic designed to induce a negative response. A second pilot study was performed on the basis of this mechanic (Fig. 2.8). Participants were placed in a neutral environment. The environment consisted of a grey coloured cuboid looped around a starting platform. A virtual blue sky environment gave the participant a sense of scale and potential height but no ground landscape was rendered below . Participants were requested to walk off the starting platform onto another platform visible below them, which represented a drop of 5m, and from there to a final platform at an increased depth below that of 10m. This VE generated a strong reported negative response from pilot participants and led to an iteration of the design during a third pilot study (Fig. 2.8). This environment began at ‘ground’ level and Participants were located on a similar neutral grey coloured platform. This platform was then animated upwards to a virtual height of 80m. The participant was requested to ‘step over’ a gap onto a platform and from their

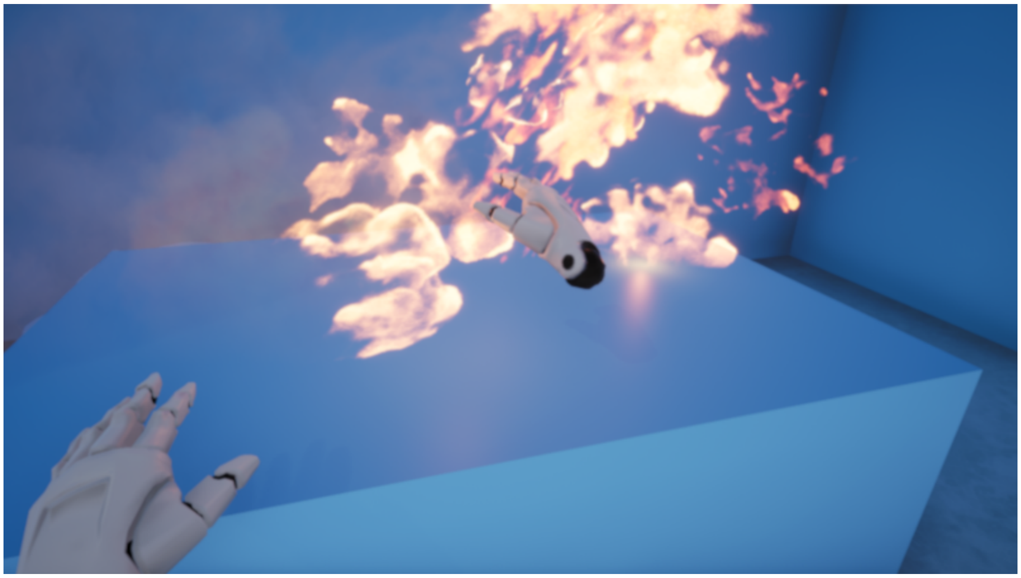

Figure 2.7: Pilot Study: Participant uses virtual hands to touch flames

walk off that platform to a lower level. For future versions of the VE, it was decided to locate participants at a ground level to measure their response to a non-threatening VE as a method of providing a baseline for the psychophysiological data collection.

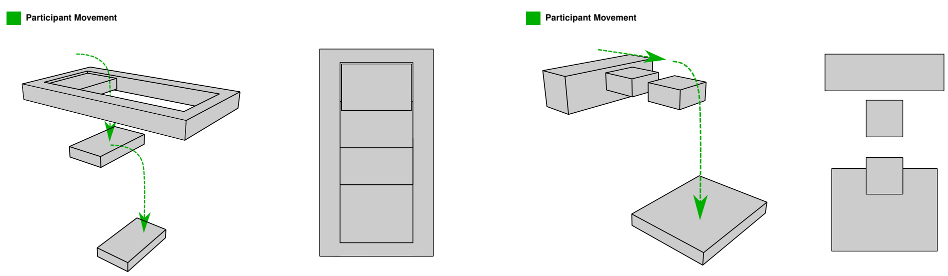

Figure 2.8: Pilot 1 and 2 Perspective and Top Views, green arrow shows participant descent path

This change in design revealed an inherent technical challenge that was present in the fear of heights mechanic, which affected the simulation when a participant looked over the edges of raised platforms and moved across separate platforms. In order to 'fall' virtually the VE was designed to have a programmatic gravity function. A raycast object, a 2D vector, was projected from the location of the headset, if this raycast detected a virtual platform beneath the user, the programmatic gravity function was deactivated. If a participant looked over the edge of a platform downwards the raycast vector interpreted this action as being out over the edge of the platform and pulled the users' location downwards in the VE making it appear as if they fell through the virtual platform. This outcome was also the case when a participant moved horizontally over two separate platforms (Fig. 2.9). In order to construct a more realistic interpretation of gravity it was decided to attach two Vive tracker sensors to the user's feet (Fig. 2.3). These individual sensors would detect when either foot was situated over a virtual platform, and the gravity function only triggered when both feet were not over the platform. The addition of the additional Vive Tracker sensors placed on the feet allowed the participant to look over the edges of platforms and to cross between suspended virtual platforms. This revised mechanic would form the basis for the fear of heights VE design in all forthcoming experimental designs (Fig. 2.10).

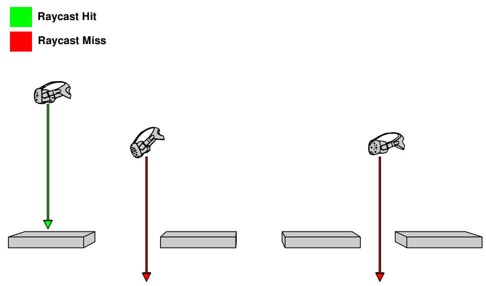

Figure 2.9: Gravity raycast trigger, user will fall if edge is looked over

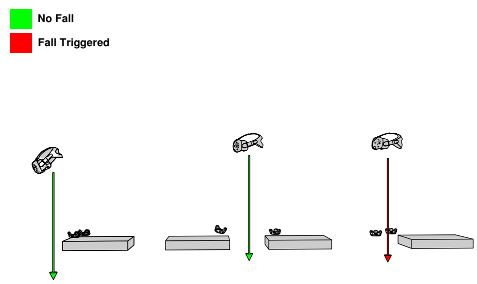

Figure 2.10: Revised foot tracked gravity trigger, foot sensors allow user to look over ledges; user only falls in far right scenario when both foot triggers are over the precipice

2.3 Study One Virtual Environment Development

The main objectives for Study One were; (1) benchmark Emteq VR sensory array (Fig. 2.28, 2.29, 2.30) against equivalent available psychophysiological sensors (Fig. 2.27). (2) establish the effectiveness of the threat of height mechanic, and (3) establish superiority of room-scale VR for induction of negative emotion. For this study the first version of the HTC Vive headset was used (Fig. 2.2), this device was tethered to the laboratory PC with a 5m cable. The VE consisted of two buildings separated by a wooden plank (Fig. 2.11). Participants were required to cross the plank bridge between the two buildings and were instructed to commence doing so when they saw a green light stimulus and the sound of a bell from a virtual traffic light model situated on the other building (Fig. 2.12). In the VE the plank appeared to have a yellow and black area at its mid point. When participants stepped on this area the virtual traffic light bell sounded and the red light came on. Participants were instructed to wait until the red light turned to green and to continue crossing the wooden plank. Two versions of this VE were created, a room-scale version and a sedentary version where participants experienced the task from a seated position. Participants in the sedentary task used a games console controller to move a virtual avatar across the plank which was observed from a raised third-person perspective virtual camera.

The laboratory assigned to the project allowed for VE tracking space of 6m x 5m (Fig. 2.13). The two buildings in the VE were separated by the virtual plank which was 4.5m long which fit within the laboratory space with consideration for a safety margin between the walls of the laboratory (Fig. 2.14). It was decided to enhance the immersion factor of the room-scale task by placing a real wooden plank on the floor of the lab. Participants

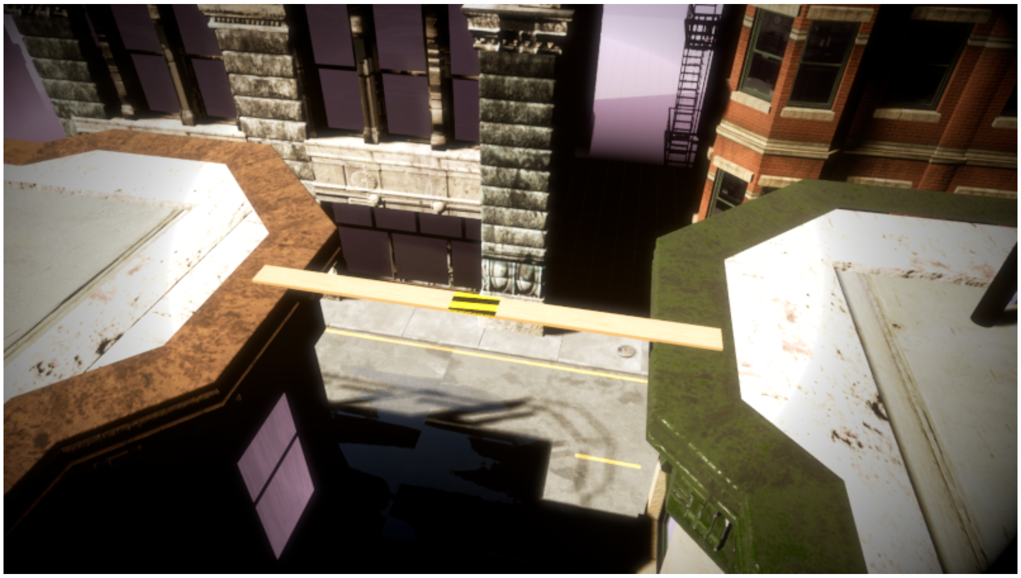

Figure 2.11: Virtual plank shown between two buildings in VE

Figure 2.12: Traffic Light used to control participant movement

walked across this plank which was located in exactly the same space in the virtual environment.

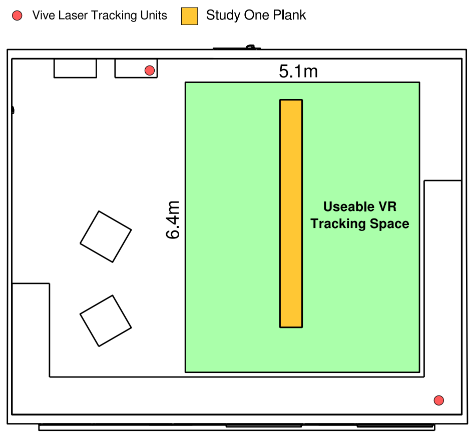

Figure 2.13: VR Space Laboratory One

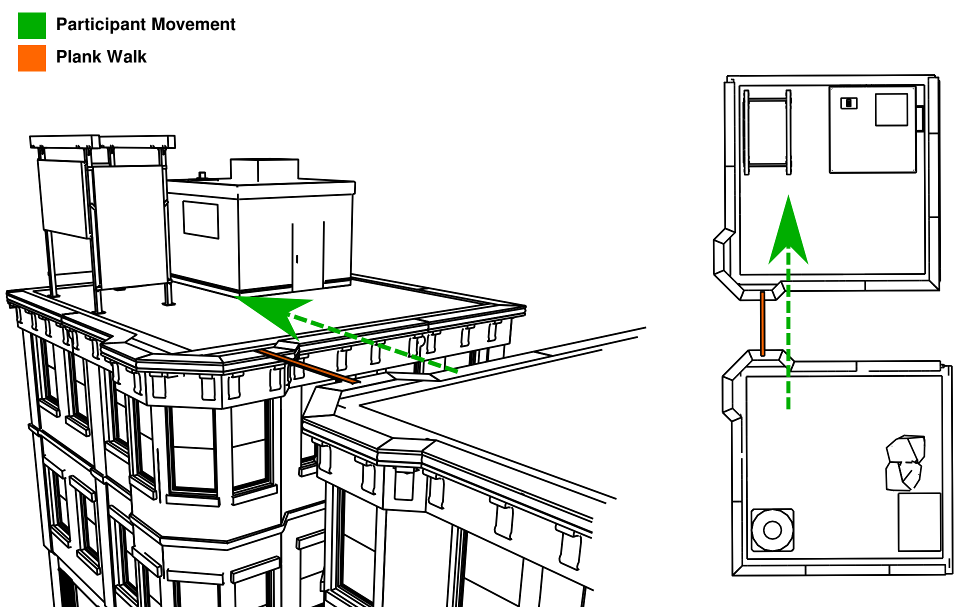

Figure 2.14: Study One Perspective and Top Views

2.4 Study Two Virtual Environment Development

The concept of a virtual height threat scenario was further developed by expanding the behavioural tracking capabilities of VE; using the mechanic represented in (Fig. 2.10), the tracking of each foot alongside the position of the hand controllers and headset could be used to 'test' each platform. Participants could cross a grid of platforms without prior knowledge of which platform was 'safe' to stand on. Participants could test each platform with one foot before committing to standing on the platform with both feet. To provide the mechanic with an additional sense of environmental realism, it was decided to alter the look of the appearance of platforms so they appeared as blocks of virtual ice. The presentation of platforms as ice blocks enhanced the threat level of the VE by making the platforms semi-transparent, in a similar fashion to a visual cliff In addition, this aesthetic change reinforced the plausibility of the physics at work in the VE, i.e. ice is known to crack and break if it cannot support the weight of a body. Therefore, the grid could incorporate a number of 'unsafe' blocks, which could also break apart when stood on with two feet and leading to a fall. It was decided to create a grid that was mostly populated with 'safe' Solid blocks interspersed with a small number of 'unsafe' Fall blocks. This binary threat mechanic was further developed by adding a third type of block, which cracked when tested with a single foot but remained solid when the participant stepped onto it with both feet. This development allowed us to manipulate the inherent threat of each grid of ice blocks in the VE; Solid blocks being the no-threat stimuli whereas Crack blocks presented sources of potential threat as they were visually indistinguishable from Fall blocks until the participant stepped onto them with both feet. In addition, the Crack block introduced a gamification element i.e. as participants had the option of testing each block with one foot to identify Crack blocks in advance of making their next two-feet movement they could use this feedback to judge the best position to move forward to. The presentation of a 4 x 4 block grid also enhanced the autonomy of the participant who could move in any direction they chose, at any speed that they desired and were invited to make as many one-footed checks as they liked. Participants were motivated to cross the grid of blocks by an end-goal, which was to reach and activate a doorway on the opposite side of the grid in order to exit the VE. This design concept led to a VE with a layout consisting of a safe starting platform, a grid of ice blocks and a goal (Fig. 2.15).

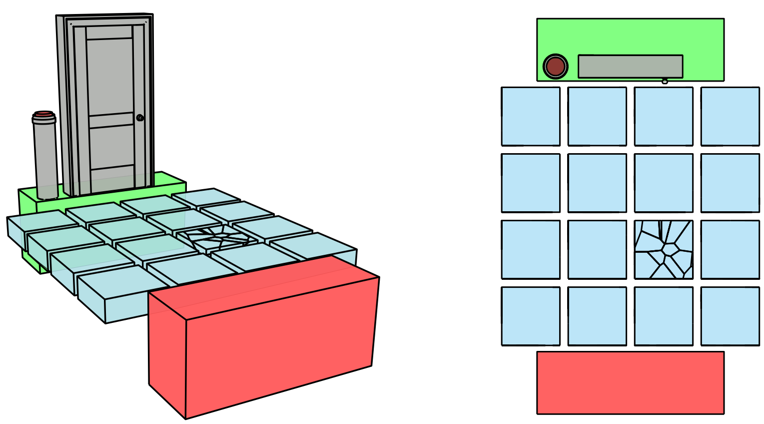

Figure 2.15: Study Two Perspective and Top Views

Restrictions on the availability of laboratory space led to the development of novel approaches. The laboratory space used for Study Two was the same as Study One and the same VR tacking area was utilised (Fig. 2.13). The 'ice-block' initial pilot study design used all of this available 6m x 5m tracking area. A 0.25m area within the tracking area and an additional 0.25m area outside of the tracking zone and the walls of the laboratory space were added for safety reasons. After initial piloting, it was decided to extend the mechanic of raising the initial height of the participant over three levels of virtual height (50m, 100m and 200m). This additional design would allow for measurement of participant reaction to increased height. The doorway was activated with a trigger volume positioned over the button in the VE as a participant moved their hand controller over the VE button the doorway would open.

It was also decided the 4x4 grid did not allow us to manipulate the level of threat at low, medium and high levels within the VE or provide a sufficient number of interactions to permit behaviour or psychophysiological analyses. Therefore, the 4x4 grid was presented in three forms, each approximating low, medium and high threat by increasing the frequency of Crack and Fall blocks in the grid (Fig. 2.16). It was hypothesised that due to the increase in virtual height threat and increased frequency of Crack/Fallblocks participants would exhibit increasingly risk averse behaviour over the three levels of the task. To facilitate this level manipulation, a key feature of the Unreal Engine framework was utilised called 'Level Streaming'; this feature is generally used within a game engine to load separate levels at the point at which an avatar completes the prior area. Level streaming (generally used for online multiplayer scenarios where the exact location of a player is a fuzzy parameter) allowed the VE design to load in a successive area (Level 2, 3) at a fixed position. This feature effectively tripled the virtual environment and permitted us to create the three different grids shown in Figure 2.18. However, it was necessary to add a transition zone between levels that we referred to as the 'Blue Return Circle' area (Fig. 2.17). If a participant interacted with a fall block or completed a level they were directed via text prompts to walk into the circle and each additional level was then started or if in the case of a fall they were returned to the safe start platform.

Figure 2.16: Layout Study Two, from left: Level 1, 2, 3

2.5 Study Three Virtual Environment Development

For Study Three we moved to a larger lab space to accommodate modifications to the ice-block layout that increased its physical dimensions (Fig. 2.18). The VR headset used for experimentation was upgraded to a HTC Vive Pro with a Vive wireless tracking module, i.e. the previous version of the VE used a Vive headset that was tethered to the PC. The adoption of the wireless module ensured participants were no longer tethered to the laboratory PC running the simulation, increasing the immersive capacity of the VE via less restricted movement. The Study Two ice-block task consisted of three levels of 16 threatening ice-blocks which participants traversed. The third study allowed us to create nine different 4x4 grids (Fig. 2.19). within the same physical space, thus dispensing with the need for a transition zone (Fig. 2.17) and providing greater latitude to manipulate the level of inherent threat in the environment. Within this larger space participants took an 's-curved' path before reaching the goal (Fig. 2.19)

The experimental design was revised so that in a counterbalanced measures design

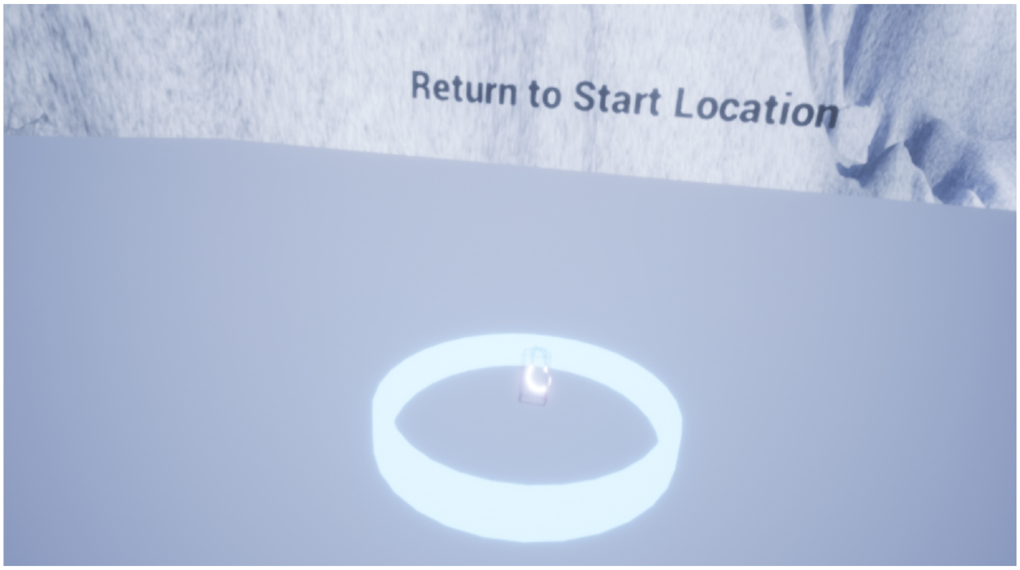

Figure 2.17: Blue Return Circle, switches scene layout to reorient participant at starting position

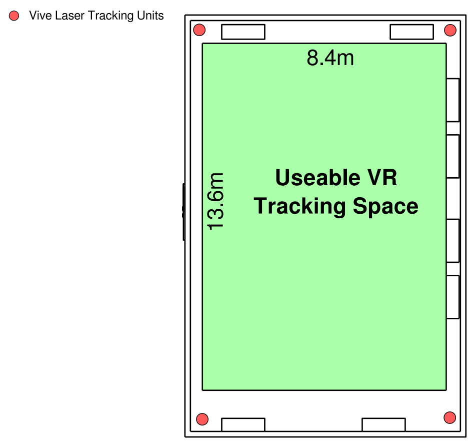

Figure 2.18: VR Space Laboratory Two

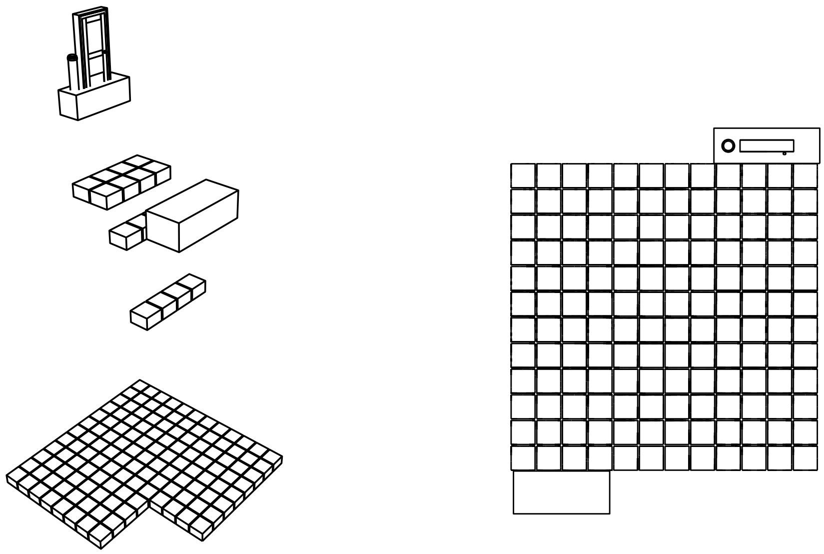

Figure 2.19: Study Three Perspective, Section 1 active, rows fall away as participant moves forwards, right, Top View

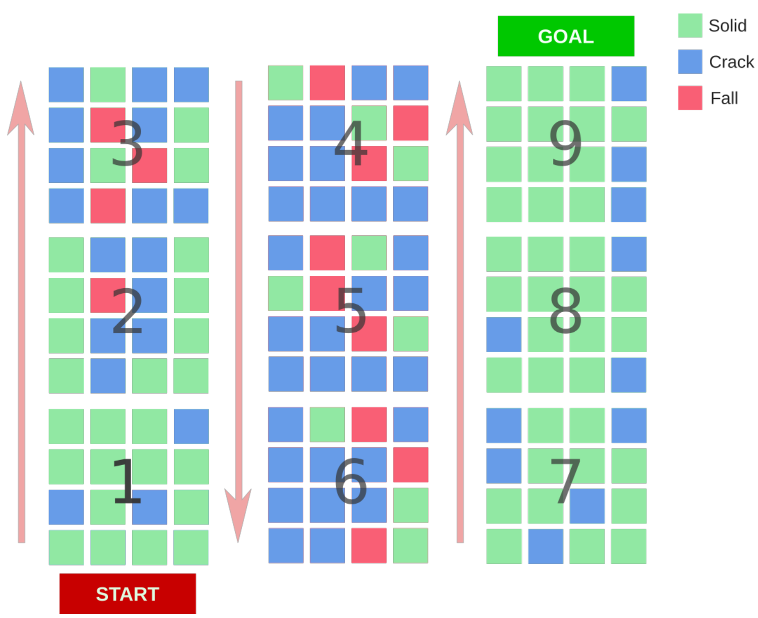

Figure 2.20: Study 3 layout

participants participated in two separate VEs one at a virtual height of 75m and the other at 'ground' level. Participants were no longer 'animated' up to a virtual height at the beginning of the Height task and this virtual height threat was not increased or decreased during the Height task. For the Ground task there was no threat of virtual height and the Fall threat blocks were removed so during this Ground task participants only interacted with Solid non-threatening blocks and the mid-threat crack blocks.

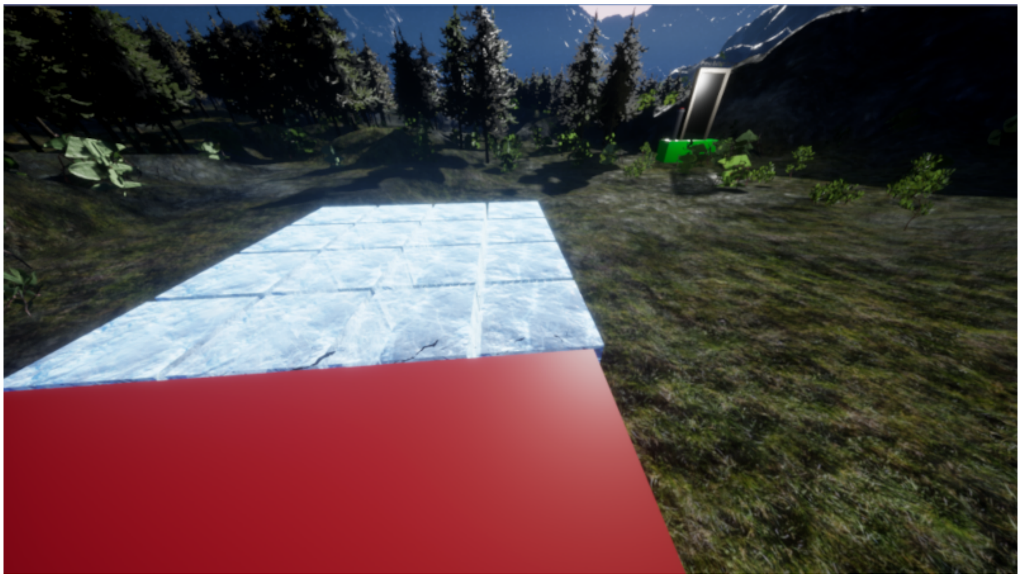

Figure 2.21: Participant view of Ground Task

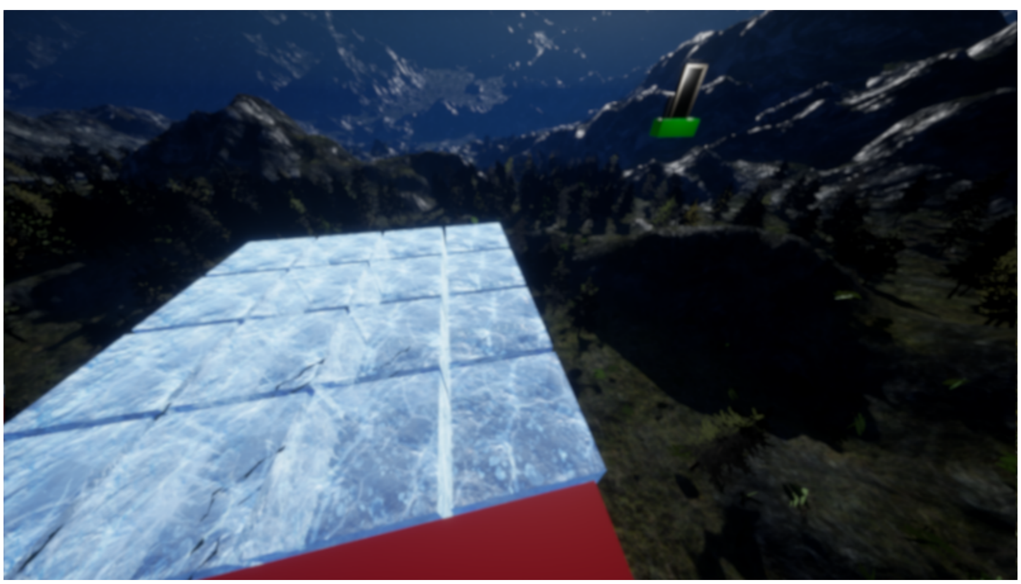

Figure 2.22: Participant view of Height Task

The first three Sections replicated the increase in threatening blocks from Study Two, Sections 4-6 maintained a high level of threat with Sections 6-9 reducing the perceived level of threat before the experiment was terminated by reaching the goal doorway. In order to distinguish the threat inherent in identifying safe blocks and the presence of virtual height, two versions of this VE were created: one at a virtual height of 75m and the other at 'ground' level. Participants were no longer 'animated' up to a virtual height at the beginning of the Height task and this virtual height threat was not increased or decreased during the Height task. For the Ground task there was no threat of virtual height and the Fall threat blocks were removed so during this Ground task participants only interacted with Solid and Crack blocks. Each Section of the Height task was animated up to the participants virtual height level after a participant had activated a trigger volume on the final row of the prior Section (Fig. 2.23). This mechanism prevented participants from completing Sections at speed ensuring that each participant completed the task in a similar time frame.

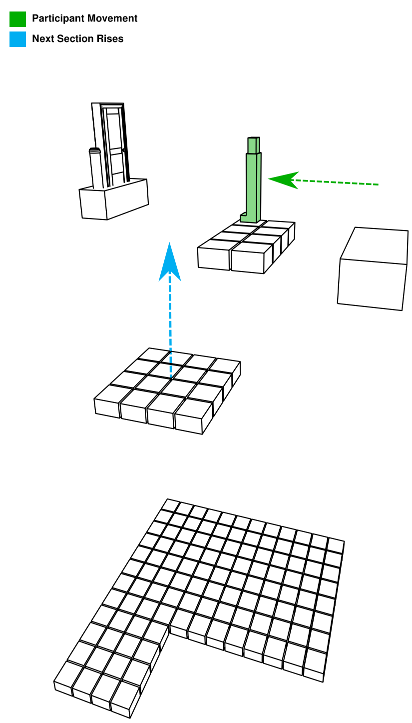

Figure 2.23: Goal doorway moves from to end location once Section 7 is in use

An additional row trigger was added. When a participant activated these row triggers a row two rows back from their current position would fall away (Fig. 2.24). This mechanism was designed to reduce backtracking. During Study Two participants had been observed making self regulatory decisions. Participants would change direction away from the goal doorway to previously explored, less threatening, areas of the task thereby reducing the level of threat they encountered. In this study that option was removed via the introduction of the falling rows mechanic.

The 's-curve' nature of the path participants were required to take required them to turn right at Section 3 and cross to Section 4 and to turn left at Section 6 and cross to Section 7. Two audiovisual signs were designed and placed at these locations to prompt the participant to turn in the correct direction (Fig. 2.25). These signs were triggered after participants completed the second row of Sections 3 and 6 (Fig. 2.26). The position of the goal doorway was placed further away from its final location so participants would not attempt to access it at Section 4. It was animated to its final location when participants entered Section 7 (Fig. 2.25).

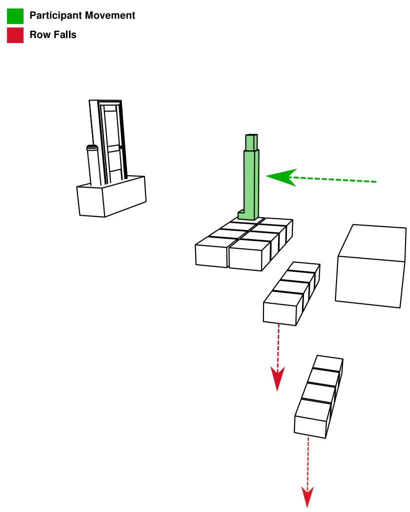

Figure 2.24: Rows drop as participant moves forward

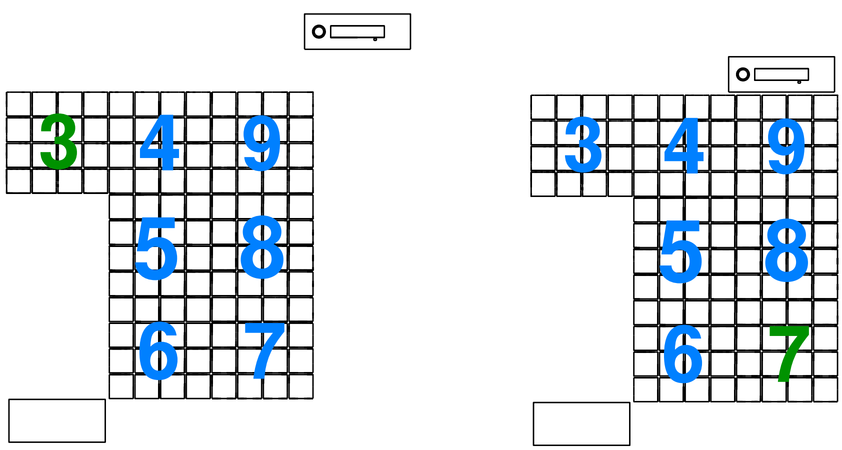

Figure 2.25: Turn Prompt triggered at Section 3 and 7

Figure 2.26: Turn Prompt

Table 2.3: Psychophysiological Measures

Measure	Sample Rate (Hz)	Filter	Smoothing	Transform	System
fEMG	1000	bandpass 49-51Hz	linear envelope 9Hz	RMS	BioNomadix/FaceTeq
ECG	1000	bandpass 49-51Hz		BPM Score	BioNomadix
EDA	1000	bandpass 49-51Hz			BioNomadix

2.6 Psychophysiological Measures

For the purposes of this project fEMG data was recorded at 1000Hz from the corrugator supercilli and zygomaticus major via the Bionomadix ambulatory psychophysiology system (BIOPAC). fEMG data were processed as follows: (1) bandpass filter applied at 49-51Hz to remove 50Hz noise, (2) filtered between 20 and 400Hz, (3) rectified and smoothed via linear envelope (9Hz filter), and (4) subjected to root mean square transformation [Boxtel, 2001, Lajante et al., 2017]. ECG data was recorded at 1000Hz via the Bionomadix system and a BPM frequency score calculated. Skin Conductance Level (SCL) was also recorded at 1000Hz via the Bionomadix system SCL Data were collected from the index finger and second digit of the non-dominant hand and subsequently filtered with a high pass filter at 0.05Hz.

2.6.1 BioPac MP150 and Bionomadix Ambulatory Sensors

This research project utilised two systems to capture fEMG data. A BioPac MP150/BioNomadix based system and a system provided by the research partner Emteq, the FaceTeq fEMG data capture system. For Study One 50% of participants psychophysiological data was captured via a BioPac MP150 system (Fig. 2.27) and accompanying AcqKnowledge 5.0 software the remaining participants psychophysiological data was captured via an Emteq FaceTeq system (Fig. 2.29). For Study Two all data was captured via the BioPac system and for Study Three all data was captured using the FaceTeq system (Fig. 2.30).

The BioPac MP150 system is a flexible, proven modular data acquisition system for life science research and is in use in top laboratories around the world. The MP150 offers multiple configurations to suit individual research and teaching needs and records multiple channels with different sampling rates at the same time. The MP150 device is the core hardware device which is complemented with add-on devices for EDA, ECG, EMG and data streams. This system was used in conjunction with the wearable BioNomadix sensor system (Fig. 2.27) to allow participants to move freely with the VE while data was recorded. The BioNomadix system is a wireless, multi-channel physiological recording platform.

Figure 2.27: Biopac MP150 and BioNomadix

2.6.2 Emteq Faceteq System

This research project was co-funded by Emteq PLC who offered the use of their FaceTeq wearable sensor for use during the experimental trials. Liverpool John Moores university assisted with design and development of this product during the course of the research program. During the course of the experimental trials three prototype versions were provided. Version 3 of the FaceTeq System recorded fEMG data for Study 3. This system was used in conjunction with Emteq designed software for fEMG data capture. The FaceTeq system is designed for the specific use case of psychophysiological data capture during VR experiments and fits within the VR headset case mounting. During the course of this research programme three versions of the FaceTeq system were used. Each device sampled fEMG signals at 1000Hz. For piloting Faceteq v.1 was used (Fig. 2.28). This device was tethered by a USB cable connected to the laboratory PC. For Study One Faceteq v.2 was used (Fig. 2.29). This device moved from a solid 3D printed sensor housing to a custom foam mounting. The reduction in size and flexibility of the sensor housing reduced cross-talk signal interference between the fEMG sensors. This device was also connected to the laboratory PC via a USB cable. For Study Three a third version of the FaceTeq sensor was used (Fig. 2.30) this device used a bluetooth wireless transmitter to communicate with the laboratory PC removing the need for a USB connection cable.

2.6.3 Procedure

Before the experiment began, each participant was presented with an information sheet that explained the procedures that would be followed, and what would be required of them during the study. The participant then signed a consent form, and was familiarized with the lab space and introduced to the room-scale VR sensors. Following familiarization, the participant was told how physiological sensors would be attached, the sites were then cleaned with abrasive gel and conductive gel applied, ECG sensors were then attached if required and fEMG sensors were attached to the face via the Biopac device or integrated Emteq headset inlay. Before the commencement of each study sensor responses were tested and adjusted.

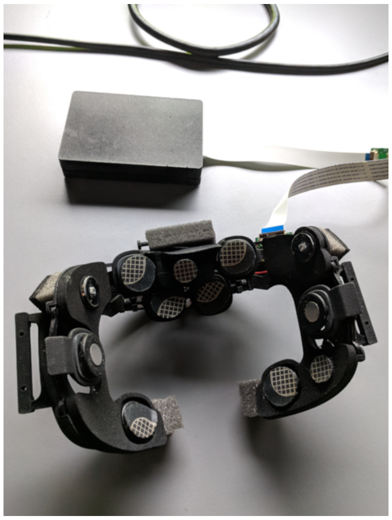

Figure 2.28: Faceteq v.1

Figure 2.29: Faceteq v.2

Figure 2.30: Faceteq v.3

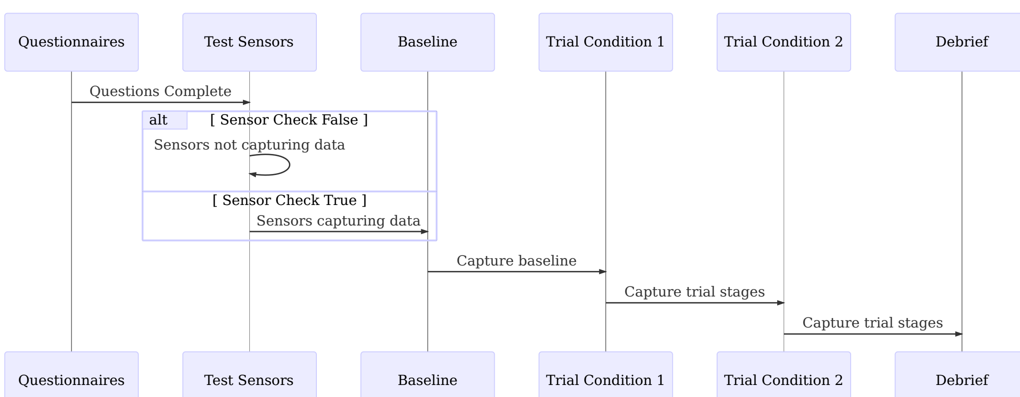

Figure 2.31: Generic illustration of data collection protocol

Figure 2.31 illustrates general protocol stages that were undertaken for each study. For Study One and Two a 30 second baseline period was established before the onset of the sedentary or ambulatory stages. For this thesis ~2mil instances of fEMG data, ~2mil instances of heart rate data ~0.4mil instances movement and behavioural data were captured per participant of Study One (N=20) these numbers are approximate as capture varied depending on the length of time each participant took to complete the VE. For Study Two ~6mil instances of fEMG data, ~4mil instances of heart rate data ~0.8mil instances movement and behavioural data were captured per participant (N=35).For Study Three ~18mil instances of fEMG data ~2.4mil instances movement and behavioural data were captured per participant (N=20). These numbers are approximate as data capture periods were dependent on the length of time each participant took to complete the VE stages.

2.6.4 Data Analysis Process

For Study One and Two Data analysis was conducted using MATLAB [MATLAB, 2010]and SPSS [IBM Corp., 2017]. Study Three data was analysed using R [R Core Team, 2021] and SPSS [IBM Corp., 2017]. Study Four data was analysed using R [R Core Team, 2021] and SPSS [IBM Corp., 2017], R was preferred over MATLAB for its parallel processing capabilities which decreased data processing time. MATLAB and the Mathworks Signal Processing toolbox processed psychophysiological data. The filtered time series data was segmented using the time codes stored in the behavioural data files captured for each participant and the unique interactions and events for each study could be compared. Custom C++ Code for use in Unreal Engine was placed into a ESMVR BluePrint library for ease of maintenance and reuse across each of the three VEs. Below is abbreviated code designed to capture a stimulus event;

```
bool UESMVRS3Library::SaveStimEventData(
    FString SaveDirectory,
    FString DataType,
    int32 ParticipantNo,
    float GameTime,
    FText GameTextTime,
    FString StimEvent,
    bool AllowOverwriting)
{
    FString IntAsString = FString::FromInt(ParticipantNo);
    FString FloatAsString = FString::SanitizeFloat(GameTime);
    FString GameTextString = GameTextTime.ToString();

    return FFileHelper::SaveStringToFile(
    GameTextString + "\t" + StimEvent + "\r\n",
    *(SaveDirectory + DataType + IntAsString + ".txt"),
    FFileHelper::EEncodingOptions::AutoDetect,
    &IFileManager::Get(),
    EFileWrite::FILEWRITE_Append);
}
```

Variables e.g. SaveDirectory can be set within the BluePrint to set the directory to save participant event data text files, ParticipantNo can be changed for each trial. GameTime sets the timestamp for each stimulus event. This results in a text file being created for each participant which records precise timings for each event of action which the researcher wants to track and allows for the precise comparison of psychophysiological time series data, See below for sample event data;

```
14:45:36.891    Start Study Ground
14:45:49.603    Intent Solid S1A4
14:45:50.027    Presence End Solid S1A4
14:45:50.113    Intent Crack S1B3
14:45:50.612    Intent Solid S1A4
14:45:53.045    Presence End Crack S1B3
14:45:53.051    Intent Crack S1B3
14:45:53.079    Presence End Crack S1B3
14:45:53.148    Intent Crack S1B3
14:45:53.184    Presence End Crack S1B3
```

Additionally highly accurate movement data can be captured and used for additional analysis. Below is a second abbreviated sample function from the ESMVR BluePrint Library. A SaveDirectory and ParticipantNo can again be set by the researcher. The following code saves the position of the headset and controllers held in the hands and two trackers attached to the feet.

```
bool UESMVRS3Library::SaveVRObjectPosition(
    FString SaveDirectory,
    FString DataType,
    int32 ParticipantNo,
    FString HeadSetData,
    FString LeftHandData,
    FString RightHandData,
    FString LeftFootData,
    FString RightFootData,
    bool AllowOverwriting)
{
    FString IntAsString = FString::FromInt(ParticipantNo);
    return FFileHelper::SaveStringToFile(
    "Headset: " + HeadSetData + "
    " + "LeftHand: " + LeftHandData + "
    " + "RightHand: " + RightHandData + "
    " + "LeftFoot: " + LeftFootData + "
    " + "RightFoot: " + RightFootData + "\r\n",
    *(SaveDirectory + DataType + IntAsString + ".txt"),
    FFileHelper::EEncodingOptions::AutoDetect,
    &IFileManager::Get(),
    EFileWrite::FILEWRITE_Append);
}
```

The researcher can choose how frequently movement data is updated and written to a separate text file containing this positional data. Output to the text file can be used in conjunction with the psychophysiological and event data in subsequent data analysis methods, see below for example output.

```
Headset: X=-29.226 Y=36.248 Z=197.910
LeftHand: X=-9.225 Y=46.868 Z=170.443
RightHand: X=-46.946 Y=48.568 Z=168.777
LeftFoot: X=-15.364 Y=26.687 Z=48.890
RightFoot: X=-42.686 Y=27.210 Z=50.725
Headset: X=-29.334 Y=35.827 Z=197.958
LeftHand: X=-9.954 Y=46.344 Z=170.761
RightHand: X=-49.558 Y=45.161 Z=168.382
```

```
LeftFoot: X=-15.446 Y=26.548 Z=48.806
RightFoot: X=-42.665 Y=27.202 Z=50.708
Headset: X=-29.262 Y=36.760 Z=197.817
LeftHand: X=-9.631 Y=46.777 Z=170.046
RightHand: X=-46.845 Y=45.039 Z=171.290
LeftFoot: X=-15.338 Y=26.709 Z=48.896
RightFoot: X=-42.645 Y=27.195 Z=50.694
```

This custom BluePrint Library resulted in three types of data being captured on a per participant basis. Psychophysiological data was captured and could be precisely divided during analysis by the time codes in the event data. Movement data also tracked the position of a participants body and could be used to analyse their speed and acceleration during specific phases of a trial (Fig. 2.32).

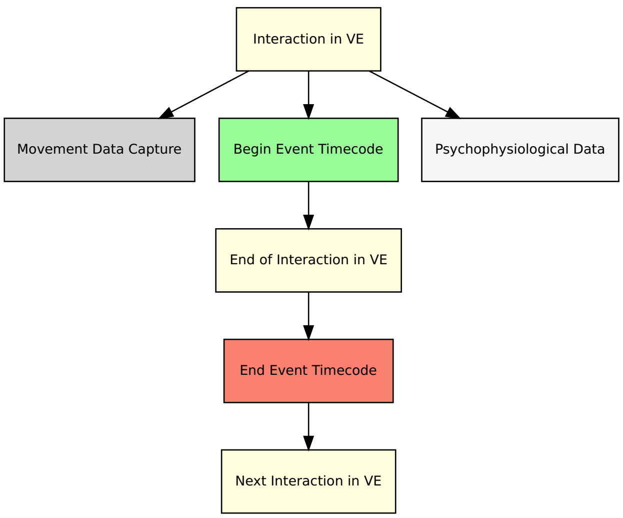

Figure 2.32: Data capture flowchart

2.6.5 Subjective Questionnaires

A variety of questionnaires were used throughout the experiments to rate participant's susceptibility to motion sickness and vertigo and to score their personality. These questionnaires were completed prior to the commencement of each study trial period. Participants were excluded if they were currently taking any medication.

2.6.5.1 Simulator Sickness Questionnaire

Participants completed the Simulator Sickness Questionnaire (SSQ) questionnaire. The questionnaire scores 16 symptoms on a four point scale (0-3), e.g. 'general discomfort' 'Fatigue' 'Headache'. Simulator sickness is generally the result of the discrepancy between simulated visual motion and the sense of movement stemming from the vestibular system.

2.6.5.2 Vertigo Questionnaire

Participants completed the Situational Vertigo Questionnaire (SVQ) questionnaire [Guerraz et al., 2001]. The SVQ includes 19 items designed to capture visual vertigo with a Cronbach's alpha score of 0.9652; participants are asked to rate the prevalence of vertigo symptoms on a 4-point scale from 0 (not at all) to 4 (very much) in a number of scenarios, e.g. 'riding as a passenger in a car on winding or bumpy roads' 'standing in a lift as it stops'

2.6.5.3 Ocean Big 5 Questionnaire

Participants completed the OCEAN.20 personality inventory [O'Keefe et al., 2012]. The OCEAN.20 inventory includes twenty items, five of which are each dedicated to each of the Big Five personality traits51, e.g., Openness, Conscientiousness, Extroversion, Agreeableness, Neuroticism. participants provided responses on a 7-point Likert scale (1 = very strongly disagree; 0 = neutral; 7 = very strongly agree) to five statements, e.g., 'My feelings are easily hurt' 'I am often nervous and tense'. The reliability of this trait as measured on the OCEAN.20 and indexed by Cronbach's alpha was 0.81.

Chapter 3

Study One

3.1 Abstract

This study was designed to test two sets of psychophysiological measuring devices (BioPac BioNomadix and Emteq FaceTeq) comparing data captured assessing functional capacity for use in the remainder of the research project. This was done by recreating a Facial Mimicry task for use in a VE. The second task within the study subjected participants (N=20, Age M=25.78, SD=3.01) to a virtual height threat. Recently the threat of virtual height has been frequently used in psychological studies. These studies have largely introduced this threat stimuli in sedentary or small laboratory spaces which allowed for very little participant movement within the VE. This study has examined the effect of modern room-scale virtual reality techniques coupled with wireless sensor technologies to examine the effects of a room-scale VE against that of a sedentary experience, hypothesising that the response to a room-scale VE may be heightened. Participants were asked to navigate a void between two virtual buildings bridged by a plank. The experiment was repeated from both a sedentary perspective and at a room-scale condition during which participants physically walked across the plank in the VE and a wooden facsimile on the floor of the laboratory. fEMG data was captured at two sites, Corrugator Supercilli and Zygomaticus Major. Results suggested that the affective capacity of the VE may be enhanced by the enhanced capacity for embodiment within room-scale condition and that future research could be conducted to operationalise this increased emotional response potency.

3.2 Introduction

Mobile devices, worn by a participant, capable of wirelessly psychophysiological data have seen increasing usage in psychophysiological experimentation. These devices are capable of recording EEG (Electroencephalogram) and EMG (Electromyography) data (See Lin et al. [2020]; Srinivas and Blustein [2011], for review) ECG (Electrocardiogram) [Ramasamy and Balan, 2018], SCL (Skin Conductance Level) [Affanni, 2020] generally recording a single measure, a number of devices are now available which can simultaneously record an array of responses. This research program will make use of the BioNomadix ambulatory psychophysiology system and a series of experimental devices provided by Emteq the study partner (See. Ch. 2 Methodology, Psychophysiological Measures). Usage of mobile sensor technology allows for the creation of highly immersive scenarios which could enhance the emotional response potential, additionally recording the body movements of the participant with a high degree of temporal accuracy. Key event interactions can be labelled with unique time codes that are matched to participant behaviour allowing for the demarcation of events at the analysis phase. These events will be completed by a participant in unique orders and over different time spans on a per trial basis. Due to the nature of the study; the mobility and freedom allowed to the participant in room-scale VR tasks encourage interpersonal differences to be displayed resulting in an inevitable variability in the order participants complete stages of a study and differences in the times taken by participants to complete these tasks. Accurate measurement by mobile sensors attached to the participant during the task allows the varied behaviour in reaction to stimuli to be recorded without sacrificing accuracy at the analysis stage. The following study presents protocol for measuring responses to facial mimicry to measure the effectiveness of an experimental fEMG sensor provided by the study partner against an established mobile EMG sensor solution (See.Ch. 2 Methodology, Psychophysiological Measures). A facial mimicry trial was constructed to test the facility of each sensor response to a series of trials of four emotive states. Four faces (female) were selected from two headshot databases [Lundqvist, Tottenham et al., 2009] were presented to participants. All faces were seen as a static neutral expression which then transitioned to a morph sequences from neutral to the facial expression state. The dominant method of assessing facial mimicry is through the use of electromyography. The specific muscles responsible for portraying different expression states are also well researched, with the zygomaticus major responsible for smiles through cheek movement, and the corrugator supercilii responsible for frowns through brow movement [Fridlund et al., 1984]. The binding of corrugator activity with negative emotions, and zygomaticus activity with positive emotions are a well-researched outcome [Brown and Schwartz, 1980]. As one of the primary measures used the fEMG response fidelity of the Emteq device and its effectiveness in comparison to alternative device was a primary outcome for this experiment. The facial mimicry task was deployed alongside a test of room-scale vs. sedentary responses in a single experimental design to minimise the effects of removing and reapplying the facial sensors for the BioNomadix device and the Emteq sensor inlay over separate tasks. The VR task attempted to measure a difference in the efficacy of a room-scale VR scenario to induce emotional responses against a sedentary version of the task.

One of the primary goals for this study is to compare sedentary and room-scale virtual environments, hypothesising that embodied room-scale VR experiences may enhance the capacity of a VE to induce emotional responses. In a sedentary VR application the user is seated in the physical environment and by moving their head the position of the worn HMD is translated to alter the view of the VR environment presented to the user on the internal displays of the HMD. A user of the sedentary VR application may or may not be permitted to move from a fixed point with the VE if so this will generally be done through movements on a video game controller's joystick, flight stick or computer mouse. This form of locomotion within the virtual environment does not match well with ambulation in the real world. It is unlikely that this form of movement will be previously known to the user and will therefore require a period of training to gain familiarity and fluency with its use and when learned is unlikely to then be an intuitive means of navigating a VE. Room-scale VR applications providing they can provide accurate visuomotor synchronicity between the additional sensors required for their use allow for naturalistic motion and navigation within a virtual environment.

Many VR research projects have attempted to measure presence and gauge its capacity to increase immersion [Baños et al., 2004, 2008, Bouchard et al., 2004, Slater, 1999] and how presence can influence emotional responses [Meehan et al., 2002] and how individual differences can influence emotional responses and affect presence [Bouchard et al., 2008] and that there is a general consensus that increased presence enhances emotional response potential. If presence is considered as a sense of 'being there' in a virtual environment which enhances a sense of immersion other research projects have studied whether a sense of embodiment [Slater, 2017, Popat, 2016] such that a user of a VR application can observe a virtual facsimile of their own real world body can in turn enhance the immersive experience. Previous research [Slater et al., 1995] has attempted to devise methods to enable participants to walk in a VE and investigate its potential to increase immersion. It was found that ambulatory functions in a VE which do not need to be learned and approximate real world walking behaviours have the potential to increase sense of immersion within a VE. This research did not have the benefit of modern room-scale technologies, the accurate tracking and software enhancements used by modern VR technologies reduce the technical requirements imposed on the researcher and allow for visuomotor synchronicity between the VR user and the simulation. Other research projects have utilised natural motion data to enhance their analysis [Bailenson et al., 2001].

3.2.1 Research Questions

1. Compare Emteq and BioPac Sensors.
2. Facial Mimicry responses will be similarly recorded between the two devices.
3. Room-scale VR condition of plank walk task will be more affective than Sedentary condition.
4. Room-scale and sedentary conditions will be similarly recorded between the two devices.

3.3 Methodology

3.3.1 Experimental Design

The study was designed with two separate trials, a facial mimicry task which contained 16 separate emotional cues with a 5 second fixation marker preceding it and a 5 second relaxation period after each emotional facial stimulus was displayed. Participants were instructed to mimic the animation of an emotional response shown to them in the VR environment. The plank walk task was designed as a between participants mixed measures design with two conditions of VR type (Sedentary, Room-scale). The conditions were delivered as separate tasks in a counterbalanced measures design. Each of the conditions required participants to cross the same space at height between two buildings bridged by a plank. The room-scale version of the task required participants to physically walk across the lab space, for the sedentary task a game controller was handed to them and they pushed forwards on the devices joystick to control their forward speed. At each condition participants were instructed to proceed by taking a cue from a virtual traffic light. Participants crossed to a midpoint area of the plank and were halted by the traffic light for ten seconds, they then completed the second half of the task when the traffic light turned green and crossed the remainder of the plank.

3.3.2 Participants

The sample consisted of 20 participants (12 female). Participants were selected from an age range of 18-35 years and prescreened for conditions such as epilepsy and any disorders which may inhibit their ability to move freely within the study environment. Each participant was exposed to all facial mimicry stimulus cues and both the sedentary and room-scale Conditions.

3.3.3 Apparatus

The HTC Vive virtual reality headset was used by each participant as they navigated through the custom VE scenario purpose built for this study. The HTC Vive system utilises laser-based tracking via two base stations positioned at either corner of the designated interactive space. These base stations are capable of tracking a 5m x 5m interactive zone.

Due to physical laboratory space restrictions this study was limited to a 5m (length) x 4m interactive area. The participants head movement was recorded via the position of the HTC Vive HMD, 2x hand controllers and 2x Steam VR trackers attached on each foot.

The VE was constructed in Unreal Engine 4.19. All assets were purpose built for the study. The VE was rendered on a desktop PC in situ (CPU AMD Ryzen 5 3600, GPU NVIDIA GTX 1060, Windows 10 OS). Custom C++ code integrated directly into the Unreal Engine system captured interactions with VE objects and recorded time instances of interactions. For 10 participants psychophysiological data was recorded via 2x BioNomadix wireless sensors attached to the participants torso (2x FEMG, 1x ECG). BioNomadix sensor data was then relayed to the MP150 recording unit and captured via AcqKnowledge 5.0 software. For the remaining 10 participants fEMG data was captured via the Emteq FaceTeq 2.0 device and ECG data captured via 1x BioNomadix wireless sensors.

3.3.4 Virtual Environment

3.3.4.1 Facial Mimicry

For the facial mimicry task participants viewed a human face transitioning from a neutral facial expression into an emotive expression of a happy, angry, disgusted or a facial expression which remained neutral. Each expression was shown four times in a random order. Each facial expression trail was divided into a 2000ms fixation period, 1500ms neutral state to expression transition, 2000ms where the facial expression was held, 2000ms blank image and a 5000ms relaxation period (See Fig. 3.1).

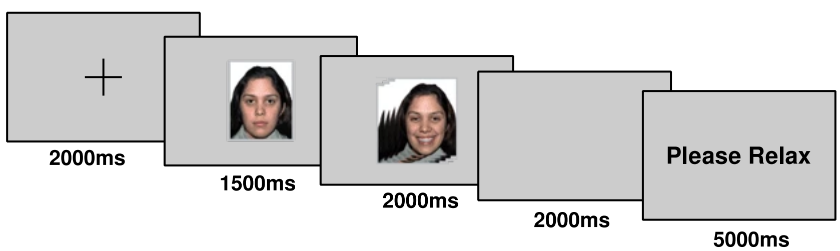

Figure 3.1: Facial Mimicry Task, 2000ms fixation, 1500ms transition, 200ms emotion, 2000ms blank, 500ms relaxtion

3.3.4.2 Sedentary vs. Room-scale

The plank walk task was designed to establish the effectiveness of the threat of height mechanic, and establish superiority of room-scale VR for induction of negative emotion. The VE consisted of two buildings separated by a wooden plank (Fig. 3.2). Participants were required to cross the plank bridge between the two buildings and were instructed to commence doing so when they saw a green light stimulus and the sound of a bell from a virtual traffic light model situated on the other building (Fig. 3.3). In the VE the plank appeared to have a yellow and black area at its mid point. When participants stepped on this area the virtual traffic light bell sounded and the red light came on. Participants were instructed to wait until the red light turned to green and to continue crossing the wooden plank. Two versions of this VE were created, a room-scale version and a sedentary version where participants experienced the task from a seated position. Participants in the sedentary task used a games console controller to move a virtual avatar across the plank which was observed from a raised third-person perspective virtual camera.

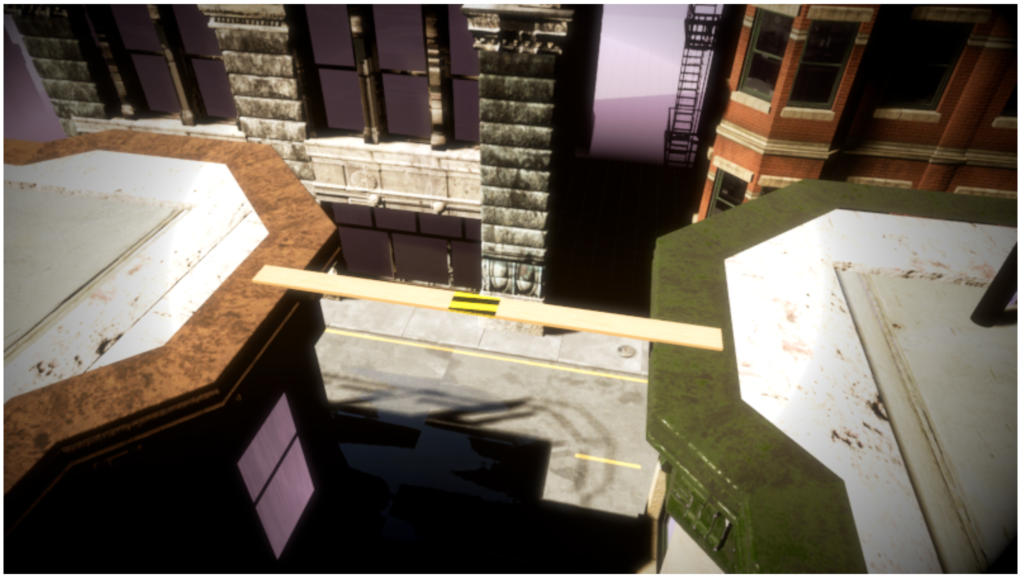

Figure 3.2: Virtual plank shown between two buildings in VE

Figure 3.3: Traffic Light used to control participant movement

3.3.5 Measures

3.3.5.1 Event Marking

The capture of participant movement data was logged via a custom C++ function added as a module to the Unreal Engine Editor. This function logged participants head, hands and feet movement to four decimal places of precision inside the VE sampled at 2.5Hz. These data were logged to a text file per participant and captured for use in analysis. Behavioural data captured key events in the simulation via a unique ID and time of occurrence of which could then later be used during analysis. This function was made possible via a secondary C++ custom function to track when a user passed through a certain area (e.g. doorway) or via the use of hand held controllers and the tracking sensors attached to the feet of the participant, 'touched' or 'stepped on' a virtual object. Logging of events linked to movement was made possible via custom trigger volumes. This Unreal Engine feature is a commonly used technique in game engines and other interactive media. It places volumes within the environment that are invisible to the user during run time. If this volume is crossed via another paired object, such as the position of the VR headset, the engine registers an event. The deployment of customised volumes allowed the C++ function to set up a list of events which a participant may or may not trigger and to record these events with precision.

3.3.5.2 Event-based psychophysiology

Behavioural event marking captured time periods in 3000ms windows. A root mean square quadratic average score was calculated from the 750ms period before the event. A second root mean square quadratic average score was calculated from the 750ms period after the event.

3.3.5.2.1 Facial Electromyography Facial electromyography (fEMG) can provide an objective quantification of emotional valence, even in the absence of observable facial expression. Research has indicated that fEMG can provide objective data as to the mental state of study participants. Schwartz et al. [Schwartz et al., 1976] reported that corrugator supercilii and zygomaticus major differentiated between non-depressed and depressed subjects during positive and negative mental states. Facial EMG has also been repeatedly used to measure emotional responses elicited by visual stimuli. Previous research revealed that activation of the corrugator supercilii correlates with the onset of negative stimuli and is inhibited by positive stimuli, the zygomaticus major is activated in response to positive stimuli and is inhibited by negative stimuli [Larsen et al., 2003].

For this study fEMG was recorded at 1000Hz from the Corrugator Supercilii and Zygomaticus Major via the Emteq ambulatory psychophysiology system (Faceteq). fEMG data were filtered above 0.25Hz and 0.75Hz using high- and low-pass Butterworth filter processed as follows: (1) bandpass filter applied at 49-51Hz to remove 50Hz noise, (2) filtered between 20 and 400Hz, (3) rectified and smoothed via linear envelope (9Hz filter), and (4) subjected to root mean square transformation [Boxtel, 2001, Lajante et al., 2017].

3.3.6 Procedure

Before the experiment began, each participant was presented with an information sheet that explained the procedures that would be followed, and what would be required of them during the study. The participant then signed a consent form, and was familiarized with the lab space and introduced to the room-scale VR sensors. Following familiarization, the participant was told how physiological sensors would be attached, the sites were then cleaned with abrasive gel and conductive gel applied, ECG sensors were then attached and fEMG sensors were attached to the face via the Biopac device or integrated Emteq headset inlay. Before the commencement of each study sensor responses were tested and adjusted.

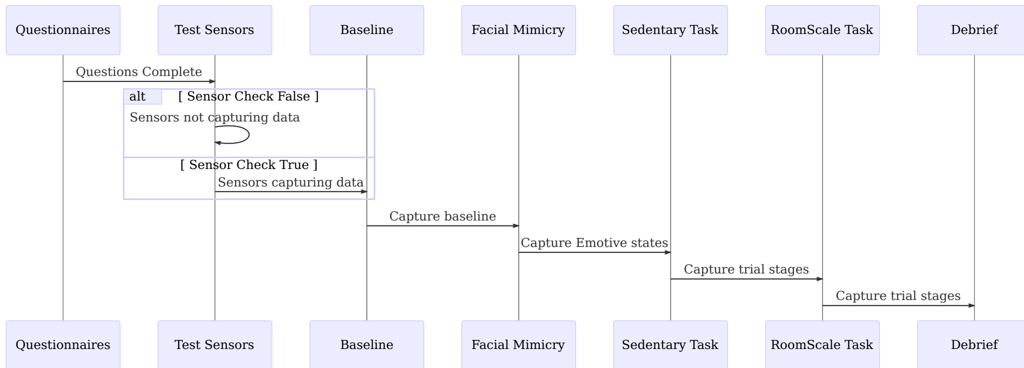

Figure 3.4: Illustration of data collection protocol

3.3.6.1 Data Analysis

For Study One participants (N=20) were divided into two groups (BionNomadix/FaceTeq). Each participant completed the task twice (Sedentary/Room-scale) in a counter-balanced measures design. The task was divided into three periods, one period after the traffic light changed and they crossed the plank to the midpoint(~10secs), at the midpoint of plank waiting for traffic light to turn green (10secs) and crossing final section of plank (~10secs). Psychophysiological changes in fEMG response, EDA and ECG could be compared across these three periods (Plank 1, Mid-point, Plank 2). Participants were also divided into two groups according to their responses to the personality inventory (Low/High Neuroticism). For Study One data analysis was conducted using MATLAB [MATLAB, 2010] and SPSS [IBM Corp., 2017].

3.3.7 Procedure

Participants were then given a verbal description of the task they were to undertake and told that this task would be performed twice. Using a counterbalanced measures design participants were tested in both the Ground and Height versions of the VE. Participants were instructed to proceed slowly and cautiously in order to emphasise considered decision-making. They were also introduced to the concept of tracking their foot position via the Vive trackers. They were informed that during the virtual Height version of the task a third type of threat block, a Fall block, would also be introduced into the ice-block grids. Participants were then fitted with the Vive Tracker sensors on their feet and asked to walk to the starting position point of the task in the physical lab space. The HTC Vive headset with Emteq fEMG sensor attached inside it was then fitted. Participants were then instructed to try to minimise any involuntary vocalisations during the study as much as possible as this would interfere with the zygomaticus measures taken from the fEMG sensor inside the VR headset they were wearing after which they were presented with either the Ground or Height scenario and the task began.

3.4 Results

The experiment was designed to measure responses to a facial mimicry task between two groups with responses in each group recorded via a different device (Emteq/BioPac) and to observe a difference in psychophysiological responses between Conditions (room-scale/sedentary), hypotheisising that room-scale VR may induce a greater response. The

Table 3.1: Facial Mimicry Contrasts

Contrast	fEMG	SE	df	t.ratio	p.value
Happy - Neutral	Corrugator	0.002	36	0.42	0.677
Anger - Neutral	Corrugator	0.004	24	3.33	0.003
Disgust - Neutral	Corrugator	0.004	25	3.74	<0.001
Happy - Neutral	Zygomaticus	0.005	19	3.71	0.001
Anger - Neutral	Zygomaticus	0.003	20	4.99	<0.001
Disgust - Neutral	Zygomaticus	0.003	19	4.45	<0.001

Table 3.2: Facial Mimicry Correlations

Device	Emotion	Mean	SD
Biopac	Overall	0.062	0.31
Biopac	Happy	0.061	0.24
Biopac	Disgust	0.034	0.34
Biopac	Anger	0.054	0.34
Biopac	Neutral	0.098	0.30
Emteq	Overall	0.012	0.18
Emteq	Happy	0.006	0.18
Emteq	Disgust	-0.008	0.18
Emteq	Anger	0.038	0.16
Emteq	Neutral	0.011	0.18

first dataset consists of facial mimicry data with four trials for each facial mimicry emotion (Anger, Happy, Disgust, Neutral). The second set of data contained the plank walk height task each participant conducted the task at each Condition a counterbalanced design alternated the order each participant conducted the plank walk task.

3.4.1 Facial Mimicry

Facial mimicry psychophysiology data was captured in 10000ms windowed time periods. A root mean square (RMS) event period was calculated for each emotional response (4x Happy, 4x Anger, 4x Disgust, 4x Neutral). Facial mimicry responses by participants ($N = 20$) were subjected to a 2x (Device: BioPac/Emteq) x4 (Emotion: Happy/Angry/Disgust/Neutral) ANOVA for both the corrugator and zygomaticus. For the corrugator data there no main effect for Device [$F(1,18) = 3.47$, $p = 0.079$] i.e. there was no significant difference in Emotion response at the corrugator between the BioPac and Emteq devices, (See Fig. 3.5). There was a significant main effect for Emotion [$F(3,54) = 3$, $p = <0.001$, $eta^2 = 0.41$]. i.e. each of the Emotion responses were significantly different to each other. Post-hoc t-tests revealed that fEMG responses were significantly different for the Anger vs. Neutral and Disgust vs. Neutral for the Corrugator (See Table 3.1). For the zygomaticus data there was no main effect for Device [$F(1,18) = 0.42$, $p = 0.524$] i.e. there was no significant difference in Emotion response at the zygomaticus between the BioPac and Emteq devices, (See Fig. 3.5). There was a significant main effect for Emotion [$F(3,54) = 3$, $p = <0.001$, $eta^2 = 0.29$]. i.e. each of the Emotion response recordings were significantly different to each other. Post-hoc t-tests revealed that fEMG responses were significantly different for the Happy vs. Neutral, Anger vs. Neutral and Disgust vs. Neutral zygomaticus responses (See Table 3.1).

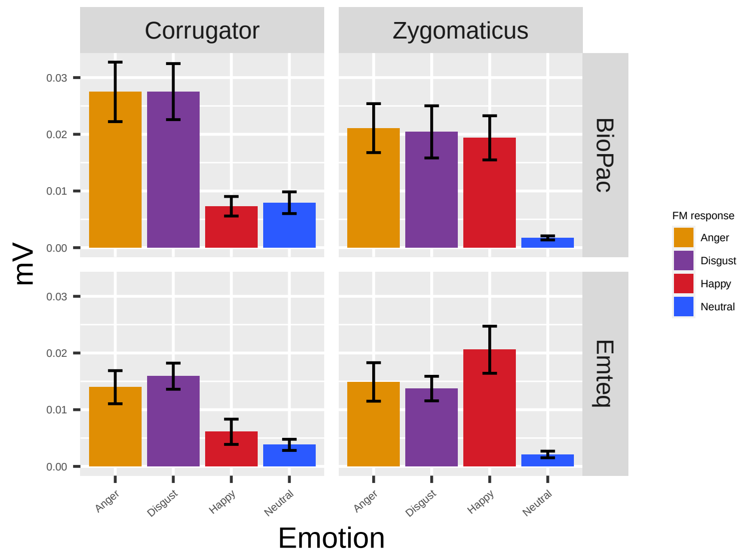

Figure 3.5: Facial Mimicry Emotion by Device, reduced corrugator response for Anger trial for Emteq device. Error bars represent standard errors

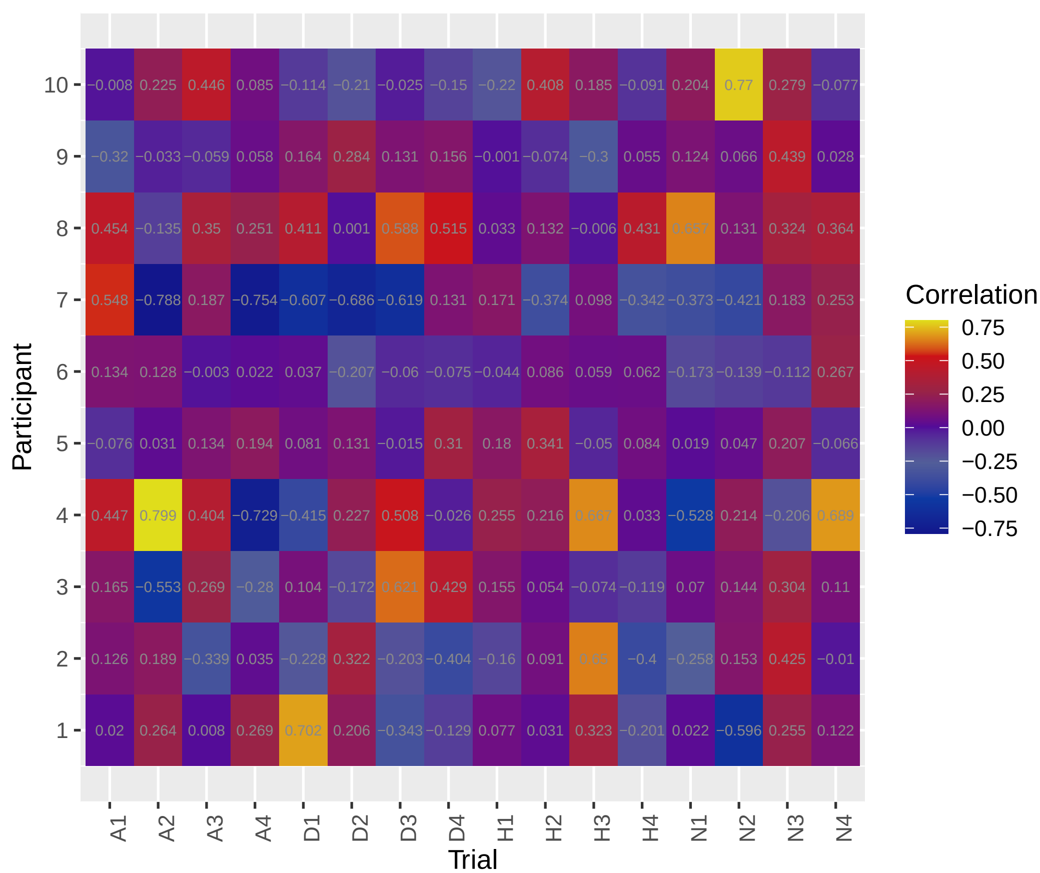

Figure 3.6: Biopac Facial Mimicry Correlations

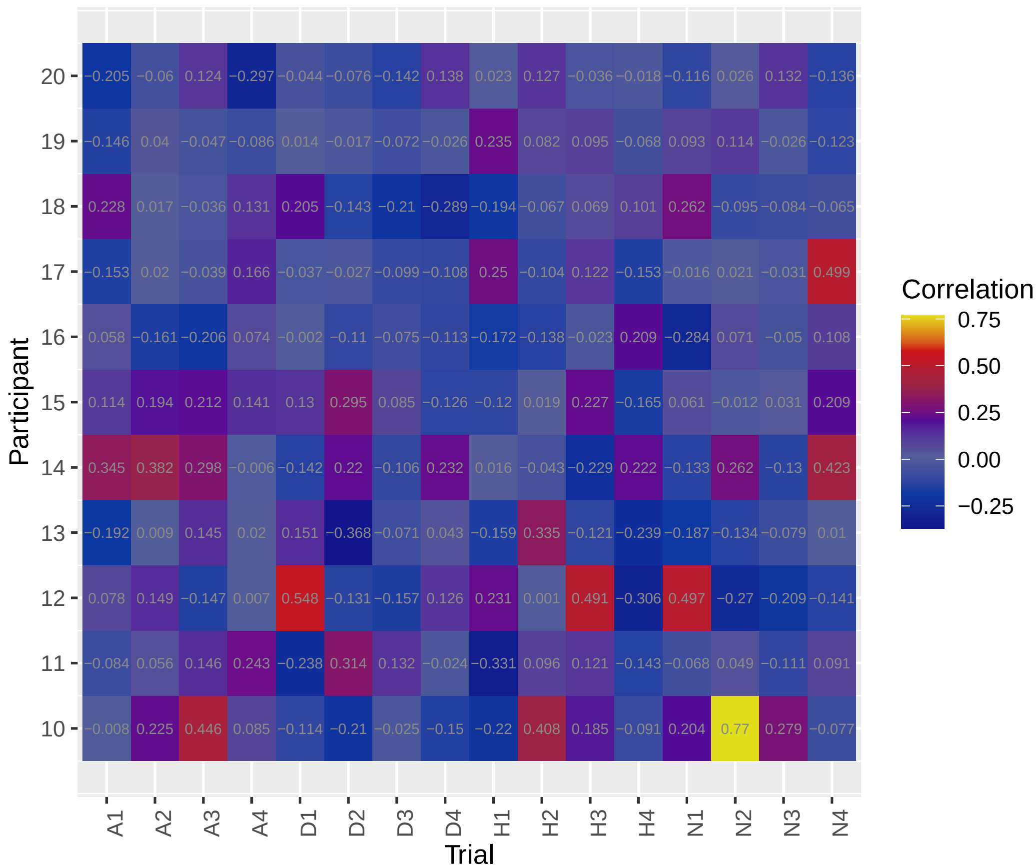

Figure 3.7: Emteq Facial Mimicry Correlations

3.4.1.1 Facial Mimicry Data Correlation

Each of the Emotion trials (4x Happy,4x Anger, 4x Disgust, 4x Neutral) were separated by Device (BioPac/Emteq) (See Fig. 3.6, 3.7), and a correlation value calculated by fEMG site (Corrugator/Zygomaticus) and for each Emotion (Happy, Anger, Disgust, Neutral). Across all Trials the mean correlation for the BioPac device [M = 0.06, SD = 0.31] was higher than for the Emteq device [M = 0.01, SD = 0.18]. In addition, correlation for the Emteq device was always less than for BioPac at each of the Emotions (See Table 3.2).

3.4.2 Plank Walk

Psychophysiology data for the plank walk task was captured in three windowed time periods, a period before the participant reached the midpoint of the plank and waited at the traffic light a period during which the participant waited for the traffic light to turn green crossed and a period from the mid-point to the end of the plank. A root mean square (RMS) for each Stage was calculated. fEMG responses by participants (N = 20) were subjected to a x 2 (Condition: Sedentary/Room-scale) x 3 (Stage:1/midpoint/2) x2 (Device: BioPac/Emteq) ANOVA for both the corrugator and zygomaticus. For the corrugator data there was a significant main effect for Device [F(1,18) = 1, p = <0.001, eta^2 = 0.65] i.e. there was a significant difference in corrugator measures between the two devices (See Fig. 3.8). For the zygomaticus data there was no main effect for Device [F(1,18) = 1, p = 0.621] i.e. there was no difference in measures between the devices. There was also a significant main effect for Stage [F(2,36) = 2, p = 0.014, eta^2 = 0.21] i.e zygomaticus levels were significantly different during the Stages of the task (See Fig. 3.9). There was also a significant interaction between Device and Stage [F(2,36) = 2, p = 0.016, eta^2 = 0.21]; Post-hoc t-tests revealed that zygomaticus activity increased significantly between the midpoint stage and Stage 2 of the task but only for the Emteq device [t(36) = -4.12, p 0] (See Fig. 3.10). There was also a significant interaction between Condition and Stage [F(2,36) = 2, p = 0.016, eta^2 = 0.21]; Post-hoc t-tests revealed that zygomaticus activity increased significantly at the room-scale Condition but only at Stage 1 of the task [t(44.81) = -2.68, p 0.01] (See Fig. 3.11).

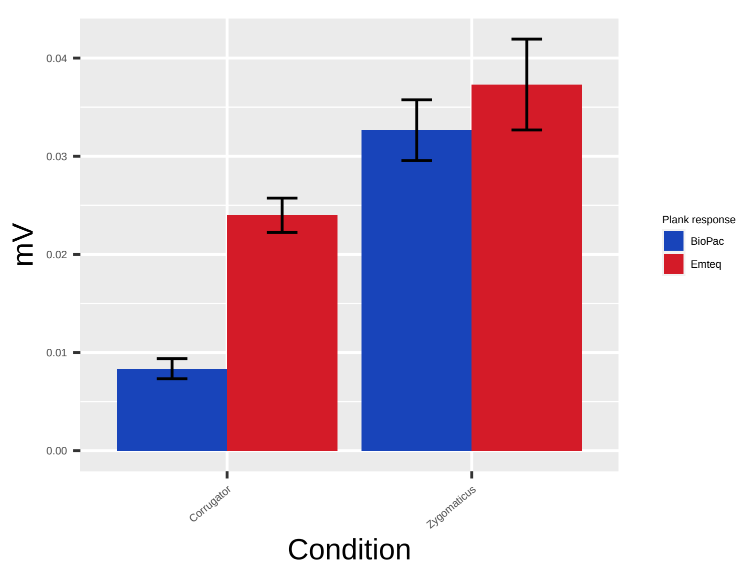

Figure 3.8: Plank Walk by Device and fEMG site, increased zygomaticus vs. corrugator activity. Error bars represent standard errors

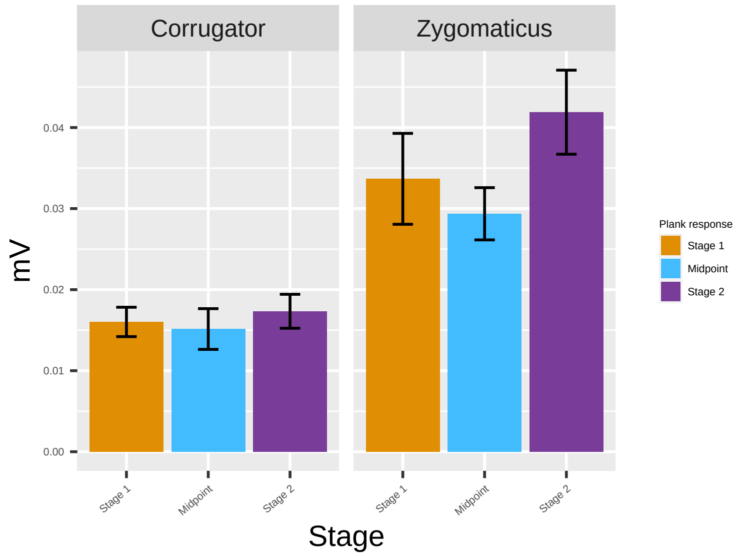

Figure 3.9: Plank Walk by Stage and femgSite, increased zygomaticus activity vs. corrugator. Error bars represent standard errors

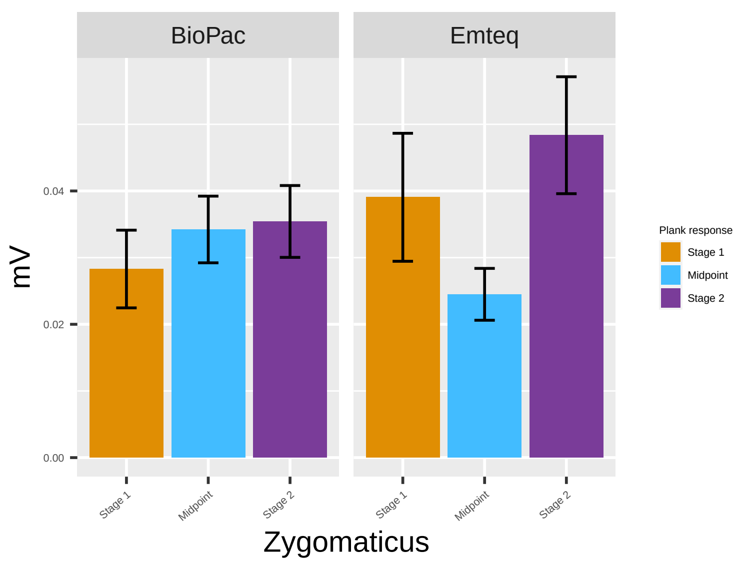

Figure 3.10: Plank Walk Zygomaticus by Stage and Device, decrease in zygomaticus response to mid point and rise in second section for Emteq device. Error bars represent standard errors

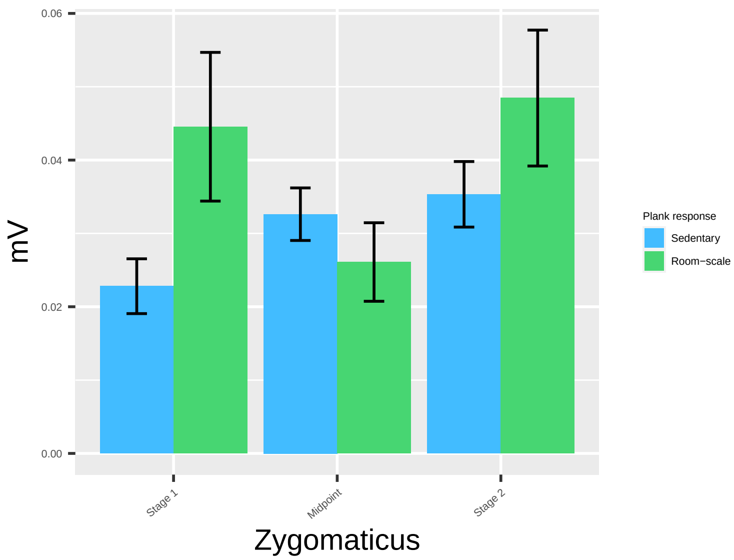

Figure 3.11: Plank Walk Zygomaticus by Stage and Condition, increased zygomaticus response for Stages 1 and 2 at room-scale. Error bars represent standard errors

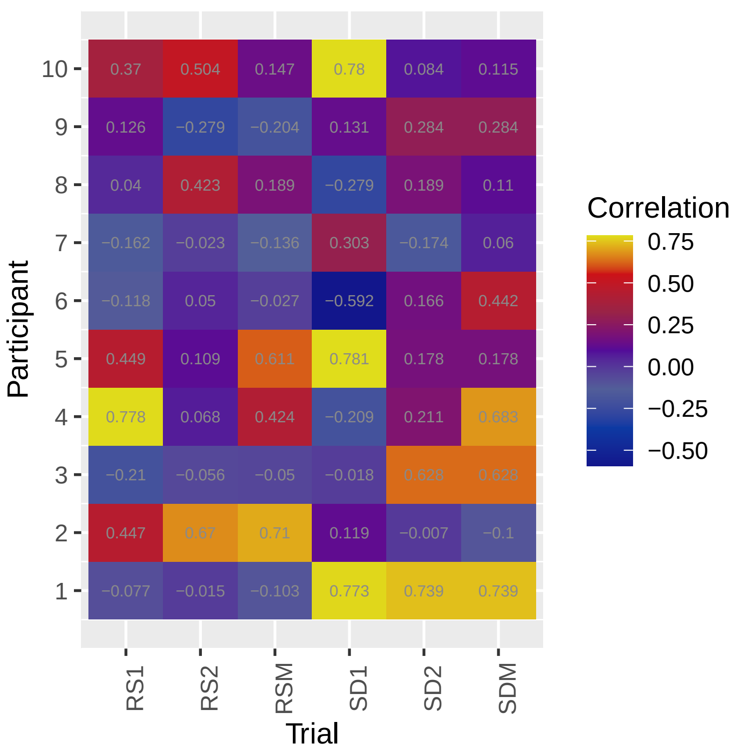

Figure 3.12: Biopac Plank Walk Correlations

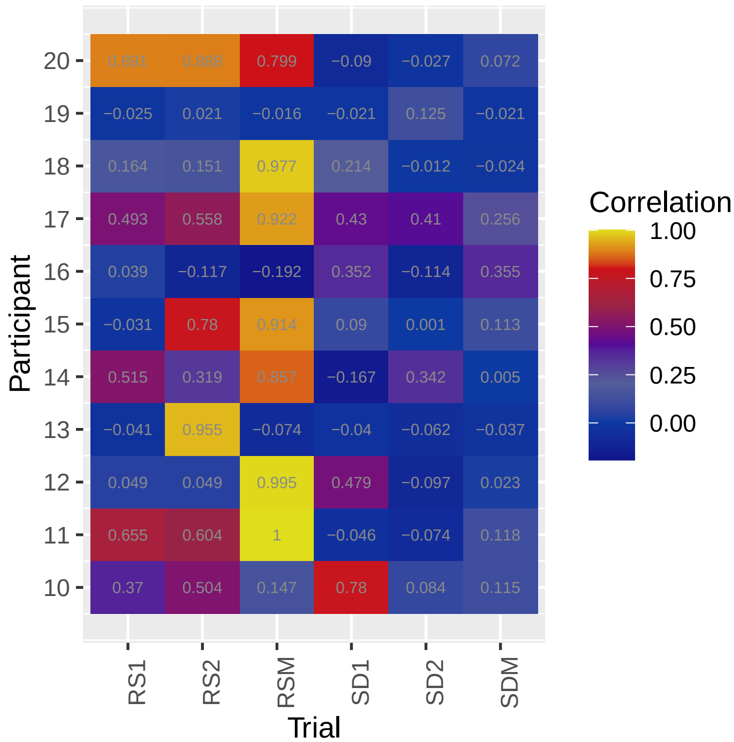

Figure 3.13: Emteq Plank Walk Correlations

Table 3.3: Plank Walk Correlations

Device	Stage	Type	Mean	SD
Biopac	Overall	All	0.198	0.33
Biopac	One	Room-scale	0.164	0.33
Biopac	Midpoint	Room-scale	0.156	0.32
Biopac	Two	Room-scale	0.145	0.29
Biopac	One	Sedentary	0.179	0.48
Biopac	Midpoint	Sedentary	0.314	0.29
Biopac	Two	Sedentary	0.230	0.27
Emteq	Overall	All	0.261	0.37
Emteq	One	Room-scale	0.271	0.34
Emteq	Midpoint	Room-scale	0.618	0.50
Emteq	Two	Room-scale	0.421	0.39
Emteq	One	Sedentary	0.120	0.23
Emteq	Midpoint	Sedentary	0.086	0.13
Emteq	Two	Sedentary	0.049	0.18

3.4.2.1 Plank Walk Data Correlation

Each of the Stages of the plank walk task (Stage 1/Midpoint/Stage 2) were separated by Device (BioPac/Emteq) and a correlation value calculated by fEMG site (Corrugator/Zygomaticus) for each Stage and Condition (Room-scale/Sedentary) (See Fig. 3.12, 3.13). Across all Stages the mean correlation for the BioPac device [M = 0.2, SD = 0.33] was lower than for the Emteq device [M = 0.26, SD = 0.18]. However correlation was lower for all Stages for the Emteq device at the Sedentary Condition (See Table 3.3).

3.5 Discussion

3.5.1 Summary of Results

The primary objectives of this study were: (1) Compare FaceTeq fEMG data capture device and assess against established BioPac fEMG data capture system hypothesising that the Emteq system would not show a significant difference in fEMG responses (2) Compare room-scale and Sedentary VR tasks hypothesising that Room-scale VR tasks have superior capacity to induce emotional responses. To compare the FaceTeq system with the BioPac system a task was created to present 16 emotional face transitions of (Happy, Angry, Disgusted and Neutral) facial expressions within a VE. The second task compared the fEMG data captured during a height threat plank walk task, each participant was required to cross the space between two virtual buildings at height over a plank. This plank walk task was divided into two with a pause at the midpoint of the crossing. It was hypothesised that the second stage of the trial would show increased fEMG responses.

For the facial mimicry task results showed that there was not a significant difference between the BioPac and Emteq devices capacity to capture fEMG data across each of the facial mimicry trials (See Fig. 3.5). For the corrugator supercilii data results showed that the corrugator response for angry and disgusted emotional states was increased than during the neutral facial mimicry trial, for the happy state corrugator response was not significantly different to the neutral response which are the expected results for these trials when no increase in corrugator response should occur during the Happy task and it should increase during the Angry and Disgust trials. Results also suggested that for the zygomaticus major data each of the facial mimicry trials for the Happy, Angry and Disgust facial mimicry tasks was significantly different than the zygomaticus response for Neutral. This result for the angry task is unexpected, for this emotional state a no significant difference in zygomaticus response was predicted and could indicate crosstalk interference between the fEMG data sites (Corrugator/Zygomaticus). An analysis of the correlation between the two devices for each of the facial mimcry trial categories (Happy/Anger/Disgust/Neutral) revealed that correlations were higher for the BioPac device than for the Emteq device. Correlation data was plotted for each device (See Fig. 3.6, 3.7) and tabulated (See Table 3.2) which suggested that there were no specific trials or patterns of correlation increase per device or facial mimicry trial. This indicates that for the facial mimicry task crosstalk or muscle co-activation had no significant effect on results.

For the plank walk task fEMG responses were measured from the time when the traffic light in the VE turned green and the participant was instructed to cross the plank to the midpoint (Stage 1). A second time period was measured (Stage 2). A period at the midpoint before the traffic light again turned green (Midpoint) and a period when participants crossed from the midpoint of the plank to the other building and the height threat plank walk task was complete (Stage 2). Participants completed this task in a sedentary position and also a room-scale version of the task during which they physically walk across the plank in the laboratory. Results indicated that there was a significant difference in response between the corrugator and zygomaticus responses and that there was increased zygomaticus response vs. corrugator during the task. This finding could indicate that participants did find the plank walk task affective but contrary to the hypothesis it did not generate a significant negative valence as no significant increase in corrugator response was detected. Results also indicated that there was a significant difference in response for the corrugator only between devices and that increased corrugator activity was measured for the Emteq device (See Fig. 3.8). Significant differences in fEMG activity were measured between each of the Stages of the task again only for the zygomaticus and only recorded by the Emteq device. A significant increase in zygomaticus activity was detected between the midpoint and the second stage of the task (See Fig. 3.10). This result could indicate that participants found the return to the safety of the second building and completion of the height threat task a positive stimulus. The Condition (Room-scale/Sendentary) data indicated that room-scale VEs have the potential to be more emotionally arousing than sedentary VR environments. For this task a significant increase in zygomaticus activity was detected at Stage 1 as participants first stepped onto the elevated plank. An opposite effect was measured at the midpoint between conditions as participants' zygomaticus response increased for the sedentary condition and decreased at room-scale at this point. This result is difficult to interpret but could indicate that participants attention was more concentrated on the traffic light indicator at this point in the task or that movement could play a role in the increase in fEMG response that is measured more research is required to determine an outcome for this factor the increase in zygomaticus activity vs. room-scale and for the latter stage of the task could also interpreted as increased activation of the zygomaticus synonymous with a grimace [Burton, 2011] provoked by anxiety, again more research is required. An analysis of the correlation between the two devices for each of Stages and Conditions revealed that correlations were higher for the Emteq device than for the BioPac device but only during the room-scale condition, this could indicate that movement may contribute towards crosstalk feedback between facial muscle groups for this device. Correlation data was plotted for each device (See Fig. 3.12, 3.13) and tabulated (See Table 3.3) which suggested that there were no specific trials or patterns of correlation increase per device or Stage except for the previous outcome for the Emteq device at the room-scale Condition.

3.5.2 Relationship to Background Research

Emotion elicitation in psychological studies has primarily focused on 2D media or sound stimuli. Virtual reality headsets have recently been exploited as tools to display emotionally stimulating experiences and research has demonstrated that the use of VR technology to present stimuli [Michaliszyn et al., 2010, Montero-López et al., 2016, Riva et al., 2007] and to induce fear in human subjects via the presentation of virtual height scenarios [Cleworth et al., 2012, Krupić et al., 2020, Meehan et al., 2002, Seinfeld et al., 2016]. The goal of this study was to benchmark two available sensors well suited to psychophysiological data capture in VR and to compare their effectiveness in room-scale and sedentary VEs. Additionally this study also attempted to expand on the available knowledge on the effects of VR technology in designing an emotionally affective scenario which was designed to function in a similar fashion in both sedentary and ambulatory room-scale scenarios in order that differences in psychophysiological responses could be examined.

In order to adequately benchmark the two fEMG capture devices a facial mimicry trial was selected that had previously been performed in a laboratory study using non VR techniques. Prior knowledge of each of the facial emotion trials could be used to predetermine results and examine results from each of the devices. This task was recreated in a VR scenario so that any adverse affects on measurements caused by the headset worn over the facial sensors could be detected and examined between the devices. A virtual height threat scenario via an elevated plank walk was designed so that the movement of participants could be easily mapped to a video game console controller and a room-scale equivalent could be developed which was sufficiently novel and hypothesised to demonstrate any differences between the two conditions without being completely estranged to the sedentary condition. Previous research on height threat VE effects also informed design and analysis phases of the study. Novel methods of behavioural tracking were developed to distinguish between key periods in psychobiological time series data which, too our knowledge, have not been attempted to this level of accuracy in any prior VR psychological study and further added to the body of knowledge in this area of research.

3.5.3 Limitations and Improvements

For the plank walk task laboratory space restrictions resulted in a short area over which the virtual plank was exposed over the virtual height. This resulted in a short time period during which a participant was exposed to the threat itself. The short distance between the buildings also meant that the participant had to make approximately ten steps to clear the distance as such it is possible that this design restriction limited the effects of the height threat and continually modulated this threat downwards as the participant was aware that each step brought them closer to the safety of the opposite virtual building. The requirement to compare a sedentary and room-scale VEs also restricted available development time and contributed to the choice of scenario. The linear nature of the task also inhibited agency and decision making opportunities that can be exploited to enhance the effects of room-scale VR scenarios, although technically a room-scale task effectively a participant was relegated to a small “slice” of laboratory/VE space. The design of a midpoint pause area may also have modulated responses to threat as it offered a pause or respite position during an already short VE scenario. Results could indicate that future scenarios designed to induce threat should attempt to acquire larger laboratory spaces and reduce any periods within a virtual environment during which participants are offered pauses or safe periods away from the primary threat stimuli.

3.5.4 Future Research

Future research should focus on a more direct attempt to investigate the Negativity Bias posit of the Evaluative Space Model The plank walk task did not explicitly allow participants to approach or avoid the threat mechanic. This task could have introduced an option for participants to step onto the exposed plank of their own volition measuring the time differences of this choice between participants and comparing their performances during the rest of the task against individual personality differences. As previously stated the linear plank task has questionable validity as a true room-scale scenario and likely yielded insufficient data, Additionally with respect to the research programme and the ESM it should be considered an threat endurance task rather than one which uses approach avoidance opportunities to permit self modulation of threat. Future research should increase participant agency such that they are permitted to take definite considered actions with regards to threat stimuli presented within the VE. The use of foot tracking devices was deemed necessary to facilitate plank navigation in the room-scale scenario and their utility was proven by this study. These devices could be utilised in a scenario as a mode of interaction with the environment.

3.5.5 Conclusion

Room-scale VEs do increase the potency of threat stimuli presentation and have increased utility in controlled laboratory conditions. Further research is required to determine the effects of movement on fEMG measures within this research context. Space restrictions can inhibit the delivery of room-scale VR scenarios and care must be taken by the researcher to reduce or remove periods during which threat stimuli delivery is paused. Furthermore scenarios which are applicable to the study of threat responses in VR cannot be assumed to take advantage of the increased agentic effects of room-scale VR and further research is required over longer, more interactive scenarios which in the context of this research programme better address the posits of the Evaluative Space Model.

Chapter 4

Study Two

4.1 Abstract

Many studies have attempted to use virtual reality as a method to induce emotional experiences. In this chapter we seek to analyse the effects of room-scale VR on perception of virtual height by combining VR with ambulatory psychophysiology[1]. Unreal Engine was used to design a custom virtual environment (VE) to deliver a graded experience of threat. Participants were required to cross a floating grid of ice blocks presented at height. The frequency of the ice blocks that could crack or crack and disintegrate, leading to a virtual fall, increased across three levels. During this study participants were exposed to low, medium and high threat (N=34, Age M=23.72 years SD=3.15). Participants were divided into two groups based on Neuroticism (High, Low). Psychophysiological data were collected from electrocardiogram, skin conductance level and two channels of facial electromyography (Corrugator Supecilli and Zygomaticus Major). This chapter will also describes methods of capturing highly accurate human body movement and the use of modern development platforms to precisely measure the unique interactions of participants in a lab environment. The chapter will then outline how the psychophysiological and behavioural data can be used in combination to gain macro and micro insights into participant behaviour in laboratory conditions. The results indicated some evidence for sympathetic activation as participants experienced greater levels of threat, i.e. higher probability of virtual fall. However, some data (heart rate and facial electromyography) also indicated evidence of habituation with exposure to the virtual environment. The results are discussed and possibilities for further research are outlined.

4.2 Introduction

Virtual Environments (VE) offer researchers the opportunity to create detailed and immersive environments to present interactive stimuli. This study attempted to integrate presence and embodied emotion as key factors in any attempt to provoke an emotional response [Cummings and Bailenson, 2016, Niedenthal, 2007]. In order to create an embodied experience a minimal sense of self is required within the context of the VE [Blanke and Metzinger, 2009]. Embodiment in VR is achieved via (1) self-location, the feeling of existing in a virtual environment (b) agency, the ability to affect the virtual environment through interaction (c) body ownership [Bailey et al., 2016, Schultze, 2010, Johnson-Glenberg, 2018]. The use of room-scale VR offers the possibility of inducing emotional experiences in an embodied fashion, where feedback from the autonomic nervous

[1] Baker, C., Pawling, R. & Fairclough, S. Assessment of threat and negativity bias in virtual reality. Sci Rep 10, 17338 (2020). https://doi.org/10.1038/s41598-020-74421-1

system is combined with postural changes during active engagement with a task. In addition, by creating an autonomous sense of self within the VE, the participant is imbued with a sense of agency, able to approach or avoid emotional stimuli or objects within a three-dimensional space as they would in a physical space.

The reliable induction of emotional response in laboratory conditions can present numerous challenges [Quigley et al., 2013]. Researchers have generally relied on the use of standardised content libraries of images, videos, affective words and musical stimuli [Schaefer et al., 2010, Bradley and Lang, 1999]. These experiences are inherently passive, can be subjective, and rely on a participant to retroactively accurately report their emotional responses. Experiments that enlist the use of confederates to subvert the course of a study and provoke emotional responses in an unwitting participants can pose ethical problems. Usage of standardised media stimuli can have questionable ecological validity, the subversive manipulation of experimental design factors have questionable moral and ethical implications.

VR presents an opportunity to deliver highly specific tasks and present scenarios which stimulate sensory responses whilst also being capable of denying a participant exposure to external stimuli that would otherwise be represented as noise during a data capture session. This allows the researcher to create highly consistent emotional experiences and to mimic the spatial dimensions of the real world space in the VE. In order to present a believable scenario that creates a sufficient amount of 'presence' [Cummings and Bailenson, 2016]. The degree to which a VR scenario can create an effective sense of presence and embodied emotion has been previously studied [Slater et al., 2009b]. Further studies have attempted to provoke a range of emotional responses. Felnhofer et al (2015). created a virtual park where positive and negative emotions were provoked by altering lighting levels and adding and removing environmental factors within the same VE [Felnhofer et al., 2015]. they claimed to successfully induce five distinct states (joy, anger, boredom, sadness, anxiety) and validated this technique using psychophysiological measures. other studies have attempted to provoke anxiety in the form of a public speaking task conducted by a human participant for a simulated audience [Felnhofer et al., 2014]. Other studies have introduced threatening agents into a VE to provoke a fear and avoidance response in the participant. Bouchard et al (2008). found that the use of hidden animated snakes into a VE increased anxiety in their experimental subjects [Bouchard et al., 2008]. Other studies have focused on the use of heights to provoke fear. Meehan et al (2002). created a scenario that acclimatised users to a virtual room, they asked participants to navigate the room and move virtual objects [Meehan et al., 2002]. After the participant had navigated this virtual space they asked the participant to move to an adjoining virtual room. This virtual space had a void in the floor. They asked participants to then drop virtual objects onto targets through a hole in the floor of this virtual room. They found that the use of virtual heights was an effective means of inducing stress. Peterson et al (2018). [Peterson et al., 2018] had participants perform beam-walking in two VEs (2.5cm from ground vs. 15m from ground), which were compared with actual beam walking at a height of 2.5cm. They reported increased heart rate and skin conductance levels in the 15m VE compared to the real or virtual 2.5cm condition. Bierderman et al (2017). attempted to transfer an elevated plus maze (EPM) previously used to study anxiety in terms of approach and avoidance in rodents to human participants in the form of a VE [Biedermann et al., 2017]. They found that approach and avoidance behaviour correlates with the extensive work done on rodents, they also applied the use of anxioselective drugs to stimulate approach and avoidance behaviour in human participants. Recent studies using height manipulation in VR have reinforced height as a valid means to provoke anxiety in humans and have suggested that its effects may have a limited range of effectiveness [Wuehr et al., 2019]. The technical challenges and feasibility of experimental design in creating VEs which provoke a range of emotions are exponentially greater than designing for the provocation of singular emotional states. Previous studies have often created scenarios whereby a limited number of variables are manipulated in the same virtual environment to provoke different emotional responses. This is likely to be due to the technical challenges and time-cost involved in creating separate VEs for each emotional state tailored to the elicitation of specific emotional reactions; furthermore it could be argued that such methods serve to make subsequent exposure to the VE in different states more derivative and lessen its ecological validity.

The Evaluative Space Model (ESM) [Cacioppo et al., 2012] was selected as a theoretical basis for the study of emotional affect. ESM proposes that all emotions are generated by a fundamental approach or avoidance response inherent to all mammalian species.The operating characteristics of approach and avoidance responses then lead to more complex emotions and behaviour in the organism. Within ESM, stimulus evaluation occurs as a vector within a three-dimensional space of positivity, negativity and net disposition to approach or avoid. The ESM suggests that there is a linear relationship between negative valence and avoidance behaviour in an organism. This is termed the *Negativity Bias* (Fig. 4.1). Heightened sensitivity to negative stimuli is a characteristic associated with increased trait neuroticism [Eysenck, 1963] and high neuroticism has also been associated with a 'harm avoidant' style of coping [Zelenski and Larsen, 1999], leading to exaggerated psychophysiological reactivity to increased threat [Drabant et al., 2011] and negative form of media stimuli [Norris et al., 2007, Reynaud et al., 2012]. For some individuals lower levels of activation can trigger avoidance responses, for others higher levels of activation are required to trigger an equivalent response. This study hypothesised that for high neurotic individuals this negative gradient will be more acute than for a low neurotic individuals i.e. higher threat perception leads to greater aversion to risk. Consequently these individuals would make more risk averse decisions in a VE. It was further hypothesised that this behaviour was more likely to manifest itself as the level of threat increased during the task. This study was concerned with creating a scenario of increasing negativity with reference to these posits of the ESM.

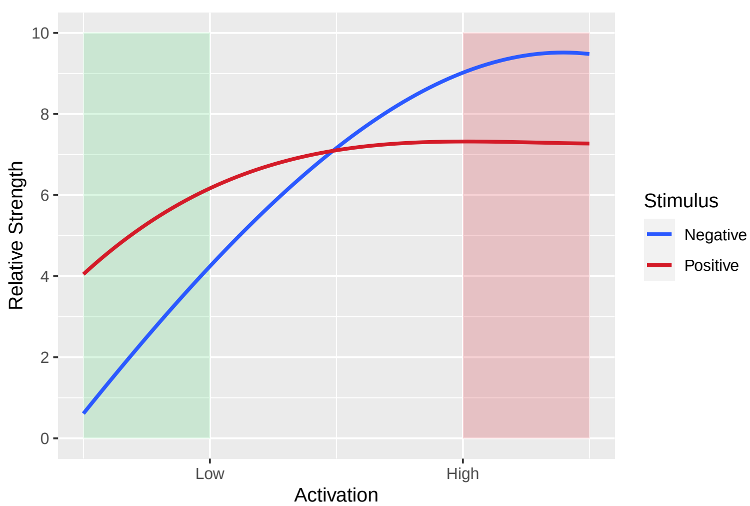

Figure 4.1: Negativity Bias, Positivity Offset

Many studies have demonstrated the effectiveness of VEs to induce emotional responses, but to our knowledge few have deliberately tried to offer a wide range of freedom of choice in a room-scale VR scenario. We hypothesise that room-scale VR, a VE in which a participant is free to move around and have their full body movement directly influence their position in the virtual space represents a natural evolution in the use of VR technologies for experimental research, further hypothesising that the emotional valences induced by room-scale VR will be greater than that of non room scale, or sedentary VR experimental setups. It was decided that the study would embrace the freedom of movement and thereby

Table 4.1: No. of Block types per Level

Threat Level	Solid	Crack	Fall
1	13	3	0
2	8	6	2
3	3	9	4

the greater degree of agency given to participants should be a fundamental part of the experimental design. It was also decided that such freedom of action would not encroach on the careful and considered delivery of a rising level of threat. The primary methods of increasing threat within the context of the VE were (1) an increase in height between each level (2) an increase in the threatening Crack and Fall blocks on each level. As such a consistent and known gradient of threat was delivered during each experimental trial with respect to the Negativity Bias postulate of the ESM.

It was hypothesised that the relationship between activation and negative emotion would be captured by the negative gradient and that this would vary between the high and low neurotic groups. It would therefore then be the agentic choice of the participant to engage (or not) with this fundamental premise of the study. It was considered that a restriction in agency or choice of action would artificially suppress differences in behaviour and psychophysiological responses between the high and low neurotic groups thus counteracting the hypotheses of the study. The primary objective of the study was to construct a VE which would allow for individually different actions on behalf of each individual whilst also increasing threat at a clearly defined rate which was broadly the same for each participant. The task was not intended to be truly realistic but efforts were made to ensure that there were an intuitive set of contextual rules a participant would quickly understand and explore according to their own unique personality traits. Finally it was hypothesised that if a negative gradient was provoked individual differences in trait neuroticism would allow us to explore the negative gradient and its effects on participants in the VE.

4.2.1 Research Questions

1. Design VE environment capable of reliably provoking threat
2. Demonstrate that the threat of virtual height is affective
3. High Neuroticism participants will be more affected by threat
4. Behavioural measures created via game engine modifications can measure behavioural differences

4.3 Methodology

4.3.1 Experimental Design

The study was designed as a within participants mixed measures design with two levels of neuroticism (High, Low) three levels of threat (Level 1, Level 2, Level 3). The threat in each level was determined by the amount of Solid Blocks (No threat) vs. Crack Blocks (Medium threat) vs. Fall Blocks (High threat). The amount of Crack and Fall blocks was increased between levels (See Tab. 4.1) and VE block layout (Fig. 4.2).

4.3.2 Participants

The sample consisted of 34 participants (21 female) with a mean age of 23.72 years (SD = 3.15). Participants were selected from an age range of 18-35 years and prescreened for conditions such as epilepsy and any disorders which may inhibit their ability to move freely within the study environment. Participants completed a personality scale questionnaire using the 'OCEAN' (Openness, Conscientiousness, Extroversion, Agreeableness and Neuroticism) Big Five personality traits [O'Keefe et al., 2012]. All protocols were approved by the University Research Ethics Committee prior to data collection. Participants were then divided into two groups according to trait high and low neuroticism (HN, LN) 1 participant was removed who registered median score on personality questionnaire (M = 24). Each participant in both groups was exposed to all three levels of the study and therefore experienced all three levels of threat.

4.3.3 Apparatus

The HTC Vive virtual reality headset was used by each participant as they navigated through the custom VE scenario purpose built for this study. The HTC Vive system utilises laser-based tracking via two base stations positioned at either corner of the designated interactive space. These base stations are capable of tracking a 5m x 5m interactive zone. Due to physical laboratory space restrictions this study was limited to a 5m (length) x 4m interactive area. The participants head movement was recorded via the position of the HTC Vive HMD, 2x hand controllers and 2x Steam VR trackers attached on each foot.

The VE was constructed in Unreal Engine 4.21. All assets were purpose built for the study. The VE was rendered on a desktop PC in situ (CPU AMD Ryzen 5 3600, GPU NVIDIA GTX 1060, Windows 10 OS). Custom C++ code integrated directly into the Unreal Engine system captured interactions with VE objects and recorded time instances of interactions. Psychophysiological data was recorded via 2x BioNomadix wireless sensors attached to the participants torso (2x FEMG, 1x ECG, 1x SCL). BioNomadix sensor data was then relayed to the MP150 recording unit and captured via AcqKnowledge 5.0 software.

4.3.4 Virtual Environment

4.3.4.1 Three Levels of Threat

The VE incorporated three distinct 'levels' or versions of the VE (Fig. 2.17). It was decided that the user would begin each level of the VE at the 'ground' level and be elevated to three different heights, i.e. level 1 = 200m, level 2 = 400m and level 3 = 600m. Note: 1m in Unreal Engine units being equal to 1m in the real world. The stages individually used the full length of the interactive space and a user was directed back to their original starting position with contextual cues at the end of this level (See Blue Return Circle). This design allowed the participant to explore the full area of interactive space on a per level basis.

Participants could interact with blocks in two ways, a one footed testing movement (risk assessment) or a two footed movement in which they committed to standing on the block with both feet (risk decision). These actions were recorded as Behavioural data. These actions in the VE were recorded in the physical space via steam VR trackers attached to the feet (See Methodology, Apparatus).

The increase in elevation at each of three levels of the VE and the increasing number of Crack and Fall blocks on each level combine to scale level of threat during the experiment.In order to create a visual indication of increasing threat pre-cracked blocks were introduced. This block was coloured with a blue hue and already in the cracked state which would normally occur if the participant stepped upon it. Two of these blocks were present on level 2 and four on the 3rd final stage serving as a visual cue to add increasing level of threat.

Figure 4.2: Layout Study Two

4.3.4.2 Goal Directed Behaviour

Before commencing the study participants were verbally instructed to test each block with a single foot prior to committing to it with both feet. Participants were then told to cross the grid of ice-blocks. If a participant made a one foot, risk assessment interaction to a Solid block, it would not visibly and audibly crack if touched with a single foot, for a Crack block, it would audibly and visibly crack. The third state, at which the block would fall and the participant virtually fall with it, would only occur if the participant committed to a Fall Block with a two-footed (risk decision) interaction. Fall Blocks behaved in the same manner as Crack Blocks until a participant committed to the riskier action of stepping on them with both feet (Fig. 4.3).

At the end of each level, the participant was required to pass through a virtual doorway by pressing a button on a pedestal situated to the right of the door (Fig. 4.4). The doorway required the participant to activate with the VE representation of their hand to open the door. This interaction was achieved by creating a custom trigger volume would activate when the hand was placed over the button and transport them to the next level of the VE. The virtual doorway provided the participant with a visible goal, which was rooted in a universal real-world concept. The virtual doorway also served the practical purpose of slowing and shaping the movement of a participant across the level. Pilot studies during the development demonstrated that some participants would choose to pass across the physical space as quickly as possible without a specific target or goal.

4.3.4.3 Blue Return Circle

At the end of each level of the VE, the participant must pass through the virtual doorway. The physical lab space was limited to 5x5 metres so this mechanic was introduced to allow the creation of the three levels of threat in the same physical space. At this point, they were instructed to turn around and return to a position within a blue circle (Fig. 4.5). They walked to position themselves within the blue circle and turned around again; at this point, the next level of the task was activated.

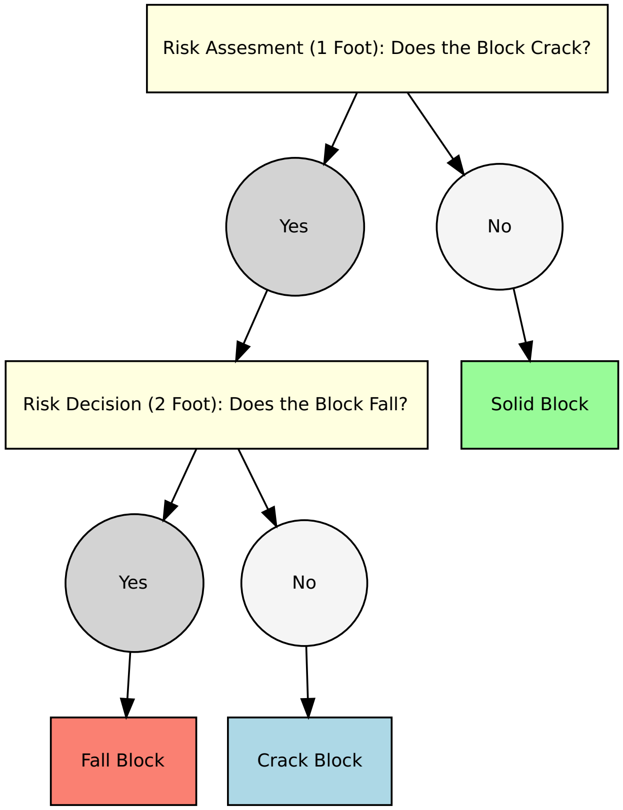

Figure 4.3: Block interaction Flowchart for Risk Assessment/Decision Actions

Figure 4.4: Doorway

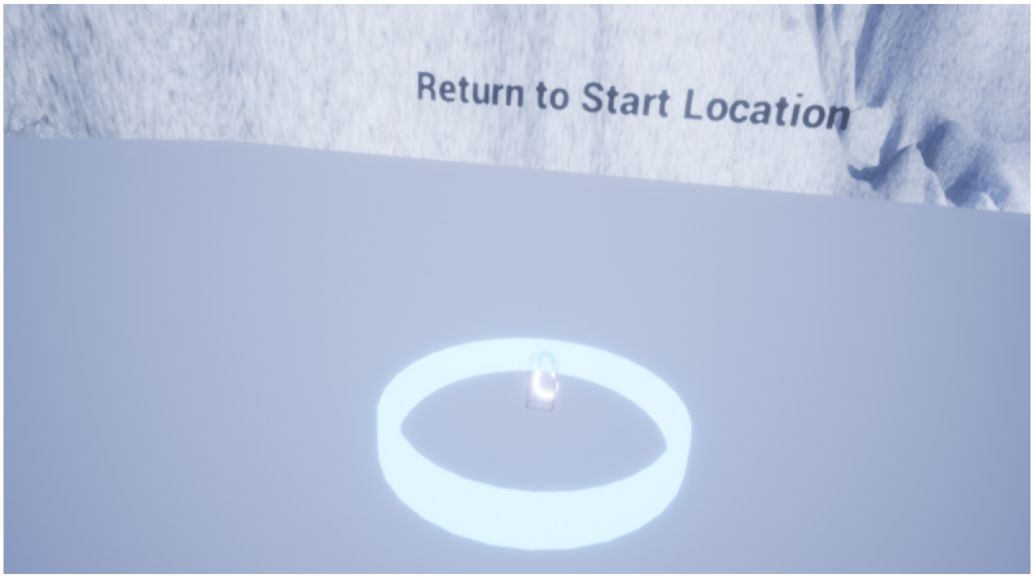

Figure 4.5: Blue Return Circle

4.3.5 Measures

4.3.5.1 Event Marking

The capture of participant movement data was logged via a custom C++ function added as a module to the Unreal Engine Editor. This function logged participants head, hands and feet movement to four decimal places of precision inside the VE sampled at 5Hz. These data were logged to a text file per participant and captured for use in analysis. Behavioural data captured key events in the simulation via a unique ID and time of occurrence of which could then later be used during analysis. This function was made possible via a secondary C++ custom function to track when a user passed through a certain area (e.g. doorway) or via the use of hand held controllers and the tracking sensors attached to the feet of the participant, 'touched' or 'stepped on' a virtual object. Logging of events linked to movement was made possible via custom trigger volumes (Fig. 4.5) this Unreal Engine feature is a commonly used technique in game engines and other interactive media. It places volumes within the environment that are invisible to the user during run time. If this volume is crossed via another paired object, such as the position of the VR headset, the engine registers an event. The deployment of customised volumes allowed the C++ function to set up a list of events which a participant may or may not trigger and to record these events with precision.

4.3.5.2 Event-based psychophysiology

The data was captured in 3000ms windows. An average score was calculated from the 1500ms period before the event. Two 750ms post event periods were then measured and subtracted from the pre-event period.

4.3.5.2.1 Facial Electromyography (fEMG). Facial electromyography (fEMG) was recorded at 1000Hz from the Corrugator supercilii and Zygomaticus Major via the BioNomadix ambulatory psychophysiology system (BIOPAC). fEMG data were filtered above 0.25Hz and 0.75Hz using high- and low-pass Butterworth filter processed as follows: (1) bandpass filter applied at 49-51Hz to remove 50Hz noise, (2) filtered between 20 and 400Hz, (3) rectified and smoothed via linear envelope (9Hz filter), and (4) subjected to

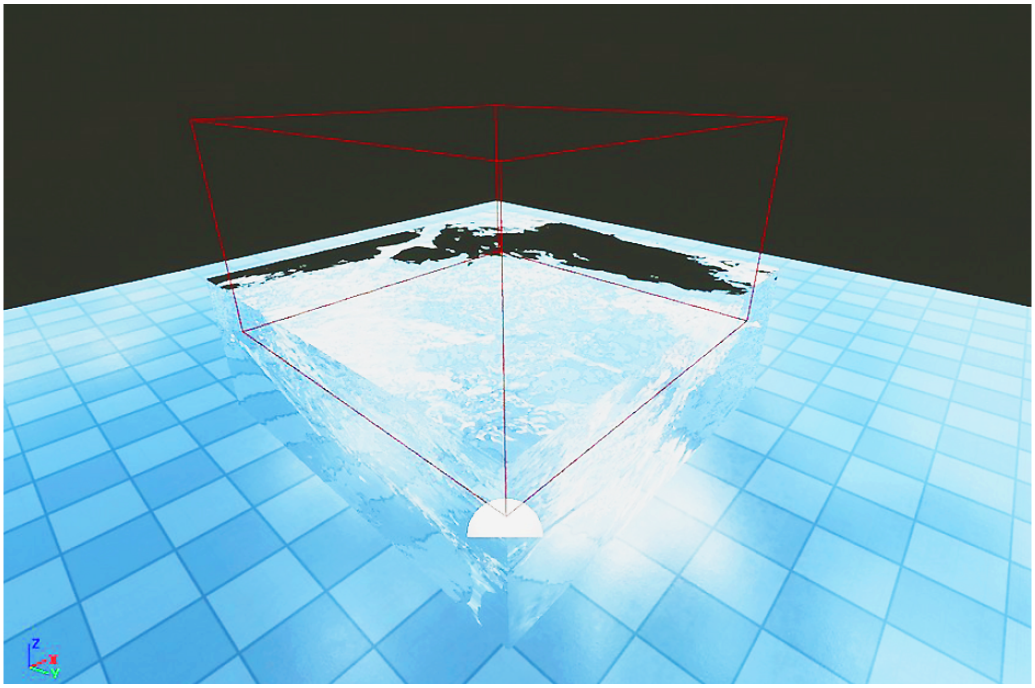

Figure 4.6: Volume Trigger above an Ice Block

root mean square transformation [Boxtel, 2001, Lajante et al., 2017].

4.3.5.2.2 Electrocardiography (ECG). Electrocardiography (ECG) has traditionally been used as a measure of the electrical potential generated in the heart cycle to treat cardiovascular diseases and detect abnormalities. Its use expanded to encompass the measurement of stress and human emotion [Rainville et al., 2006]. ECG analysis measures this cycle of electrical activity over time. Each cycle consists of P, R and T segments. The P complex or segment is caused by atrial depolarization. The R segment occurs during ventricle depolarization the T complex occurs during atrial repolarization. Using R peak analysis methods, it is possible to sum the total number of peaks over time as beats per minute (BPM). Increases in heart rate are associated with increases in physical activity and sensory stressors.

For this study Electrocardiogram measures were also recorded at 1000Hz via a second BioNomadix wireless wearable physiology device and recorded participant ECG output throughout the trial, this was then filtered with high/low pass Chebyshev filter 0.5Hz and peak analysis was performed.

4.3.5.2.3 Skin Conductance Level (SCL). Electrodermal activity (EDA) is a blanket term used to describe changes in the electrical properties of the skin. Skin Conductance Level (SCL) can be measured by observing a change in current flow between two electrical potential points in contact with the skin. EDA can be used to measure sympathetic responses to emotional stimuli e.g. threat by measuring changes in skin conductance level [Braithwaite, 2013].

For this study Skin Conductance Level (SCL) was also recorded at 1000Hz during each trial via the BioNomadix wireless system and was taken from the index finger and the fifth digit of the hand, it was subsequently filtered with a high pass filter at 0.05Hz.

4.3.5.3 Data Analysis

For Study Two participants (N=35) were divided into two groups (Low/High Neuroticism). The task was divided into four periods, A base-lining period in a neutral area (30secs), Level 1 when the height threat was at its lowest (~2min), Level 2 when the height threat was at its mid level (~2min). Level 3 when the height threat was at its greatest level (~2min). Psychophysiological changes in fEMG response, EDA and ECG could be compared across these three periods (Level 1, Level 2, Level 3) against the base lined psychophysiological response. The time-series psychophysiological data was further subdivided by periods spent on each ice-block type (Solid/Crack/Fall) and the movement action subdivided into two groups (1-foot, 2-foot). One footed movements to a block type were considered a "checking" or Risk Assessment action. Two-footed movements were considered to be a commitment to moving onto a block or a Risk Decision action. For Study Two Data analysis was conducted using MATLAB [MATLAB, 2010]and SPSS [IBM Corp., 2017].

4.3.6 Procedure

Before the experiment began, each participant was presented with an information sheet that explained the procedures that would be followed, and what would be required of them during the study. The participant then signed a consent form, and was familiarized with the lab space and introduced to the room-scale VR sensors. Following familiarization, the participant was told how physiological sensors would be attached, the sites were then cleaned with abrasive gel and conductive gel applied, ECG sensors were then attached if required and fEMG sensors were attached to the face via the Biopac ambulatory device. Before the commencement of each study sensor responses were tested and adjusted.

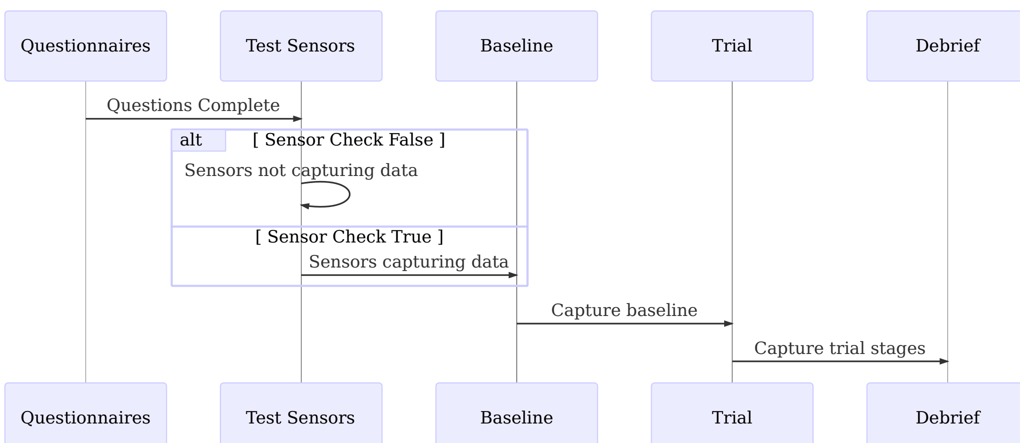

Figure 4.7: Illustration of data collection protocol

4.4 Results

The experiment was designed to explore the negative gradient postulate using two distinct sets of data. The first dataset consists of behavioural data that characterised movements and selection of actions as participants experienced increased levels of threat. The second set of data include fEMG (corrugator, zygomaticus)and SCL. These data are event-related and refer to specific periods of action, which were: (a) risk assessment, i.e. one-foot checks to evaluate whether the block would crack or not, and (b) risk decisions, i.e. two-footed commitment to a block which was either solid or cracked.

In addition, the study was designed to investigate individual differences in trait neuroticism. All participants completed the OCEAN scale [O'Keefe et al., 2012] prior to the study. The median score on the trait neuroticism scale was 24 and this value was used to split the participant sample into two groups of high and low neurotics.Two participants scored 24 on the neuroticism scale and were omitted from further analyses, leaving 15 participants in each group. The High Neuroticism (HN) group had a mean neuroticism score of 29.94 (s.d. = 3.87) whereas the mean for the Low Neuroticism (LN) group was 17.94 (s.d. = 3.71). A between-groups t-test was performed on these data to confirm that trait neuroticism was significantly higher for the HN group [t(29.95) = 8.95, $p < .01$].

4.4.1 Behavioural Data

4.4.1.1 Analysis of Fall Block activations

During the experimental trial 64.52% (N = 31) of participants triggered a Fall block either L2 or L3 of the study, Fall blocks could only be triggered with a two-footed activation. There were no fall blocks to trigger at L1. During L2 there were a total of 26 Fall block activations. This total declined to 22 at L3. Participants spent a significantly longer amount of time on Solid blocks at L3 than at any other point in the experimental trial (see Fig. 4). No participants triggered > 2 Fall Blocks per level, there were a total of 6 opportunities to trigger a Fall Block during an experimental trial (L2 = 2, L3 = 4). 54.84% of participants triggered 1 fall Block at L2 29.03% triggered 2 Fall Blocks at L2. At L3 54.84% triggered 1 Fall Block and 16.13% triggered 2 Fall Blocks. Only a single participant triggered 1 Fall Block at L2 and increased the number of activations triggering 2 Fall Blocks at L3.

4.4.1.2 Timings

The average time spent by participants standing on each type of block (solid or cracked) was subjected to a 2 (High/Low Neuroticism) x 3 (Level) x 2 (Block type) ANOVA. 10 participants were removed from the data set for this analysis due to missing data, i.e. they did not interact with both Solid and Cracked Block types on one of the three Levels used in the study. There was a main effect for Level [F=(2, 32) = 14.54 , p = <.001, eta^2 = .476], i.e. participants spent longer on average on each block at Level 3 (M = 17.09, SE = 1.56) compared to either Level 1 (M = 9.76, SE = 1.56) or Level 2 (M = 9.6, SE = 1.56). There was also a significant effect for Block type, participants spent longer on solid blocks (M = 13.39, SE = 1.36) compared to cracked blocks (M = 10.91, SE = 1.36). A significant interaction between Level x Block type was also found [F=(2, 32) = 42.12 , p = <.001, eta^2 = .725]; the average time participants spent on Solid blocks was significantly higher than the cracked blocks at Level 3 (i.e. maximum threat level), (see Figure 4). Post-hoc t-tests revealed that participants spent longer standing on Cracked blocks at Level 1 [t(25.21) = -2.54, p 0.02]; this trend was reversed at Level 3 when participants spent longer standing on Solid blocks [t(26.78) = 4.17, $p < .001$].

4.4.1.3 Frequency of Movement

The number of times that each participant interacted with each block was recorded. The Context of these interactions were categorised as risk assessment (testing the block) and risk decision activations (stepping onto the block with two feet). This independent variable was included in a 2 (Neuroticism: HN vs. LN group) x 3 (Levels:1,2,3) x 2 (Block type: solid vs. cracked) x 2 (Context: risk assessment vs. risk decision activations) ANOVA. There was a main effect for Context [F=(1, 29) = 11.31 , p = .002, eta^2 = .281], participants performed a greater number of risk assessment (one foot) (M = 4.19, SE = 0.18) than risk decision (two feet) interactions (M = 3.61, SE = 0.18). There was also a significant main effect for Block type [F=(1, 29) = 31.28 , p = <.001, eta^2 = .519],

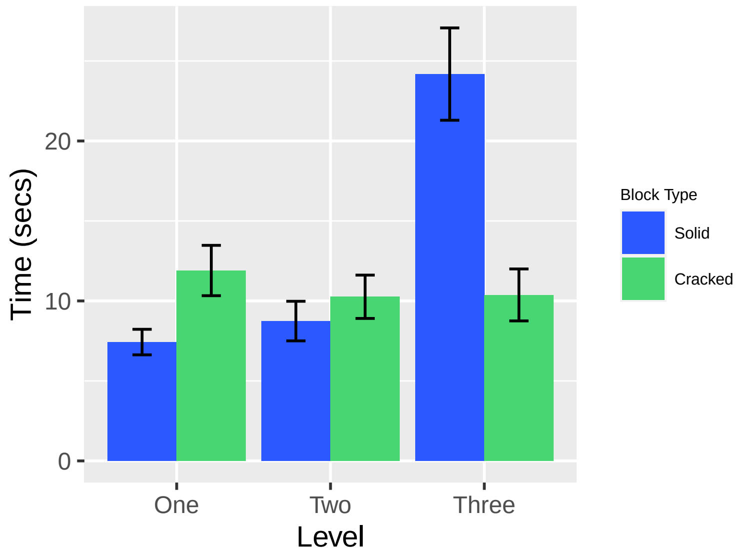

Figure 4.8: Average Time spent on Solid block vs. Cracked block over all Levels of the VE (N=18), increase in time on solid blocks at level 3. Error bars represent standard errors

participants interacted with Solid blocks (M = 4.46, SE = 0.19) more frequently than Cracked blocks (M = 3.33, SE = 0.19). There was a significant main effect for Level [F=(1.69, 49.12) = 56.25 , p = <.001, eta^2 = .660] participants interacted with more frequently with both types of blocks at Level 1 (M = 4.99, SE = 0.19) compared to Level 2 (M = 3.74, SE = 0.19) or Level 3 (M = 2.95, SE = 0.19). The ANOVA also revealed a significant interaction between Context x Level [F=(1.87, 54.28) = 49.78 , p = <.001, eta^2 = .632]; post-hoc t-tests revealed that participants made a greater number of risk decision interactions compared to risk assessment interactions, but only during Level 1 [t(88.53) = -2.14, p 0.04]. This trend was reversed during Levels 2 [t(118.78) = 5.25, p <.001] and 3 [t(105.9) = 4.24, p <.001] as participants increased their frequency of risk assessment checks compared to risk decision movements (see Figure 5).

There was also a significant 2-way interaction between Block Type x Level [F=(1.61, 46.62) = 177.24 , p = <.001, eta^2 = .859]; post-hoc tests revealed that participants interacted with greater number of Solid blocks (M = 7.62, SE = 0.24) compared to Cracked Blocks (M = 2.37, SE = 0.24) at Level 1. This trend was reversed during Level 3 (M = 2.05, SE = 0.24),(M = 3.86, SE = 0.24), (see Figure 6). This pattern reflects the greater frequency of solid blocks at Level 1 and cracked blocks at Level 3 (see Figure x in Method).

The ANOVA also revealed a significant 3-way interaction between Context x Level x Neuroticism [F=(1.87, 54.28) = 3.14 +, p = .055, eta^2 = .098]. Subsequent post-hoc t-tests revealed that the HN group made a significantly greater number of risk assessment activations (i.e. testing the blocks) compared to the LN group but only during level 3 [t(59.87) = 2.69, p 0.01] (See .Fig 7).

A second significant 3-way interaction was observed between Block Type x Level x Neuroticism [F=(1.87, 54.28) = 9.61 , p = <.001, eta^2 = .249]. Post-hoc t-tests revealed a higher frequency of interactions with Solid blocks for the HN group at Level 1 [t(59.94) = 1.79, p 0.08] (see Fig 8).

4.4.2 Psychophysiology Event Related Analysis

Psychophysiology data was captured in 3000ms windowed time periods. An average score was calculated from the pre-event period. Two post-event periods (0-750ms and 751-1500)

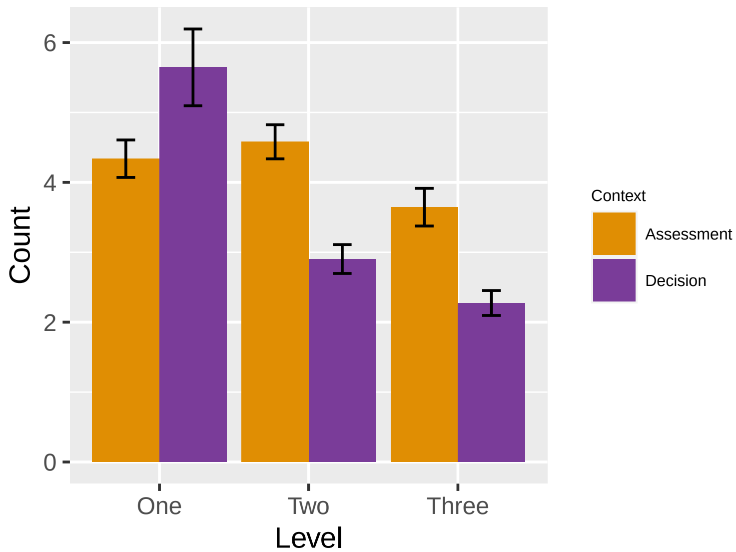

Figure 4.9: Average frequency of one-footed vs. two-footed interactions with both over the three Levels of the VE (N=29), increase in Assessment vs. Decision actions during task. Error bars represent standard errors

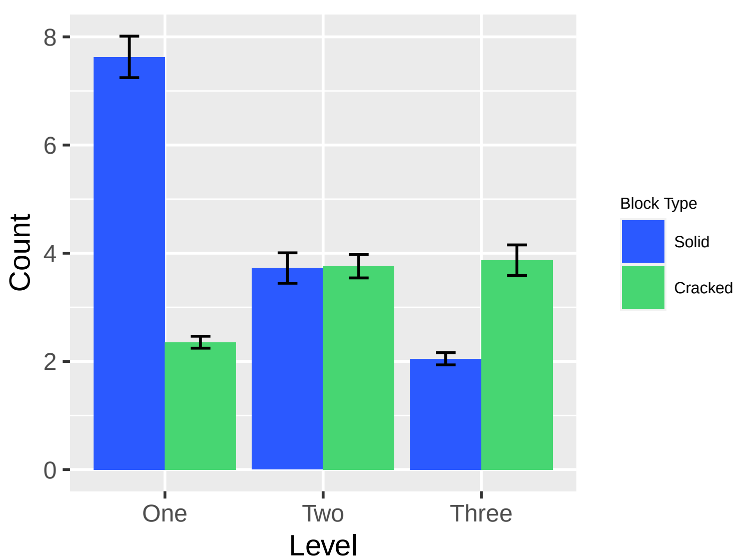

Figure 4.10: Average frequency of Solid vs. Cracked interactions with both interactions (assessment, decision) over the three Levels of the VE (N=29), interactions with block types during task. Error bars represent standard errors

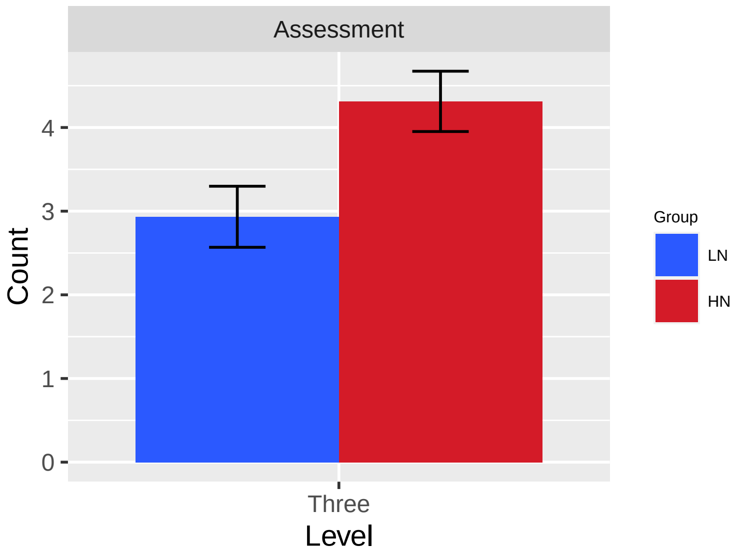

Figure 4.11: Average frequency of Assessment vs. Decision interactions over Level 3 of the VE (N=29), increased assessment behaviour for neurotic trait. Error bars represent standard errors

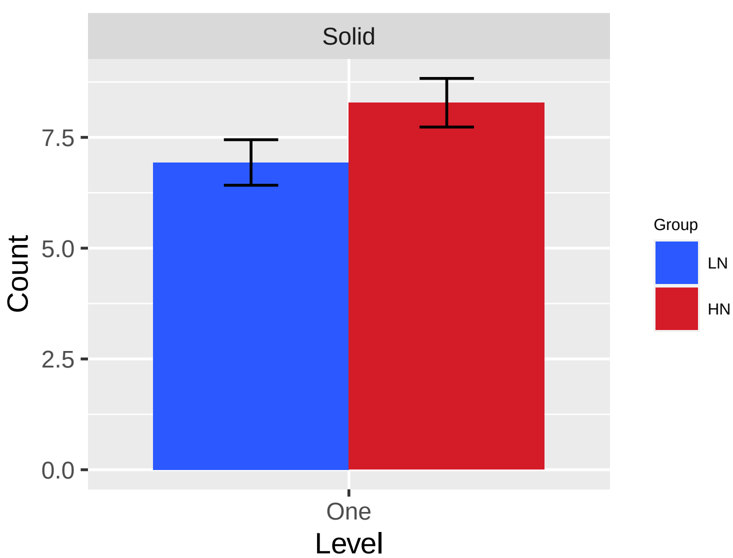

Figure 4.12: Average frequency of one-footed vs. two-footed interactions over Level 3 of the VE (N=29), increased interaction with solid unthreatening blocks for neurotics. Error bars represent standard errors

after the interaction were then subtracted from the pre-event average to create two post event change scores (Period 1, Period 2).

Period 1 = Average during 0-750ms after Interaction - Pre-Interaction Average Period 2 = Average during 751-1500ms after interaction - Pre-Interaction Period

These two periods of data were then subjected to a 2 (High/Low Neuroticism) x 2 (Context) x 2 (Period) ANOVA.

4.4.2.1 SCL (Skin Conductance Level)

There were no statistically no significant effects from the 2 x 2 x 2 ANOVA conducted on the SCL data.

4.4.2.2 Corrugator Supercilii

There were no significant main effects in the 2 x 2 x 2 ANOVA conducted on corrugator data. However, the analysis revealed a significant three-way interaction [F=(1, 27) = 5.18 , p = .031, eta^2 = .161]; post-hoc t-tests confirmed that corrugator activity was higher during the post-event period for risk assessment actions [t(46.95) = -2.57, p 0.01] on Cracked Blocks compared to Solid blocks, see Fig 9.

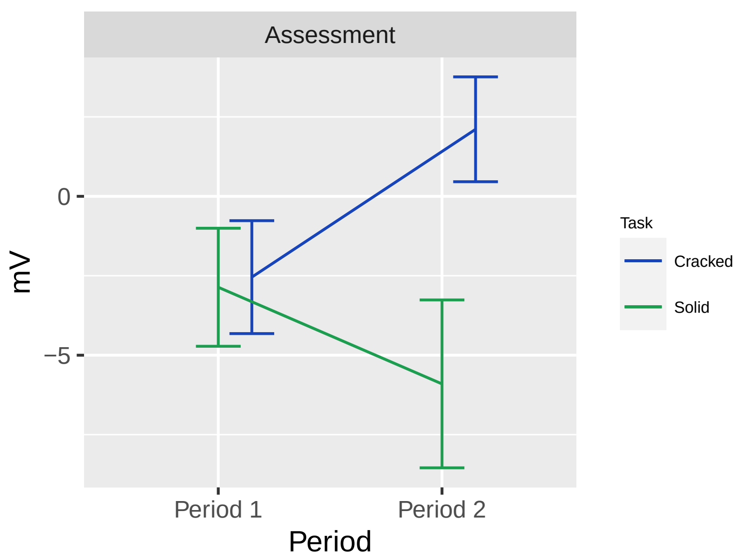

Figure 4.13: Change scores Corrugator Context vs. Block type (N=29), increased P2 corrugator response for Crack blocks. Error bars represent standard errors

4.4.2.3 Zygomaticus Major

There were no significant main effects in the 2 x 2 x 2 ANOVA conducted on the zygomaticus data. There was a significant effect for Period and BlockType [F=(1, 27) = 5.02 , p = .033, eta^2 = .157] and a significant three way interaction [F=(1, 27) = 4.59 , p = .041, eta^2 = .161]; post-hoc t-tests revealed that the zygomaticus activation significantly increased between Period 1 and Period 2 when participants interacted with a cracked block, irrespective of Context [t(94.33) = -1.95, p 0.05], see Fig 10.

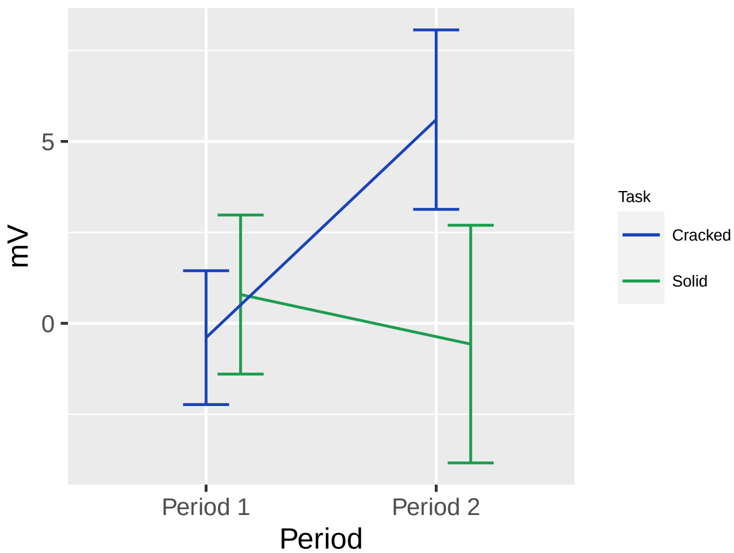

Figure 4.14: Change scores Zygomaticus Cracked vs. Solid blocks, increased zygomaticus response for Crack blocks at P2. Error bars represent standard errors (N=29)

4.5 Discussion

4.5.1 Summary of Results

The decline in Fall Block activations indicate that the studies highest threat situation led to more risk averse behaviour and a subsequent decline in fall block activations by L3 despite there being an increased number of fall blocks at L3. It could also indicate that the Fall Block mechanic was an effective means of inducing threat regardless of personality group (High neurotic, Low Neurotic).

The Corrugator Supercilii showed a significant interaction for Block Type, Context (Risk Assessment, Risk Decision) and Period (Post event period 1, Post event period 2). The corrugator was more activated during the second post event period for Cracked blocks than for the same period on Solid blocks. We theorize that this may be indicative of a negative response to the block cracking. This response could be caused by the 500ms delay in the interaction with the Crack block and the animation of the ice cracking and accompanying ice cracking sound effect (Fig. 4.13). This delay was introduced to make the interaction with the block more realistic and only occurred during risk assessment actions with Crack blocks - a negative response to a block that was not Solid.

The Zygomaticus Major data showed a significant interaction for Period and Block Type and a significant interaction between Context, Period and Block Type. Zygomaticus activity significantly increased between Post event period 1 and Post event period 2 when the block was Cracked. We theorize that this may be due to a grimace response to the cracking of the block. Anecdotally it could be due to increased vocalization during participant interactions with this more threatening block type. There were two categories of behavioural data. The Timing data showed that participants spent significantly longer standing on blocks during Level 3 when threat level was maximal. Unsurprisingly, we also found that: (i) participants favoured standing for longer periods on the Solid blocks throughout the course of a trial and (ii) participants spent significantly longer standing on Solid blocks during Level 3 . This finding reflects the fact that solid blocks were perceived as 'safe', and once identified and located, participants dwelled on those 'safe' blocks, particularly during Level 3 when the threat level was highest. Participants also spent a statistically significant longer amount of time standing on the Cracked blocks at

Level 1. This finding suggests that a degree of perceived threat can be tolerated before the hypothesised Negativity Bias effect manifests itself. It could also suggest a novelty effect, testing the parameters of the study by “trying out” the mechanics of the environment. The greater prevalence of Crack blocks from L2 onwards could also have increased their perceived threat as participants had a much greater chance of being forced to make a two-foot interaction with a Crack block.

The Frequency data demonstrated that participants made a greater number of risk decision actions (2 feet movement to blocks) at L1 compared to risk assessment actions (1-foot movements). By Level 3 this trend had reversed and participants were making more risk assessment decisions. The increase in risk assessment decision making indicates that participants opted for more cautious, risk averse actions when the level of threat increased between Levels 1 and 3.

It was hypothesised that the high neurotic group would experience a greater negativity bias in accordance with ESM. We found evidence that the high neurotic group performed a greater number of risk assessment decisions at L3, which constituted the highest level of threat (Fig. 4.12). This finding was indicative of a strategy of carefully testing each block with a one foot prior to committing to a two-footed movement. This strategy was also manifest in the high neurotic group at L1 where threatening interactions were minimal. This indicates that; (1) threat was generally perceived as higher by the HN individuals than their LN peers, and (2) HN individuals will adopt a more risk conservative strategy, in this case, stepping on solid blocks.It should be noted that although the frequency of threatening blocks (Crack, Fall) increased with Level progression the high neurotic group demonstrated greater propensity to avoid interaction with these more threatening blocks.

The psychophysiological data consisted of fEMG, SCL and ECG datasets. Unfortunately the skin conductance levels from the SCL data showed no significant effects. The 3000ms windows for each block type interaction may have been too short a length for tonic SCL responses to show an effect.

4.5.2 Relationship to Background Research

Previous studies have demonstrated that VEs are capable of inducing reliable emotional responses. Previous literature on the study of presence in VEs has generally focused on changes to an environment. [Felnhofer et al., 2014] created a virtual public speaking scenario, participants were expected to deliver a speech in front of a simulated audience, the facial reactions of the virtual audience were manipulated to deliver positive or negative responses to the speaker. Other studies have sought to induce emotional responses via directly manipulating background environment and ambient sound in a virtual park, or by explicitly focusing on an environment inherently hostile to humans, a dark environment [Felnhofer et al., 2015, Toet et al., 2009] or the stimulation of phobias such as a fear of heights [Diemer et al., 2015] and on the use of specific actors within the VE which are expected to produce a fear response [Bouchard et al., 2008] .

All of these studies found that VR had the potential to be a useful tool to generate emotional responses. The studies focus on manipulating variables in a scenario usually by running the experience, variables changed, with a different participant. None of these studies seek to manipulate a stimulus during a study very little research has been done in this area, and none have utilised the greater potential for embodied emotion available with room-scale VR. A general focus on visual and aural stimuli also makes a participant consciously aware that a negative change has been made to an environment and any use of virtual actors human or otherwise inevitably leads to an uncanny valley dilemma. Previous research has indicated that place illusion and context plausibility can lead to realistic behaviour in virtual environments [Slater, 2009].

This study has attempted to use current technology and build on empirical research to deliver a VE that is designed to induce an embodied emotional experience that: (1) maximised presence by being room-scale and having foot-tracking, and (2) promoted agency by allowing participants to make strategic decisions. It also allows us to assess negative gradient in the context of ESM using behavioural as well as psychophysiological data as outcome measures. This study provides empirical data to support this but we believe it also provides the basis for a framework for more accurately measuring human behaviour in VEs. These methods can then be used to more accurately pinpoint time periods in an experimental trial that presence, immersion and agency all act on a subject to induce an emotional response. Other studies have attempted to ascertain whether stressful virtual environments can increase a sense of presence [Meehan et al., 2002] This study sought to isolate behaviour unique to two groups of high and low neurotics. It further hypothesized that if threat and consequential stress are forced on a subject it will be more difficult to isolate differences between the two groups.

If a study is designed to measure psychophysiological responses using a scenario that is controlled but also permits behavioural choice participants will express individual differences in personality. In essence we sought to create a scenario whereby individuals can express themselves through behavioural choices and psychophysiology, not overly restricted by experimental design. We believe this study's emphasis on agency and use of interactivity as the primary means of stimulating emotional response enhances its ecological validity.

4.5.3 Limitations and Improvements

Room scale VR, by its nature, requires the use of a physical space which corresponds to the virtual layout of the constructed VE. One of the key limitations of the study was the use of lab environment which was limited in size. At the time the study was conducted the Steam VR API maximum distance between base stations was 5m x 5m. This restriction required the design of a method to return each participant to the position at which they began the study from (see Methodology, Blue Return Circle). This undoubtedly had a negative effect on immersion, although each participant remained within a contextually correct VE. They were consciously then aware of the restrictions in both virtual and physical space. In the context of the technological and physical restrictions this method of directing a participant back to their starting position was necessary. It must be pointed out that new advances in key technologies now allow for the 'daisy-chaining' of additional base stations allowing for increased area in which room-scale VR studies can be conducted.

The physical space in which the study was constructed was also rectangular. This meant that third party applications were used to rotate the area of interaction prior to each trial run so that maximum length was given to forward movement of each participant across the array of ice-blocks to their 'goal doorway'. If a larger space were used extra lateral rows of interactive blocks could have been added increasing agency and choice or to add increased threat. Ideally the study could be modified for a larger interaction area and a participant could proceed through the Levels without the need for the redirection mechanism. The Blue Circle redirection mechanic have also introduced a variance in the level of threat each participant received as they were free to return to the Blue Circle restart point in their own time. This redirection mechanic was also used to return any participants that triggered a fall block they then had to return to the starting point of each level. This mechanic may have mitigated the effects of any threat reaction from each fall and offered a counter balance to any amount of threat a participant may be subjected to during the trial.

The psychophysiological and behavioural data showed no evidence that the increase in virtual height per level (See Methodology) had any effect on threat perceived by participants in both groups. There has been some recent research that suggests that once a level of height is reached there is no further increase in perceived threat [Wuehr et al., 2019]. This mechanic of the study may be dropped from a future version of the VE.

At the time the study was conducted technology was not available to facilitate the use of wireless head mounted displays. The headset used was tethered by wired connection to a PC in the lab environment. Although subtle we suggest that the physical drag of this wire and its interaction with the participant as they moved and turned their body during the study had a negative effect on immersion. Furthermore this wire also made frequent contact the cables connected to the wireless sensor transmitters attached to the participants body. This contact on unshielded cables used to measure fEMG responses was recorded as noise during the course of each trial. It was not possible to completely filter out this noise from the sensor data entirely and increased the variance in captured data.

4.5.4 Future Research

Future research could focus on a broader attempt to explore the use of VEs as a means to validate the posits of the Evaluative Space theorem. It would be logical to examine a contrast in behaviour between groups of participants with respect to the Positivity offset postulate of the theorem. This postulate represents a counter to the Negativity Bias postulate. It stipulates that at low levels of arousal the compulsion to approach will outweigh any desire to avoid a stimulus. We hypothesised that in line with theories of behaviour put forward by the Evaluative Space Theorem low neurotic individuals would be compelled to exploitatively navigate a low to neutrally stimulating environment. Conversely, as discussed in the prior Limitations and Improvements section there is broad scope for improvement in the experimental design of the study and its exploration of the negativity bias postulate of the ESM theory. Several flaws, if addressed, may help to remove unnecessary variance in the collected data, and maximise agency and independent action.

If the study were to be repeated it may be appropriate to screen for the effects of vertigo and high, low neuroticism. Whilst we believe it to be beyond the scope of the current research plan to examine the effects of dispensation of individuals towards vertigo symptoms who participated in the test. It should be considered when the results of the study are examined.

The behavioural data yielded by the study lends itself to further study in two main areas. If the limitation of physical space were overcome it may be possible to develop a more nuanced initial level layout that provoked low or high neurotic behaviour. Such a phase could then be used to profile candidates and then predict future behaviour and compare that with how each participant actually behaved. Furthermore, it could be possible to adapt the parameters of each trial based on early participant action. The rest of the trial could then be adjusted to create an adaptive virtual environment. Such an environment could be used to more effectively categorise the behaviour of participants or to modify the trial in an attempt to subvert the natural behavioural tendencies of a participant. This could have potential therapeutic benefits for treatment of behavioural phobias and disorders .e.g. Vertigo. VE scenarios could be developed to select for candidates who demonstrate risk-aversive or risk-taking propensity, or to stimulate and explore such behaviour if required in stressful real world scenarios.

Such a framework for recording behaviour, categorisation and for deeper understanding of human emotional responses could have applications in many non research situations. For instance training program regimes of individuals in high pressure, high risk situations. As a measure of how such individuals respond to such situations and as a measure by which it could be predicted how individuals may respond to repeated exposure to such situations.

4.5.5 Conclusion

Psychological models of threat can be tested in an embodied room scale VE which is realistic enough to create a sense of presence and agency for the participant. We believe that the empirical evidence demonstrated by the study in most cases supports our hypotheses. In particular, the response of the high neurotic group to an increasing level of threat in a VE. The results of the study also suggest that behavioural data could be utilised in conjunction with psychophysiological data to increase the richness of the dataset.

Moving forward, it is conceivable that the demonstrated methods could be used in a more complex VE scenario built to examine negative emotional states in greater fidelity or similarly applied to the study of positive emotions. It must also be said that the methods also reduce the technical debt undertaken by psychological researchers in more accurately measuring human behaviour when compared to the software and practical constraints of comparable technologies e.g. motion capture. The accuracy of the behavioural tracking data the study has obtained may actually be superior to any methods that, to our knowledge, have previously been used in psychological studies. Furthermore we suggest that when used together with psychophysiological data the capacity for comparison and correlation between the two forms of data capture enhances the detail obtained from this study and any future study.

Chapter 5

Study Three

5.1 Abstract

Building on the study completed in Chapter 4 we seek to further analyse the effects of room-scale VR on threat perception by utilising a larger physical space and advances in room scale VR technology to increase the scale of the VE design. Unreal Engine was again used to design a custom virtual environment (VE) with two conditions one at ground level and the second at 75 virtual meters. Participants were required to cross a floating grid of ice blocks presented at each condition. The larger physical space allowed for three times the number of interactive blocks compared to the previous study (Study 2: 48 blocks, Study 3: 144). During this study participants were exposed to low, medium and high threat (N=20, Age M=25.5 SD=5.75). The threat blocks were divided into Sections of 16 blocks three of these Sections formed a Stage. This study attempted to increase perceived threat according to the negative gradient (Stage 1), maintain that perception of threat (Stage 2) and then reduce that threat in order to demonstrate a reversal of the negative gradient (Stage 3). Psychophysiological data were collected from two channels of facial electromyography (Corrugator Supercilii and Zygomaticus Major).The results indicated some evidence for the negative gradient. risk averse behaviour increased for the Height condition vs. Ground and was enhanced by increasing the threat via interactive block mechanic. Additionally results showed that this negative gradient can also manifest itself on a receding scale of threat valence if perceived threat is bidirectionally modulated by altering threat perception during a VR task. The chapter will then outline how the psychophysiological and behavioural data can be used in combination to gain macro and micro insights into participant behaviour in laboratory conditions and how this behaviour can be manipulated bidirectionally via the use of large-scale VR tasks.

5.2 Introduction

This study attempted to observe both a rise in negative gradient and a subsequent fall through the manipulation of threat stimuli. The ESM proposes that negative stimuli provoke an avoidance response and that for relative levels of activation the response to negative stimuli will be greater causing an increased propensity for avoidance behaviour [Cacioppo et al., 2012]. This negativity bias (Fig. 5.1) may confer an evolutionary advantage to an organism sensitising it towards potential sources of threat in an environment. This behavioural advantage should also operate when perceived environmental threat levels are decreasing. i.e. an organism will show less propensity for avoidance behaviour when the level of negative stimuli in an environment is perceived to be in decline, i.e. an opposite curve for the negative gradient (See Fig. 6.3). To our knowledge no research has been conducted which has attempted to modulate threat in order to induce and dissuade avoidance behaviour in controlled laboratory conditions. To do so requires a method of reliably and consistently provoking the negativity bias response which can also be modulated to reduce perceived threat. This study utilised a VE which used a large room-scale environment to use the threat of elevated virtual height in conjunction with interactive threatening blocks to modulate the level of perceived threat in the virtual environment, this is an expansion of the paradigm used in study one, an attempt to provide evidence for a reversal of negative gradient and that negative gradient can be increased and decreased within the same VE.

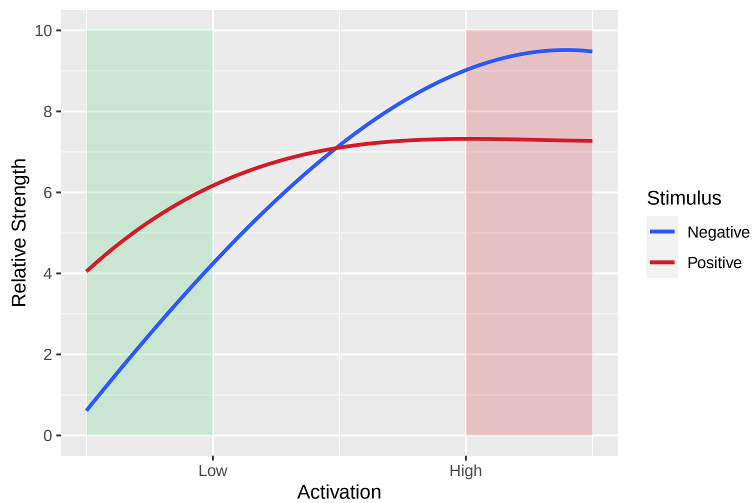

Figure 5.1: Negativity Bias, Positivity Offset

A number of studies have explored the use of virtual height as a method of inducing threat in a VE [Cleworth et al., 2012, Freeman et al., 2018, Krupić et al., 2020, Peterson et al., 2018]. Biedermann et al (2017) recreated the elevated plus maze (EPM) in a VE to study the effects of anxiety on movement in human participants, the EPM having been used to study approach avoidance behaviour in rodents for over thirty years. The study found that human behaviour was approximate to rodent responses, human participants avoided the open arms of the maze which were exposed to the height threat and spent less time at the threatening parts of the EPM [Biedermann et al., 2017]. The study design incorporated two Conditions, A Height Condition which was viewed from 75m of virtual height elevation and a Ground Condition which presented a similar VE from ground level. Perceived threat was also manipulated via three types of threatening interactive blocks; Solid (no threat), Crack (mid threat), Fall (high threat). These blocks were arranged in 9 Sections and participants were tasked with traversing this array of sections, determining the level of threat presented by each type of block via two modes of interaction; 1) Testing its threat level with a one-footed motion (Risk Assessment), 2) deciding to progress by stepping on each block with both feet (Risk Decision). The array of 9 Sections was aggregated into three Stages (Fig. 5.4), Stage 1 (Sections 1-3) manipulated the ratio of threatening to non-threatening block types to increase the negative gradient of perceived threat, Stage 2 (Sections 4-6) maintained a high level of perceived threat, Stage 3 (Sections 7-9) reduced the ratio of threatening to non-threatening blocks attempting to decrease the negative gradient of perceived threat. Perceived threat was manipulated in the current study via two mechanisms; 1) elevated virtual height between the ground level and height condition. 2) modulation of the frequency of threatening blocks i.e. both conditions of the study increased and decreased the number of threatening blocks across the Stages of the task and the height condition contained a further threat potential via the presence of Fall blocks within the most threatening Sections.

In order to accomplish the goal of the study to modulate perceived threat and observe a rise and fall in negativity bias it was necessary to utilise a larger physical environment which was enabled by advances in room-scale virtual reality technology. Room-scale VR can enhance a sense of place [Quigley et al., 2013, Slater and Wilbur, 1997, Slater, 1999] immersion can be further enhanced by interactive mechanics that allow for user initiated actions [Slater, 2009] giving a participant greater agency within the VE. Wireless technologies can also be used to eliminate headset cables, which can interrupt immersion and inhibit wearable sensors capacity to capture psychophysiological data. The researcher can also use the larger VE volume to observe behavioural responses over the course of a longer trial period in which the participant can naturalistically explore a VE. In summary in order to observe the modulation of negativity bias the study design required 1) a large physical environment 2) a VE design which could utilise the physical space to facilitate the modulation of perceived threat 3) advances in VR technology which would allow for wireless data capture in the controlled environment and enhance the immersion potential of the VE.

The primary objective of the study was to construct two VEs which would reveal how the two Conditions overall threat level worked in conjunction with a modulation of user instigated Risk Assessment and Risk Decision actions to create an observable modulation in negativity bias within each Condition of the study. Analysis of behavioural and psychophysiological would then reveal how the design of the study manipulated threat perception and provoked risk avoidance behaviour within a room-scale VE constructed to utilise a large scale controlled environment. It was hypothesised that for the Height Condition of the study the elevation threat would induce an increased level of Risk Assessment (one-footed) behaviour than for the Ground Condition. It was also hypothesised that participants would move more slowly at the Height Condition. The study employed a counterbalanced design which could generate a transfer effect, participants who undertook the Height Condition prior to the Ground could exhibit less risk averse behaviour and move more rapidly at the Ground Condition. Any transfer effect would have to be considered at the analysis phase.

The hypotheses for study three were;

(1) At Stage 1 when the negative gradient was increasing participant propensity for risky behaviour would reduce, the corresponding increase in Risk Assessment behaviour and indirect route between Sections reducing their speed of movement.
(2) At Stage 2 where threat level was maintained participants would maintain a relatively high level of risk averse behaviour and reduced speed. It was hypothesised that at Stage 3 the reduction in threatening block types would reverse the trend in behaviour and a decreasing negative gradient would be observed. (3) Observable trends in behaviour across the Stages would be reduced at the Ground Condition where there was no threat of elevation and none of the Fall blocks, the most threatening block type, in any of the Stages of the study.
(3) Analysis of the fEMG data would reveal increased corrugator and reduced zygomaticus activity for the Height Condition. It was also hypothesised that corrugator activity would increase during Stage 1 of the study, a greater amount of corrugator activity vs. zygomaticus would be observed at Stage 2 and a reduction in corrugator activity at Stage 3 would be observed. Additionally it was hypothesised that zygomaticus activity would correspondingly decrease across these Stages of the study as perceived threat level increased.
(4) For individual threat block interactions it was also hypothesised that there would be an increase in corrugator activity vs. zygomaticus when participants revealed a Crack block during a Risk Assessment action and an increase in zygomaticus activity when participants' Risk Assessment actions revealed a Solid block. For Risk Decision actions it was hypothesised that when participants stepped on Solid blocks with both feet there would be an increase in zygomaticus activity and a reduction

Table 5.1: No. of Block types per Section/Stage

Stage	Section	Solid	Crack	Fall
1	1	13	3	0
	2	9	6	1
	3	4	8	3
2	4	3	10	3
	5	3	10	3
	6	3	10	3
3	7	11	5	0
	8	11	3	0
	9	11	3	0

in activity for the corrugator. It was hypothesised that for Risk Decisions made on Crack blocks there would be a rise in Corrugator activity and a reduction in Zygomaticus activity.

5.2.1 Research Questions

1. Iterate on Study Two design
2. Compare height threat across two conditions
3. Increase VE size to modulate interactive (ice-block) threat, increase at onset of task, decrease at end.
4. Use behavioural measures to examine behavioural variables e.g. Risk Ratio which combine interactions to measure behavioural changes during threat modulation.

5.3 Methodology

5.3.1 Experimental Design

The study was designed as a between participants mixed measures design with two conditions of threat (Ground, Height). The conditions were delivered as separate tasks in a counterbalanced measures design. Each of the conditions contained nine Sections of sixteen threat blocks. The threat level in each Section was determined by the amount of Solid Blocks (No threat) vs. Crack Blocks (Medium threat). The Height version of the task also contained the highest threat level blocks (Fall Blocks). The first three Sections (Stage 1) were designed to increase the level of perceived threat. Stage 2 (Sections 4-6) were designed to deliver the highest amount of threat and sustain that level. Stage 3 (Sections 7-9) were designed to create a sharp drop in perceived threat before the end of each task. (See Fig. 5.4 for layout and Table 5.1 for numbers of threat blocks by Section and Stage).

5.3.2 Participants

The sample consisted of 20 participants (11 female). Participants were selected from an age range of 18-35 years and prescreened for conditions such as epilepsy and any disorders which may inhibit their ability to move freely within the study environment.

5.3.3 Apparatus

The HTC Vive Pro virtual reality headset was used by each participant as they navigated through the custom VE scenarios purpose built for this study. The HTC Vive Pro system utilises laser-based tracking via two base stations positioned at either corner of the designated interactive space due to the increased size of the available lab space two additional base stations were used and “daisy chained” together. These base stations are capable of tracking a 10m x 10m interactive zone. The participants head movement was recorded via the position of the HTC Vive Pro HMD, 2x Valve Index hand controllers and 2x Steam VR trackers attached on each foot.

The VE was constructed in Unreal Engine 4.23. All assets were purpose built for the study. The VE was rendered on a desktop PC in situ (CPU AMD Ryzen 5 3600, GPU NVIDIA GTX 1060, Windows 10 OS). Custom C++ code integrated directly into the Unreal Engine system captured interactions with VE objects and recorded time instances of interactions. Psychophysiological data was recorded at 1000Hz from the Corrugator supercilii and Zygomaticus Major via the Emteq Faceteq ambulatory psychophysiology system.

5.3.4 Virtual Environment

5.3.4.1 Two Levels of threat

The task was divided into two separate VEs. A Ground Level in which the participant negotiated the 9 sections of the task at ground Level with the Fall threat blocks replaced with Crack blocks and a second Level at 75m virtual height which did contain Solid, Crack and Fall blocks (See Fig. 5.2, 5.3)

Participants could interact with blocks in two ways, a one footed testing movement (risk assessment) or a two footed movement in which they committed to standing on the block with both feet (risk decision). These actions were recorded as Behavioural data. These actions in the VE were recorded in the physical space via steam VR trackers attached to the feet (See Methodology, Apparatus).

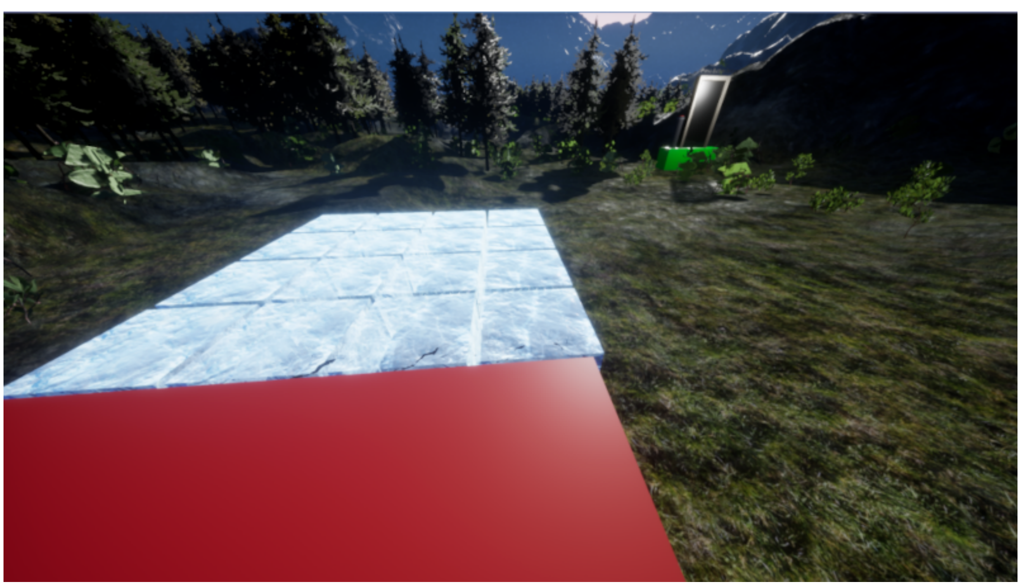

Figure 5.2: Participant view of Ground Task

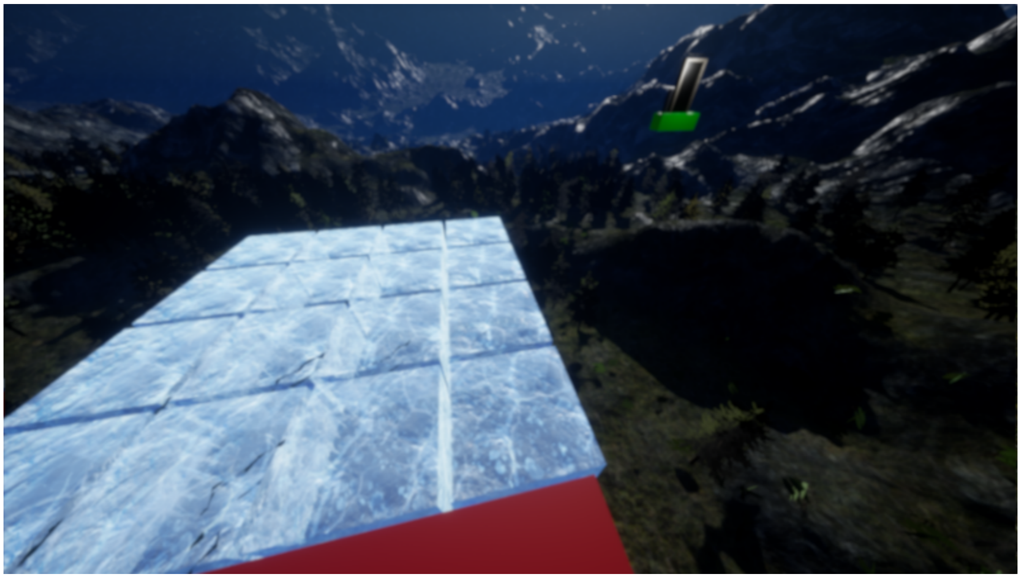

Figure 5.3: Participant view of Height Task

5.3.4.2 Three Stages of threat manipulation

Each section of the VE contained 16 ice blocks (See Fig. 5.4 for numbered Sections). The nine numbered sections created three Stages of threat. Stage 1 (Sections 1-3) was designed to increase threat and create a negative gradient. Stage 2 (Sections 4-6) was designed to increase threat beyond Section 3 of the previous stage and maintain this level of threat until Section 6, the end of Stage 2. Section 3 was designed to sharply reduce the level of perceived threat in order to create a reversal of the negative gradient.

5.3.4.3 Rising Sections and turning

Participants moved within the physical space and VE by taking an "s-shaped" course (See Fig. 5.4). Participants turned to the right to transistion between Sections 3 and 4 and to the left to transisiton between Sections 6 to 7. A visual sign prompt was generated when participants entered Section 3 and 6 to prompt this participant movement (See Fig. 5.5).

5.3.4.4 Reducing back-tracking

Each of the ice-block rows within a Section registered when a participant first stepped onto it with a two-footed Risk Decision movement. A row of ice-blocks would trigger a falling animation and fall away after a participant had stepped onto a row two rows in front of it (Fig. 5.6). This prevented a participant from turning around and back-tracking through the ice-block layout in order to prevent them from retreating into previous Sections which were perceived to be less threatening, maintaining a consistent direction towards the end goal and allowing for the modulation of negativity bias within the study design to be maintained.

5.3.4.5 Moving the goal

The visible goal doorway (Fig. 5.2, Fig. 5.3) was situated away from its final location at the onset of each of the task Conditions. It was observed during piloting that participants would attempt to step over from Section 4 to the end goal platform. In order to prevent this the goal doorway was moved and a movement animation was triggered when participants entered Section 7 moving the goal to its final position (See Fig. 5.4)

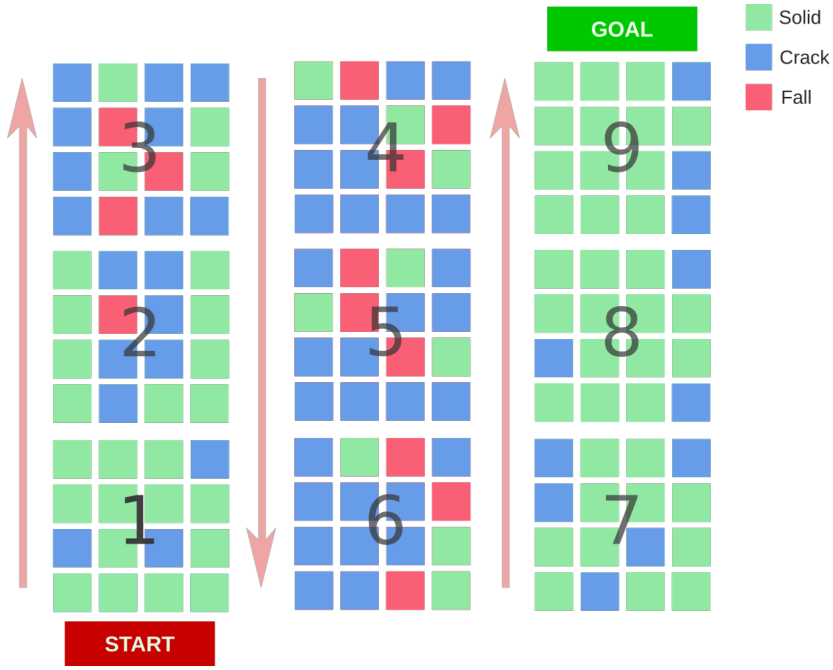

Figure 5.4: Study 3 layout, 1-3 increase threat, 4-6, maintain high threat, 7-9 reduced threat

Figure 5.5: Turn Prompt

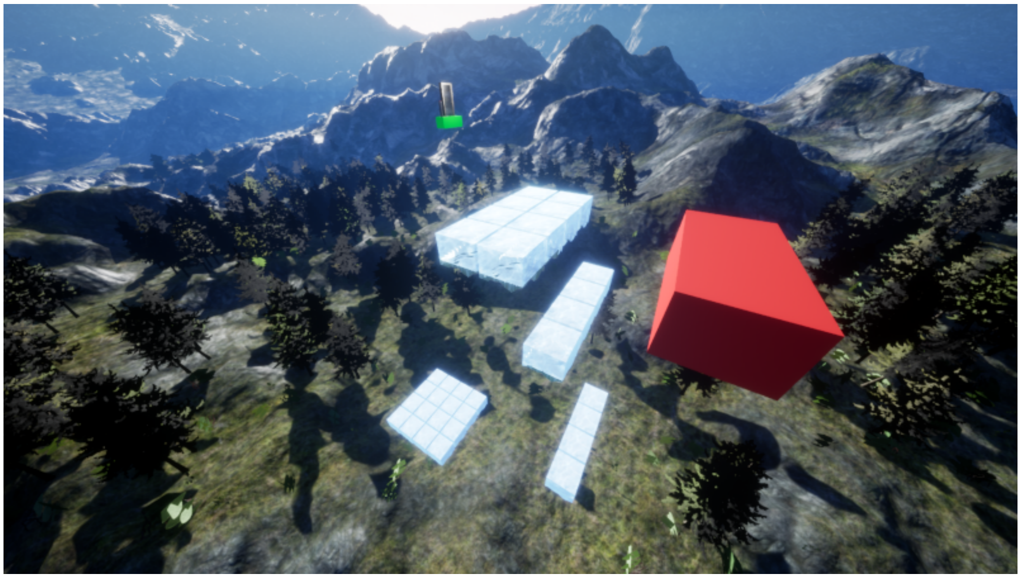

Figure 5.6: Rows 1 and 2 dropping as user moves to Section 1 row 3, Section animates upwards from below

5.3.5 Measures

5.3.5.1 Event Marking

The capture of participant movement data was logged via a custom C++ function added as a module to the Unreal Engine Editor. This function logged participants head, hands and feet movement to four decimal places of precision inside the VE sampled at 2.5Hz. These data were logged to a text file per participant and captured for use in analysis. Behavioural data captured key events in the simulation via a unique ID and time of occurrence of which could then later be used during analysis. This function was made possible via a secondary C++ custom function to track when a user passed through a certain area (e.g. doorway) or via the use of hand held controllers and the tracking sensors attached to the feet of the participant, "touched" or "stepped on" a virtual object. Logging of events linked to movement was made possible via custom trigger volumes. This Unreal Engine feature is a commonly used technique in game engines and other interactive media. It places volumes within the environment that are invisible to the user during run time. If this volume is crossed via another paired object, such as the position of the VR headset, the engine registers an event. The deployment of customised volumes allowed the C++ function to set up a list of events which a participant may or may not trigger and to record these events with precision.

5.3.5.2 Event-based psychophysiology

The data was captured in 3000ms windows. A root mean square quadratic average score was calculated from the 750ms period before the event. A second root mean square quadratic average score was calculated from the 750ms period after the event.

5.3.5.3 Facial Electromyography

Facial electromyography (fEMG) was recorded at 1000 Hz from the corrugator supercilii and zygomaticus major via the Faceteq HMD insert. fEMG data were processed as follows: (1) bandpass filter applied at 49-51 Hz to remove 50 Hz noise, (2) filtered between 20 and 400 Hz, (3) rectified and smoothed via linear envelope (9 Hz filter), and (4) subjected to root mean square transformation [Boxtel, 2001, Lajante et al., 2017].

5.3.5.4 Data Analysis

For Study Three (N=20) Each participant completed the task twice (Ground/Height) in a counter-balanced measures design. Each task (Ground/Height) was divided into three Stages which consisted of three Sections (16x threatening ice-blocks), Stage 1 (Sections 1-3) when perceived threat level was increased (~2min), Stage 2 (Sections 4-6) when when perceived threat level was maintained at a high level (~2min). Stage 3 (Sections 7-9) when perceived threat level was reduced (~2min). Psychophysiological changes in fEMG response, EDA and ECG could be compared across these three Stages (1-3) and in each of the Sections (1-9). The time-series psychophysiological data was further subdivided by periods spent on each ice-block type (Solid/Crack/Fall) and the movement action subdivided into two groups (1-foot, 2-foot). One footed movements to a block type were considered a "checking" or Risk Assessment action. Two-footed movements were considered to be a commitment to moving onto a block or a Risk Decision action. For Study Three data was analysed using R [R Core Team, 2021] and SPSS [IBM Corp., 2017].

5.3.6 Procedure

Before the experiment began, each participant was presented with an information sheet that explained the procedures that would be followed, and what would be required of them during the study. The participant then signed a consent form, and was familiarized with the lab space and introduced to the room-scale VR sensors. Following familiarization, the participant was told how physiological sensors would be attached, the sites were then cleaned with abrasive gel and conductive gel applied, ECG sensors were then attached if required and fEMG sensors were attached to the face via the Biopac device or integrated Emteq headset inlay. Before the commencement of each study sensor responses were tested and adjusted.

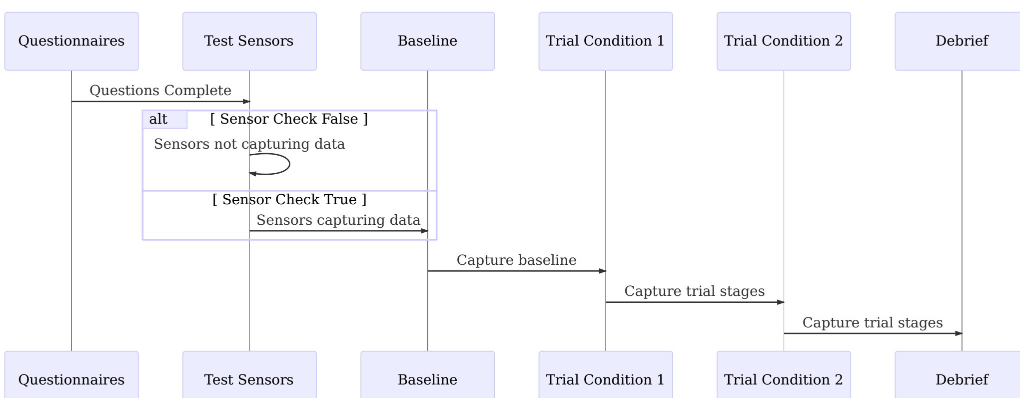

Figure 5.7: Illustration of data collection protocol

5.4 Results

5.4.1 Behavioural Data

5.4.1.1 Timings

The average time spent by participants (N = 20) standing on Solid blocks at Height and Ground Levels (Condition) during each Stage (Sections 1-3, 4-6, 7-9) of the study was subjected to a 2 (Condition) x 3 (Stage) ANOVA. There was no main effect for Condition [F(1,19) = .145 , p = 0.71]. There was no significant interaction. There was a main effect for Stage [F(2,18) = 3.97 , p = 0.04, eta^2 = 0.31], i.e. participants spent less time standing on Solid blocks at the third stage of the study when the perceived threat level was minimal. Subsequent post-hoc t-tests revealed that participants spent less time on average standing on Solid blocks during the third Stage of the task than at Stage 1 [t(2) = 2.37, p =.03] or Stage 2 [t(2) = 2.52, p=.02] (See Fig. 5.8).

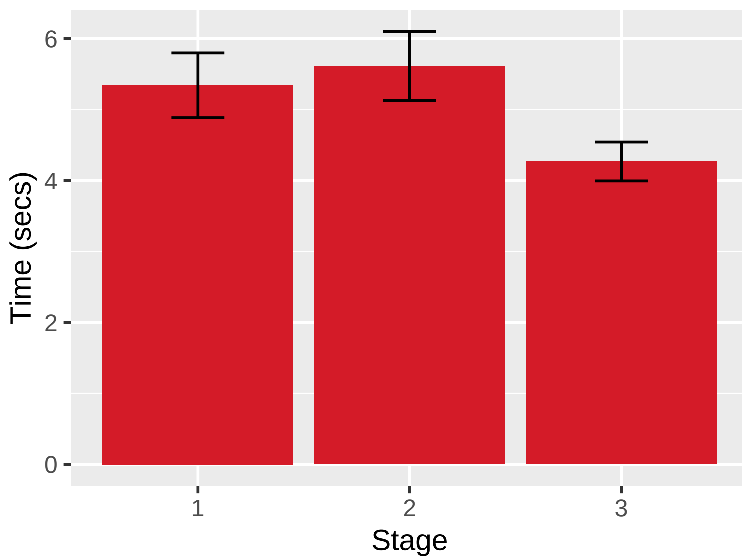

Figure 5.8: Average time spent in Stages, reduced time in stage three of task. Error bars represent standard errors

The time each participant (N = 19; one participant omitted due to technical error) took to complete each Section (Sections 1-9) at Height and Ground Levels (Condition) of the study was subjected to a 2 (Condition) x 9 (Section) ANOVA. There was no main effect for Condition [F(1,18) = .40, p = .54]. There was a main effect for Section [F(8,11) = 3.97 , p = <.01, eta^2 = .90]. Post-hoc t-tests revealed that participants spent significantly less time in each condition at Sections 7,8 and 9 (See Fig. 5.9).

Post-hoc t-tests also revealed that participants spent significantly less time at Section 4 [t(18) = -2.2, p=.04], Section 5 [t(18) = -2.6, p=.02] and Section 9 [t(18) = 2.3, p=.04] at the Height Condition, i.e. Participants spent significantly more time in the most threatening Sections of the Height task. This behaviour was reversed at the least threatening part of the Ground task, Section 9 (See Fig. 5.10).

5.4.1.2 Risk Ratio

The sum of the first type of interactions with blocks during the task, one-footed Risk Assessment was calculated for each participant. The sum of the second type of interaction, the two-footed Risk Decision was also calculated for each participant. The sum of Risk Assessment interactions was then divided by the sum of the Risk Decision interactions and a Risk Ratio was calculated for each participant during each Section (1-9) of the task.

The Risk Ratio data were subjected to a 2 (Condition) x 9 (Section) ANOVA. There was a significant main effect for Condition [F(1,19) = 8.86 , p <.01, eta^2 = 0.32] and a significant main effect for Section [F(1,12) = 8.06 , p <.01, eta^2 = 0.84]. i.e. participants made more risky decisions at Sections 7, 8 and 9 when perceived threat was at its lowest, in addition there was a pronounced increase in risky decisions at Section 5 (See Fig. 5.11).

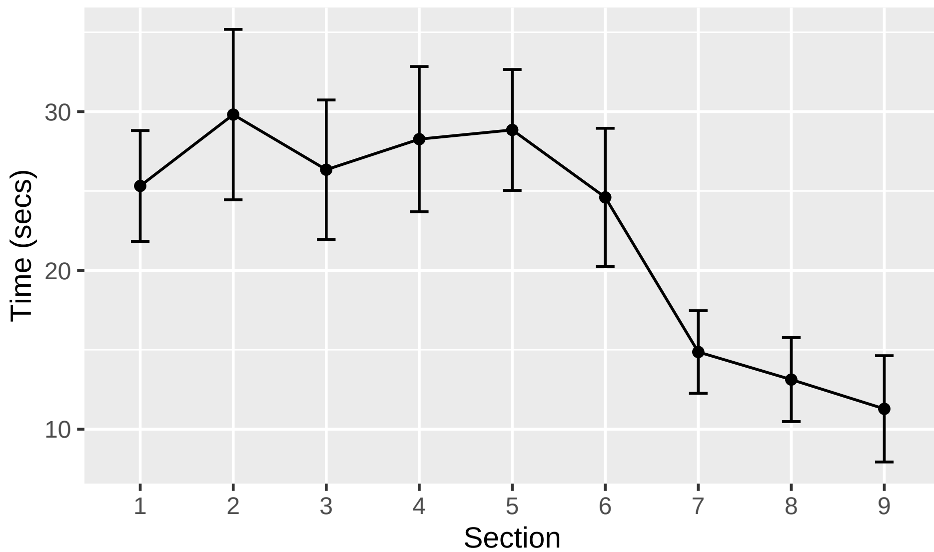

Figure 5.9: Average time spent in Sections. Error bars represent standard errors

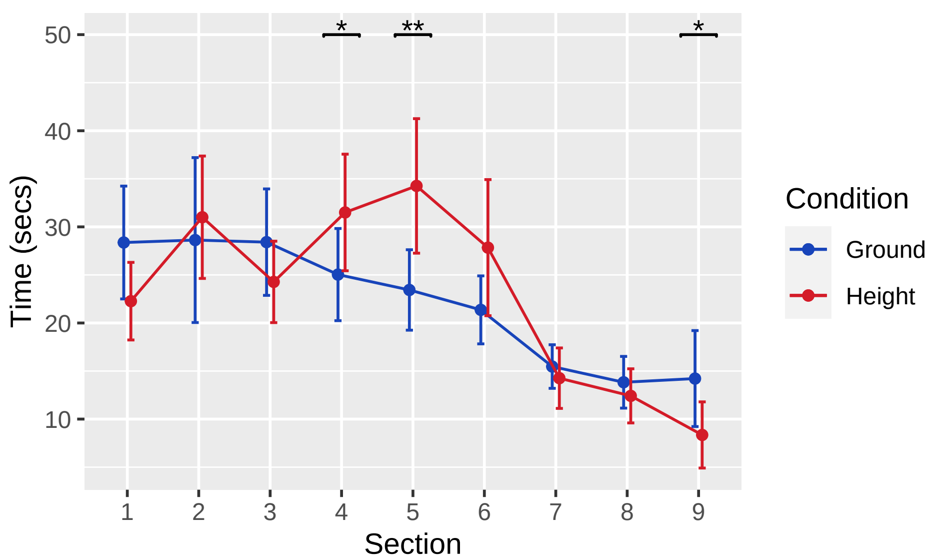

Figure 5.10: Average time spent in Stages by Condition. Error bars represent standard errors

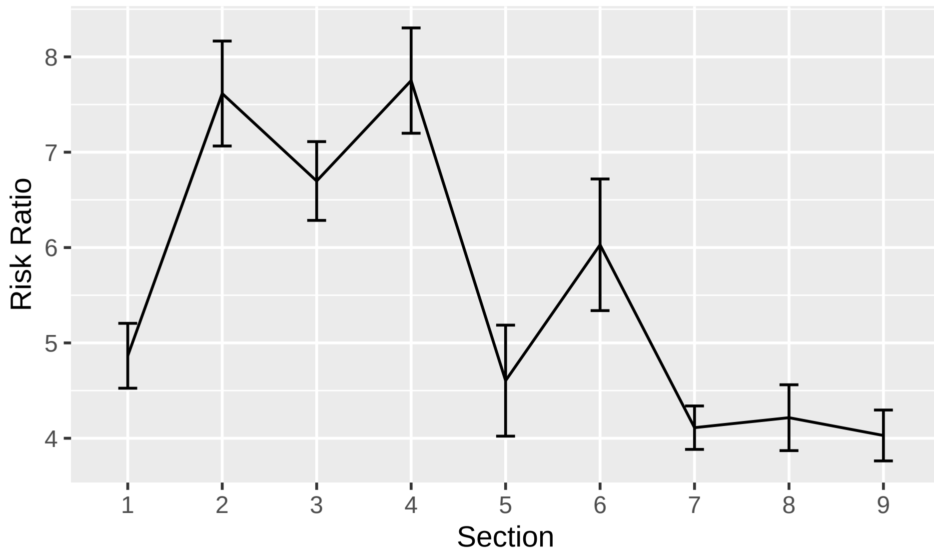

Figure 5.11: Risk Ratio in Sections. Error bars represent standard errors

There was also a significant interaction between Condition and Section [F(1,12) = 5.7, p <.01, eta^2 = 0.79], which is illustrated in Fig. 5.12. Post-hoc t-tests revealed that participants made less risky decisions the Height condition at Sections 2 [t(19) = -3.81, p <.01], 5 [t(19) = -4.96, p <.0001] and 6 [t(19) = -3.62, p 0.002]; see Fig. 5.12 for descriptive statistics. In addition, Risk Ratio was significantly lower at Height compared to Ground Condition at Section 9 [t(19) = 2.24, p <.03].

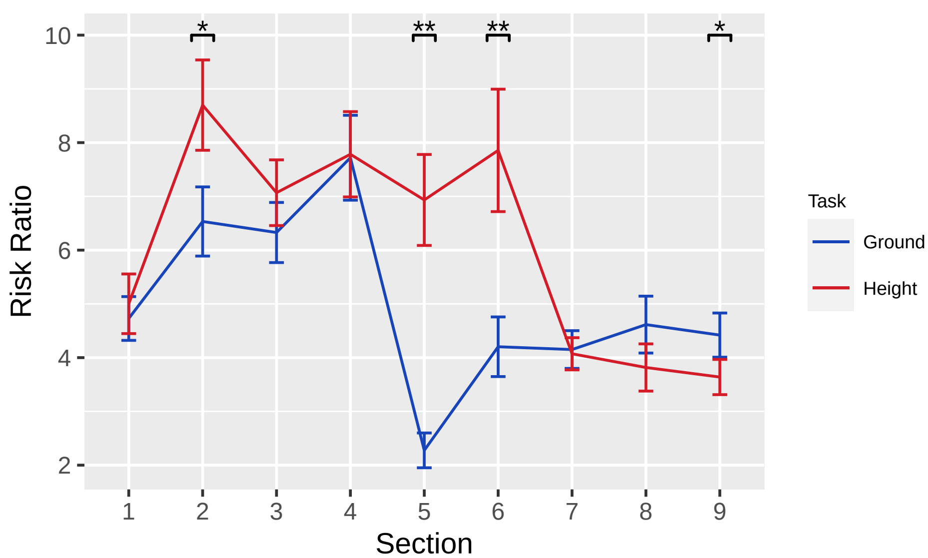

Figure 5.12: Risk Ratio in Sections by Condition. Error bars represent standard errors

5.4.1.3 Negative Gradient

A slope for Risk Ratio scores over Sections 1-4 was calculated for each participant for the Ground version of the task. A slope for Risk Ratio scores for Sections 1-4 was calculated for each participant for the Height task. These slopes were subjected to a two-way ANOVA. There was an insignificant effect for Condition (Height / Ground) [F(1,19) = .34 , p = 0.57]. A slope for Risk Ratio scores for Section 6-9 was calculated for each participant for the Ground version of the task. A slope for Risk Ratio scores for Section 6-9 was calculated for each participant for the Height task (See Fig. 5.13). These Sections of the task were subjected to a two-way ANOVA. There was an effect for Condition [F (1,19) = 22.2 , p = <.01, eta^2 = 0.54]. Post-hoc t-tests revealed a significant difference between the Height and Ground versions of the task during these final Sections [t(19) = -3.62, p<.01] i.e. when the Risk Ratio slopes were increasing during the initial Sections of the task participants became more risk averse to a similar extent. In the latter Sections of the task when threat levels were decreasing participants became significantly less risk averse in the Height task.

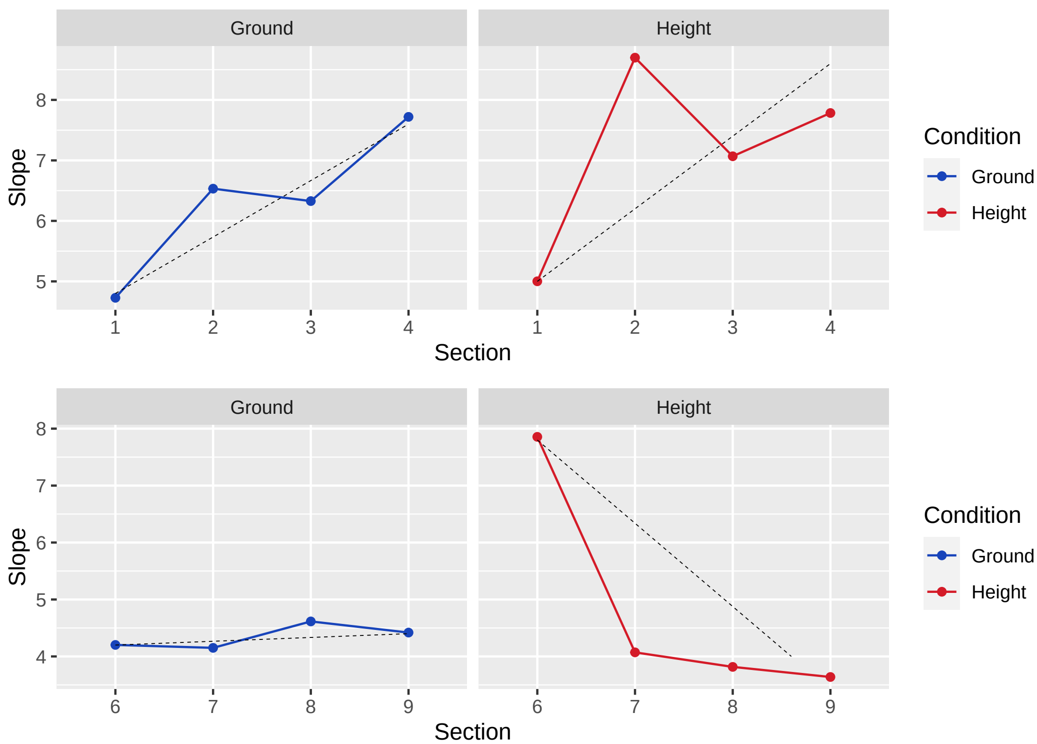

Figure 5.13: Negativity Bias Slope Sections 1-4 and 6-9 by Condition, increasing slopes for initial sections at Ground and Height, reduced slopes at later sections for Height only

5.4.2 Psychophysiology Event Related Analysis

Psychophysiology data was captured in 3000ms windowed time periods. An root mean square (RMS) pre-event period (750ms) before the interaction was calculated. An RMS post-event period (750ms) after the interaction was calculated. A participant was removed from the dataset (N=19) as they did not commit to any Risk Decision actions on Crack blocks during the study.

Period 1 = RMS 750ms before Interaction.
Period 2 = RMS 750ms after interaction

5.4.2.1 Risk Assessment interactions

Corrugator supercilii Period 1 and Period 2 RMS data for Risk Assessment interactions with Solid and Crack Blocks during the Ground and Height versions of the task were subjected to a 2 (Condition: Height / Ground) x 2 (Block: Solid / Crack) x 2 (Period 1, Period 2) ANOVA. There were no significant main effects for Condition [F(1,17) = 4.41 , p = 0.51], Block [F(1,17) = 1.77 , p = 0.2] and Period [F(1,17) = 0.87 , p = 0.36]. There was a significant interaction between Condition and Block [F(1,17) = 8.07 , p < .011, eta^2 = 0.32]. Post-hoc t-tests revealed a significant difference between the Corrugator response for Solid and Cracked blocks at Period 1 for the Height Condition [t(18) = 3.28, p=.04]. i.e. Corrugator activity was greater for the Solid blocks at Height Condition for Period 1 (See Fig. 5.14). There were no significant interactions.

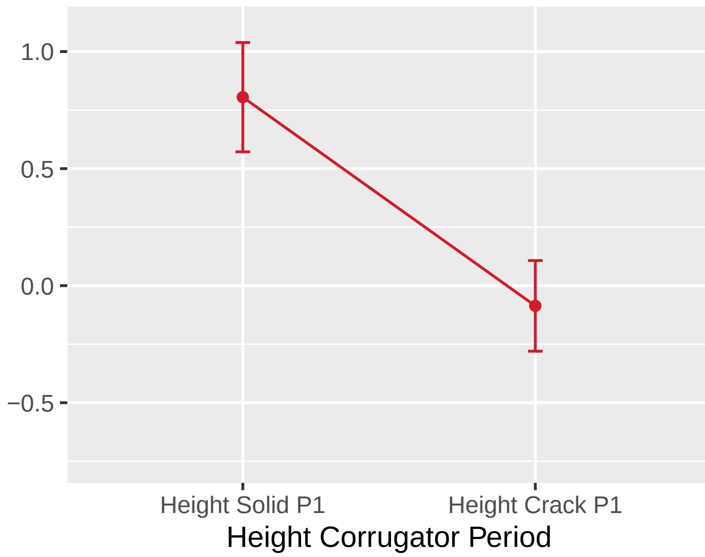

Figure 5.14: Risk Assessment Corrugator response Period 1 pre-movement for Solid vs. Crack blocks at Height Condition. Error bars represent standard errors

Zygomaticus Period 1 and Period 2 RMS data for Risk Assessment interactions were subjected to a 2 (Condition: Height / Ground) x 2 (Block: Solid / Crack) x 2 (Period 1, Period 2) ANOVA. There was a significant main effect for Condition [F(1,18) = 10.64, p <.01, eta^2 = 0.39] i.e. zygomaticus activity was higher at the Height Condition. There were no significant main effects for Block [F(1,17) = .674, p = .423] and Period [F(1,17) = .498, p = .490]. There was also a significant interaction between Condition and Block [F(1,18) = 11.9 , p 0.03, eta^2 = 0.412]. Post-hoc t-tests revealed a significant difference between the Zygomaticus response for Solid and Crack blocks at the Height Condition [t(18) = 2.39, p =.03]. i.e. Zygomaticus activity was greater for the Solid blocks at the height condition during Period 1 (See Fig. 5.15). There were no significant interactions.

5.4.2.2 Risk Decision interactions

There were no significant main effects in the 2 x 2 x 2 ANOVA conducted on Corrugator supercilii data, Condition [F(1,18) = .19, p .67], Block [F(1,18) = .003, p .96] and Period [F(1,18) = .01, p .94].

Zygomaticus data for Risk Decision interactions were subjected to a 2 (Condition: Height / Ground) x 2 (Block: Solid / Crack) x 2 (Period 1, Period 2) ANOVA. There was no significant main effect for Condition [F(1,18) = .60, p =.45]. There were significant main effects for Block [F(1,18) = 7.49, p =.014, eta^2 = .29] and Period [F(1,18) = 5.89, p =.026, eta^2 = 0.25]. i.e. Zygomaticus activity was greater when participants stood on Crack vs. Solid blocks (See Fig. 5.16) and greater at Period 1 (M = 0.84, SE = .05) vs. Period 2 (M = -.21, SE = .07).

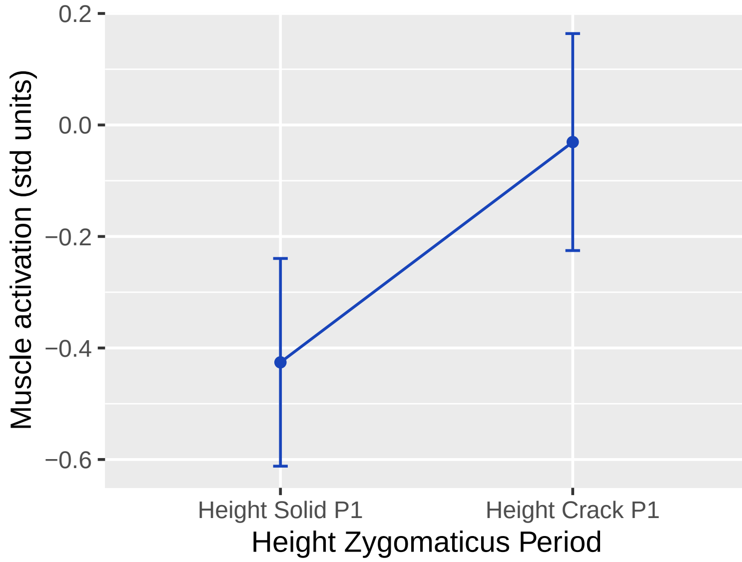

Figure 5.15: Risk Assessment Zygomaticus response Period 1 pre-movement for Solid vs. Crack blocks at Height Condition. Error bars represent standard errors

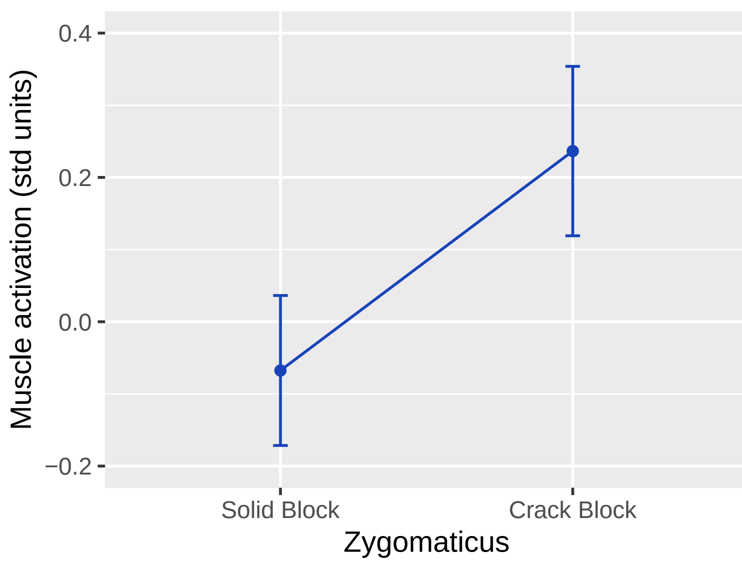

Figure 5.16: Risk Decision Zygomaticus response Solid vs. Crack blocks. Error bars represent standard errors

5.5 Discussion

5.5.1 Summary of Results

The study was designed to explore a number of hypotheses associated with the perception of threat within the VE, which were: (1) participants' perception of threat would be greater when they experienced the VE at Height vs. Ground due to elevated perspective and possibility of a fall, and this effect would be particularly pronounced during sections 3-6 where risk of fall was greatest, (2) participants' perception of threat would decrease dramatically during sections 7-9 due to decrease of Crack and Fall blocks, (3) participants would exhibit an increased negative gradient and threat perception during the first four sections of the VE due to increasing frequency of Crack and Fall blocks, but this effect would only be observed at Height, and (4) participants would exhibit a reversal of the negative gradient during sections 6-9 due to decreasing frequency of Crack and Fall blocks, but this effect would only be observed at height. These effects were investigated by tracking the speed of movement and movement strategy of our participants, we assumed that increased threat perception is associated with slower speed of movement (e.g., take longer to cross each section, spend longer standing on each block) and an increased frequency of Risk Assessment interactions, i.e., higher prevalence of checking behaviour prior to movement.

The average amount of time spent standing on each solid block was captured across the three stages of VE. We observed that participants spent significantly less time standing on these blocks during the third and final Stage of the VE presumably due to the reduction level of threat (Fig. 5.4). The Timings data by Section (See Fig. 5.12) showed that participants traversed Sections 7-9 at higher speed than all prior Sections i.e. participants spent less time in those Sections where threat was lowest. These data also exhibited a linear trend during the Ground condition as participants spent less time successively per Section during the course of the task. The same data revealed that participants spent significantly more time at Sections 4 and 5 during the Height compared to the Ground condition due to the threat of the virtual height itself and the probability of falling (See Fig. 5.13). There was also a significant difference in times between Conditions during Section 9, i.e. participants in the Height Condition spent significantly less time on Section 9 compared to the Ground Condition (See Fig. 5.13). We may assume that completing the VE during the Height condition evoked aversive feelings of anxiety compared to the Ground condition, which prompted participants to move quickly across the final section in order to terminate an uncomfortable experience.

The Risk Ratio data combined both forms of interaction (one-footed and two-footed risk assessment and decision actions) into a composite score that represented the ratio of checking behaviour to movement behaviour, i.e. a higher risk ratio = higher level of checking behaviour. The analysis of risk ratio data revealed a significant increase in risky behaviour at Sections 7,8 and 9 as well as an decrease at Section 5 (See Fig. 5.14). i.e. participants made fewer Risk Assessment actions vs. Risk Decision actions when threat was reduced the final three sections, but an erroneous decrease occurred at Section 5 when the number of cracked and fall blocks were highest. The significant interaction between Condition and Section allowed us to investigate this unexpected finding (See Fig. 5.15) and we found that participants in the Ground condition significantly decreased checking behaviour during Sections 5 and 6 compared to the Height condition; in addition, we also noted participants increased checking behaviour during Sections 2 and 3 in the Height vs. Ground condition (See Fig. 5.15). It is assumed that the combination of Height Condition with an increasing number of Crack and Fall blocks from Sections 1-3 led to the observed rise of Risk Assessments during the early part of the VE, i.e., checking behaviour only increased when Crack blocks became more frequent when there was a possibility of a virtual fall. This finding demonstrates that an increase in Crack blocks alone, without an elevated perspective/possibility of a virtual fall failed to induce any feeling of threat for participants in the Ground condition. This interpretation is supported by the significant drop in Risk Assessment actions observed for participants in the Ground condition at Sections 5 and 6 (See Fig. 5.15). A significant increase of risk ratio was also observed for participants in the Height condition during Section 9 (See Fig. 5.15). This effect confirmed that participants in the Height condition performed a lower number of checks in this final section compared to Ground condition, and this finding confirmed an increased desire to terminate the VE during the Height Condition.

The VE was constructed with increased frequency of Crack blocks over Sections 1-4 and a symmetrical decrease over Sections 6-9. These sections were designed to induce increased negative gradient due to rising threat in the early part of the VE and a corresponding decrease of negative gradient when the prevalence of Crack blocks sharply declined from Sections 6-9. This hypothesis was examined by calculating a slope over the Risk Ratio scores for Sections 1-4 and Sections 6-9. Analysis of Risk Ratio slopes revealed that participants became increasingly risk averse as perception of threat increased during the Sections 1-4 in both Height and Ground conditions (upper panel of Fig. 5.16) . When threat perception reduced in the latter Sections, the expected decline of negative gradient was only observed for participants during the Height Condition. This finding was due to a combination of risk perception being significantly increased during Sections 5-6 in the Height condition (See Fig. 5.15), hence checking behaviour substantially decreased once participants made the transition to Sections 7-9 where Crack/Fall blocks were infrequent. In addition, the decreased level of checking behaviour observed for participants in the Ground condition (See Fig. 5.15) at Sections 5 and 6 prevented any equivalent downward adjustment of negative gradient being observed (lower panel of Fig. 5.16).

Analysis of the movement data revealed that participants increased the speed of their movement during the final three Sections of each Condition due to decreased Risk Assessment behaviour. It should be noted that the perceived threat was manipulated in two ways within the VE: Elevation of view/possibility of virtual fall and configuration of Section (low vs. high probability of crack and fall blocks). These manipulations are interlinked, the Ground condition decreased initial threat perception and removed the possibility of a fall. It was this combination of elevated perspective, possibility of a fall and the increased frequency of crack blocks that was necessary to manipulate threat and produce changes in participant behaviour. Participants experienced an increasing negative gradient and a constant threat of elevation during the first four sections in the Height condition, which increased their tendency to exhibit time-consuming risk aversive behaviour, e.g. increased checking, increased decision-making time. At the Ground Condition participants displayed a different pattern. Without an elevated perspective and any possibility of a fall, participants adjusted to the VE over the first 3-4 sections and consequently participants took a direct route through the VE that minimised checking behaviour and decision-making time. Removal of Crack and Fall blocks at Sections 7-9 reduced perceived threat and the requirement for Risk Assessment actions and this pattern was observed across both Conditions. For participants in the Height condition, we observed a reversal of the negative gradient as participants transitioned from sections associated with high threat to low threat; for reasons already stated, the same pattern was not observed in the Ground condition. In addition, participants in the Height condition completed the final Section 9 faster and with fewer checks than in the Ground condition. This finding suggests that risk averse behaviour can be suppressed by close proximity to an end-goal, especially when the task was aversive and stressful.

The fEMG data were analysed separately with respect to two forms of interaction: Risk Decision (2-feet movement) and Risk Assessment (1-foot movement). It was hypothesised that corrugator activation would increase during those interactions that were negatively valenced, e.g. 1-foot/2-feet movement to crack block. With respect to the zygomaticus activation, we expected increased reactivity in positive situations, e.g. 1-foot/2-feet movements to solid blocks. It was anticipated that these patterns of fEMG activation would be more pronounced during the Height compared to the Ground condition due to increased threat. These data were analysed in an event-related fashion that included Condition, Block Type and Period (pre-movement vs. post-movement) in the analyses.

For Risk Decision interactions, we observed no significant effects for corrugator activation, which was unexpected. Contrary to our hypotheses, activation of the zygomaticus was observed to increase when participants made a two-feet movement to a Crack block compared to a Solid block (Fig. 5.16). There was also a significant decline of zygomaticus activation during the post-event period compared to the pre-event period. This pattern of results is logical if we interpret increased activation of the zygomaticus as synonymous with a grimace [Burton, 2011] provoked by anxiety. This interpretation would explain the pattern observed in our analyses, i.e., increased anxiety when making a two-footed movement to a Crack block.

Corrugator data for Risk Assessment (one-footed) interactions showed a significant interaction between Condition and Block. Corrugator activity increased for Solid Blocks at the Height Condition. This result is difficult to interpret as prior to one foot interactions taking place all blocks were visually identical, although when considered with the following Zygomaticus result it could indicate that Risk Assessment interactions with Solid Blocks were generally more affective than for other types of blocks at the Height Condition only.

Zygomaticus data for Risk Assessment interactions also showed a significant interaction between Condition and Block. Zygomaticus activity was greater for the first Period when assessing Solid Blocks with a one-footed movement at the Height Condition, i.e. participants responded positively when they had located a less threatening location to move to from their current position.

In summary the combination of virtual height threat and increasing the frequency of threatening blocks between Sections 1-6 caused participants to move more slowly in the high threat sections and provoked risk averse behaviour. For the Ground condition the absence of virtual height threat and possibility for falling meant that participants moved more quickly and made riskier decisions at ground level. At Sections 7-9 participants made more risky decisions and moved more quickly at both Conditions when the number of threatening blocks was reduced. At Section 9 participants moved more quickly and made riskier decisions due to a desire to terminate an aversive experience. An increased negative gradient was observed in both Conditions at Sections 1-4 due to the increasing threat. A corresponding decline in negative gradient was observed for Sections 6-9 but only at Height due to the high perception of threat at Sections 4-6 which was not observed at the Ground Condition.

5.5.2 Relationship to Background Research

There is a dearth of available data on approach/avoidance behaviour in humans utilising full body movement in a controlled environment. Persistent and ecologically valid threats, which also include attainable goals; avoidance of threat at the cost of achieving a goal, are difficult mechanics to balance and can present ethical issues if taken to an extreme. The vast majority of current research on emotion and approach/avoidance behaviour present stimuli from specialized media databases [Lang, 1995, Samson et al., 2016], use of confederates [DeSteno et al., 2006] or approximate behavioural responses from eye-tracking or joystick responses [Blanchard, 2017]. One exception to this statement is the experiment conducted by Biedermann et al (2017) that recreated the elevated plus-maze (EPM) in virtual reality in order to study the effects of anxiety on approach/avoidance behaviours in humans [Biedermann et al., 2017]. Biedermann et al reported that participants spent less time in those areas of the EPM associated with subjective anxiety, which is supportive of the strategy used in the current study of using patterns of voluntary movement as a proxy measure of threat perception. The response to virtual height as a threat mechanic has been frequently studied in a laboratory environment [Cleworth et al., 2012, Krupić et al., 2020, Meehan et al., 2002, Seinfeld et al., 2016] but to our knowledge no other study has attempted to utilise virtual height in conjunction with other user instigated threat mechanics to modulate the perception of threat during the course of the task.

According to the negativity bias postulate of the ESM [Cacioppo and Berntson, 1999, Cacioppo et al., 2012], adaptive responses to negative and positive stimuli are driven by the extremity of the stimulus and its relative proximity to the organism. The ESM suggests that affective cognition of positive and negative stimuli operate across a diametric scale convergent about an axis of valence, minimal activation on this scale provokes an approach response. Higher activations induce an overpowering desire to avoid the excitatory stimuli when it is negative [Cacioppo et al., 2012, pg. 54, Fig 3.3]. The study was designed to incorporate 9 Sections of ice-block threat components divided into three Stages. Stage 1 increased perceptual threat hypothesising that avoidance behaviour would increase during this phase leading to an increased negativity bias. Stage 2 sustained a high level of threat. Stage 3 reduced the number of Crack block components and removed the Fall block components. It was hypothesised that at Stage 3 a reversal in the negativity bias would manifest itself in the form of reduced avoidance behaviour. The study was also separated into two trial conditions, Height and Ground, the Ground condition removed the virtual height threat and contained no Fall blocks. Evidence was found for an increase in negativity bias at Stages 1-3 but it was only maintained at the Height Condition. As the level of perceived threat fell at the Ground Condition participants became less risk averse

We suggest that the ESM postulate of Heteroscedacity [Cacioppo et al., 2012, pg. 4 table 3.1] could explain this behaviour. The postulate states that negative stimuli produce an increased range of responses and that in the absence of threat “staying the course” is sufficient. At this point in the task participants had exhausted the moderately negative stimulus response presented by the Crack block component. The absence of virtual height threat reduced the overall threat perception at this Condition and at this point in the task, due to the rise in the number of Crack blocks at this Stage, participants would be fully aware of the limited threat this mechanic exposed them to. In effect participants no longer felt the need to adapt their behaviour to further discovery of this mechanic and could take the most efficient path towards the visible goal doorway; staying on the course. Behavioural convergence at Stage 3 of the task suggested that, at the Height Condition when the threatening block mechanic was reduced the elevated height of the study was not sufficiently threatening to induce risk averse behaviour. In addition behaviour at Section 9 suggests that the prior appraisal of threat in an environment can modify the individuals perception of immediate threat when a goal becomes attainable and the remaining stress factors are less significant in the context of what has already been endured.

Activation of the zygomaticus major is consistently associated with positive emotions, while activation of the corrugator supercilii muscle is associated with the unpleasant and attenuated by pleasant emotional states [Lang et al., 1993, Larsen et al., 2003, Sato et al., 2013, Tan et al., 2011]. The results of this study do not support the traditional association of zygomaticus with positive valence. For the Risk Decision data zygomaticus levels increased when participants stepped on Crack blocks with both feet at both the Height and Ground and zygomaticus levels were greater for the pre-event period. This finding could indicate an anticipatory grimace response as participants make a potentially risky decision to step on a Crack which could be a Fall block. Contextual threat could provide some explanation for this finding, a number of studies have demonstrated that zygomaticus response to stimuli can be ambiguous and context dependent [Burton, 2011, Golland et al., 2018, Martin et al., 2017]. The Risk Assessment interaction was inherently less risky than a Risk Decision action, a Crack block if revealed increases the level of immediate threat to a participant but this threat is contextual. A Crack block is less threatening to a participant if it is in the immediate proximity of a Solid block or multiple

Solid blocks as a participant will have a clear route to avoid further interactions with this block and not need to make a Risk Decision action that could result in stepping onto a Fall block. The psychophysiological data for Risk Assessment showed a significant increase in corrugator level and a decrease in zygomaticus level for the pre-movement period (P1) when a participant moved to assess a Solid block at the Height Condition. This finding runs contrary to the hypothesis and is difficult to explain, by design before a Solid or Crack block is interacted with they are identical in appearance.

5.5.3 Limitations and Improvements

The study was designed as a repeated-measures experiment where participants served as their own point of comparison, however, this design of the study could have led to a transfer effect. Participants who conducted the Height Condition before the Ground condition may not have been as susceptible to the rise in negativity bias during the first Stage of the Ground Condition. The rapid decline in the Risk Ratio data that was observed at Stage 2 during the Ground Condition (See Fig. 5.12) and unexpected zygomaticus and corrugator effects for Period on Crack blocks (Fig. 5.14, Fig. 5.15) could have been caused by transfer effects. Post-hoc ANCOVAs were conducted to examine movement data using the order of presentation as a covariate. No evidence emerged from these analyses that order of presentation exerted any influence on those significant effects reported in the Results .

In future tasks using a similar VE it would be beneficial to control for inter-individual variability in movement strategy, the design of the study could be supplemented through the use of a tutorial/acclimitisation stage undertaken before either of the Condition tasks. This short task would be conducted in a VE at Ground level and introduce participants to the layout of one of the 16 block Sections in the forthcoming study. The tutorial would illustrate how participants could move through the environment and how one-footed/two-footed movements interact with Solid and Crack blocks. This tutorial task data could then be used for additional base lining of the fEMG data and serve as a reference upon which to measure their rate of movement and propensity to risk aversive behaviour in the absence of elevation threat.

Evidence observed for a rise in negativity bias at Stage 1 and the reversal of this bias at Stage 3 indicated that the design of these Stages was successful. Stage 2 maintained an elevated threat level at the Height Condition only (Fig. 5.10) and risk averse behaviour was reduced for participants at the Ground Condition (Fig. 5.12). Analysis of negativity bias revealed that at the Ground Condition participants threat perception was reduced after Section 5 (Fig. 5.11, Fig. 5.12), this may have been due to participants realising that the Crack blocks alone hold no threat during this condition of the task; essentially, without the virtual height mechanic and fall threat the Ground condition interactions with solid and crack blocks are no longer interesting to the participant. A redesign of the block layouts for each Condition could have extended the rise in negativity bias to an additional Section; Sections 1-5. A reduction in negativity gradient could then have been designed for Sections 5-9. Such a redesign would have resulted in a more gradual rise and fall in perceived threat. These changes to the design may have revealed an observable declining slope for the negativity gradient at the Ground Condition.

For the Risk Ratio data at Section 9 participants demonstrated an increased propensity for risky behaviour, greater than for Section 9 at the Ground Condition. It was hypothesised that this behaviour is due to the close proximity of the goal doorway and a desire to terminate the stressful VE. The mechanic of the study design which moved the doorway into its final position (See. Methodology, Moving the Goal) could have been altered so that the doorway was in its final position only when participants entered Section 9. This change could have removed the effect of proximity to the goal and the effect of declining negative gradient observed without this complication. Goal proximity and its mitigating effects of threat could be modulated in this way in future controlled environment studies.

5.5.4 Future Research

The Study utilised very recent developments in VR delivery technologies to maximise the spatial area available to conduct a trial. The virtual reality lightboxes (See Ch. 2 Methodology) were "daisy-chained" together. Increasing the number of these devices from two to four doubled the available spatial area in which a study could be conducted. This allowed the design of the study to build on current research techniques in room-scale VR. Physical barriers such as laboratory walls were less of a hindrance upon study design and hazard for participants. Future studies could increase the number of lightboxes allowing for an even larger area in which to modulate threat perception. Modulation of threat could then be altered allowing for repeated rises and declines in negative gradient. In this way a future study could attempt to observe how many peaks and declines it is possible to observe, or if there is a limit on how many modulations are possible before a participant becomes acclimitised to threat.

A future study could also consider adding in interactive blocks which produce positive stimuli with consideration to the positivity offset effect of the ESM. An additional interactive block could be designed to produce a positive sound when stepped on as an audio cue and/or visually appear to change from ice to a solid material (stone, metal). These blocks could be introduced at the Section level, designed to produce a positively offset Stage or to add a third Condition to the study. It could also be possible to use these blocks as a mechanic to mitigate the threat of falling; if discovered by a participant they could trigger the destruction of any fall blocks in that Section leaving empty gaps in the layout that participants could easily avoid. This would alter the Risk Ratio equation into a Risk Reward Ratio.

5.5.5 Conclusion

Psychophysiological responses to threat perception can be studied in a VE that utilises current advances in VR technology to allow for modulation of threat perception within a discrete room scale environment. The redesign of the study two experiment for a larger laboratory size and expansion of the study three VE layout. Empirical evidence discovered by this study supported our hypotheses. Stage 1 of the study demonstrated that a negativity bias can affect movement speed and induce risk averse behaviour. Stage 3 of the study showed that this effect can be reversed by reducing perception of threat. These results were due to the persistent threat at the Height condition suggesting that participant negotiation of the threatening block mechanic was also influenced by the overall level of threat perceived in each Condition; if the threat of virtual height is removed, participants moved more quickly using an unrestricted repertoire of behaviour. There is also evidence to suggest that risk/reward perception of the end goal is affected by the level of threat within a VE.

Future studies could advance the use of the threat block mechanic to introduce a positive interaction allowing for the negative gradient to incorporate Positivity Offset in conjunction with modulation of goal proximity and risk reward mechanisms of ESM to be studied in greater fidelity. Further studies could be undertaken in larger controlled environments which could allow for the effects of repeated modulation of the negative gradient.

Chapter 6

Study Four

6.1 Abstract

The studies conducted by this research program recorded psychophysiological measures and behavioural data during room-scale VEs which incorporate an over-arching threat e.g. virtual height and modulate additional threat mechanics (Solid, Crack, Fall blocks) during the course of a task to operationalise risk-averse behaviour. Accurate tracking of participants movement allowed for the creation of behavioural measures such as Risk Ratio which permitted the analysis of participants' responses to increased threat and resultant risk averse behaviour. We observed changes in these behaviours and in this chapter we present calculated slopes generated from behavioural measures across sections of a VE, the gradient of these slopes records the net disposition of a participant in response to change in threat level and operationalises the ESM negative gradient. Study Four comprises further analysis of the Risk Ratio slope data from Study 3 and constructs a combined dataset (N=55, Age M=24.3, SD=3.55) from all Levels of Study Two and Sections 1-3 of Study Three, this early part of Study Three, contained the same number of interactive blocks and layout within the VE as Study Two's entire task. Linear regression analyses are conducted on the Study Three dataset incorporating variables from that dataset not previously included. This chapter also conducts linear regression and logistic regression analysis on the combined dataset. The chapter will not contain any new methodological processes. The chapter will then outline how this further analysis expands on results with regards to the Risk Ratio findings from Chapter 5. In summary this chapter will attempt to address variables which were recorded but not previously included in the results of previous chapters in an attempt to frame previous results with respect to variables and measures which further detail aspects of the ESM and variables which are known to affect behavioural responses in experiments conducted in laboratory conditions.

6.2 Introduction

The Negativity Bias and Positivity Offset posits of the ESM [Cacioppo and Berntson, 1999, Cacioppo et al., 2012] suggest that adaptive responses to negative and positive stimuli are driven by the extremity of the stimulus and its relative proximity to the organism. Higher activations induce an overpowering desire to avoid excitatory stimuli that are negative; this effect produces a gradient for negatively biased stimuli that is steeper than that of positive activation (See Fig. 6.1). With respect to the work conducted in the current thesis, as threat is increased within a VE we expect to see a corresponding rise of risk-averse behaviour. i.e. as the number of Crack blocks within each section of the virtual environment increases, we would expect to observe increased one footed Risk Assessment actions and increased amounts of time spent on Solid blocks. If the increase of threat over the course of the VE does not provoke these risk-averse behaviours, we would expect to observe an increased number of falls, i.e., risk-averse behaviour serves a protective function.

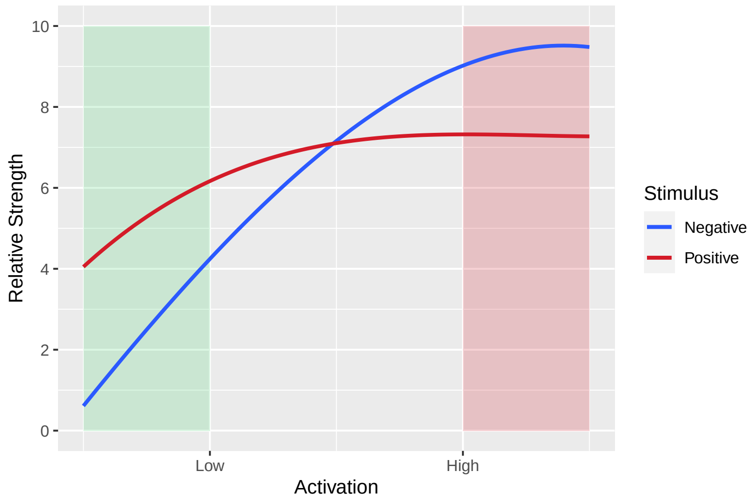

Figure 6.1: Negativity Bias, Positivity Offset

The purpose of the current chapter and additional analyses is to fully explore the role of individual differences as an influence on behaviour in the VE. We propose that individual differences in the appraisal of negative stimuli, i.e., in this case, the inherent level of threat in the VE, e.g. threat should result in a steeper negative gradient as the level of threat changes from low to high. For example, previous research has indicated that heightened sensitivity to negative stimuli is associated with increased trait neuroticism [Larsen and Ketelaar, 1989, 1991]; therefore, due to this increased negativity bias, we may expect those participants with higher trait neuroticism scores to exhibit a steeper negative gradient compared to individuals with low levels of trait neuroticism. Similarly, increased trait openness corresponds with reduced sensitivity to risk because it promotes exploratory behaviour [Kashdan et al., 2004]. We would also expect to see the same increase of risk averse behaviour due to standard demographics, such as age and gender [Chapman and Lyness, 2008, Ormel, 2000, Roberts et al., 2006, Scollon and Diener, 2006, Weisberg et al., 2011] i.e. older participants may score lower for trait neuroticism and display reduced risk averse behaviour and that female participants display increased risk aversion when faced with negative stimuli due to increased trait neuroticism.

As level of threat is modulated within the VE via the manipulation of interactive threat blocks (See Fig. 6.2) we would expect to observe a corresponding increase of behaviours associated with risk aversion from section 1 to section 3. For the purposes of the current study, risk-averse behaviour is characterised by three dependent variables, these were Risk Ratio, Hesitancy, and time spent on Solid blocks. Risk Ratio represents the ratio of one-footed checks (risk assessment) to two-footed movements (risk decision) within a section of the VE, i.e. increased risk ratio = greater proportion of one-foot checks compared to the two-footed movement.Due to an increased level of threat from section 1 to section 3, we would expect participants to indulge in a greater proportion of one-foot checks of blocks before committing to a two-footed movement, and the risk ratio should increase. Hesitancy was a measure of time between two-footed risk decision actions when participants had selected a block to move to. Increased hesitancy should correlate with increased decision making time and be sensitive to increased risk aversion increasing at higher threat levels. Time spent on solid blocks was also selected as a measure of risk aversion. Increased time on Solid blocks, the lowest threat level interactive block, should correlate directly with risk aversive behaviour especially at areas of high threat within the VE where Solid blocks were rare, e.g. section 3.

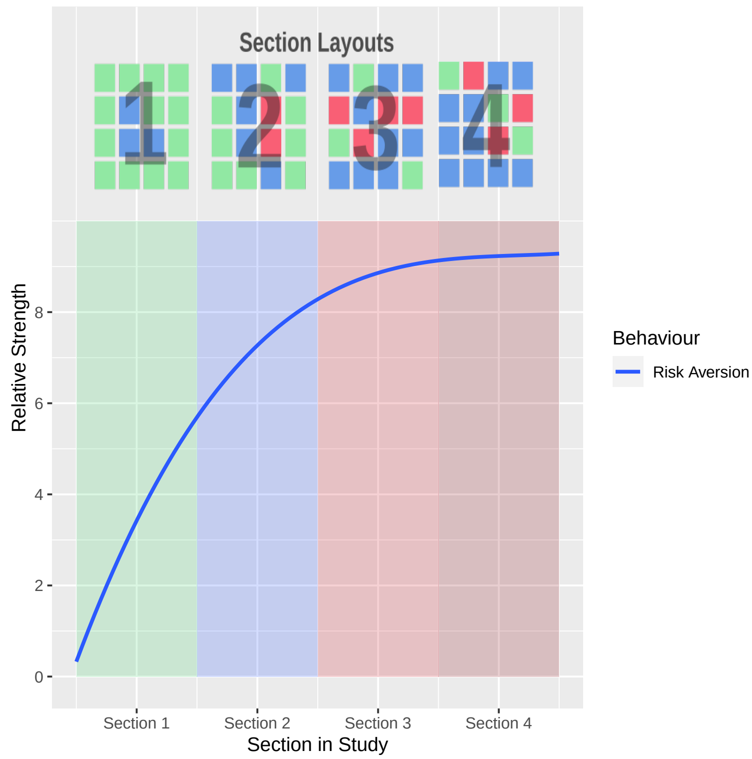

Figure 6.2: Hypothetical relationship between level of threat in the VE and increase in risk-averse behaviour. Note: green squares = solid blocks, blue squares = crack blocks, red squares = fall blocks.

The pattern of risk-averse behaviours recorded across all three sections were used to calculate slopes that represented the gradient of this trend. A higher slope value indicating a greater increase in risk-averse behaviour across the three sections compared to a lower slope value (See Fig. 6.3). It was hypothesised that higher slope values of risk-averse behaviour would be observed for participants who scored higher on trait neuroticism i.e. due to increased negativity bias for those individuals. Given that Openness has an association with reduced sensitivity for risk, we would expect the slope values for risk-averse behaviour to be lower for individuals with high scores on trait Openness.

The VE designed for the second ice block experiment (study 3) incorporated 3 sections in the final stage of the VE where the threat was suddenly reduced, i.e. the number of crack and fall blocks were reduced. It was hypothesised that the reduction in threat at Sections 6-9 of the Study Three VE it was expected that we would observe a decline in slope value at this stage of the task but that this decline in slope values would be less pronounced for participants that scored higher for trait neuroticism.

The thesis has reported two studies using the ice-block VE, but to date, we have not attempted to analyse the patterns of fall data that we observed. Therefore it was decided to combine Sections 1-4 of Study Three and all three Levels of Study Two into a combined dataset in order to use measures of individual difference and risk averse behaviour to predict the likelihood of falling. It was hypothesised that the likelihood of a fall in the VE would be influenced by two factors: (1) individual traits (e.g., individuals high in Openness may be less sensitive to risk and more likely to fall), and (2) risk-averse behaviour (e.g., greater risk aversion should be protective and reduce the likelihood of a fall). It is highly

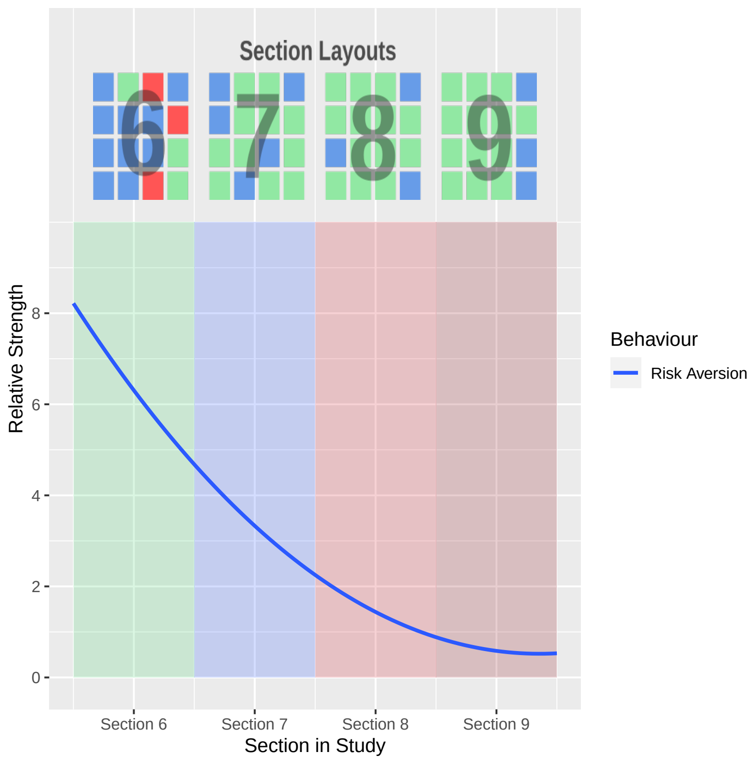

Figure 6.3: Hypothetical relationship between level of threat in the VE and decrease in risk-averse behaviour. Note: green squares = solid blocks, blue squares = crack blocks, red squares = fall blocks.

likely that traits (1) and behaviours (2) both contribute to the likelihood of a fall.

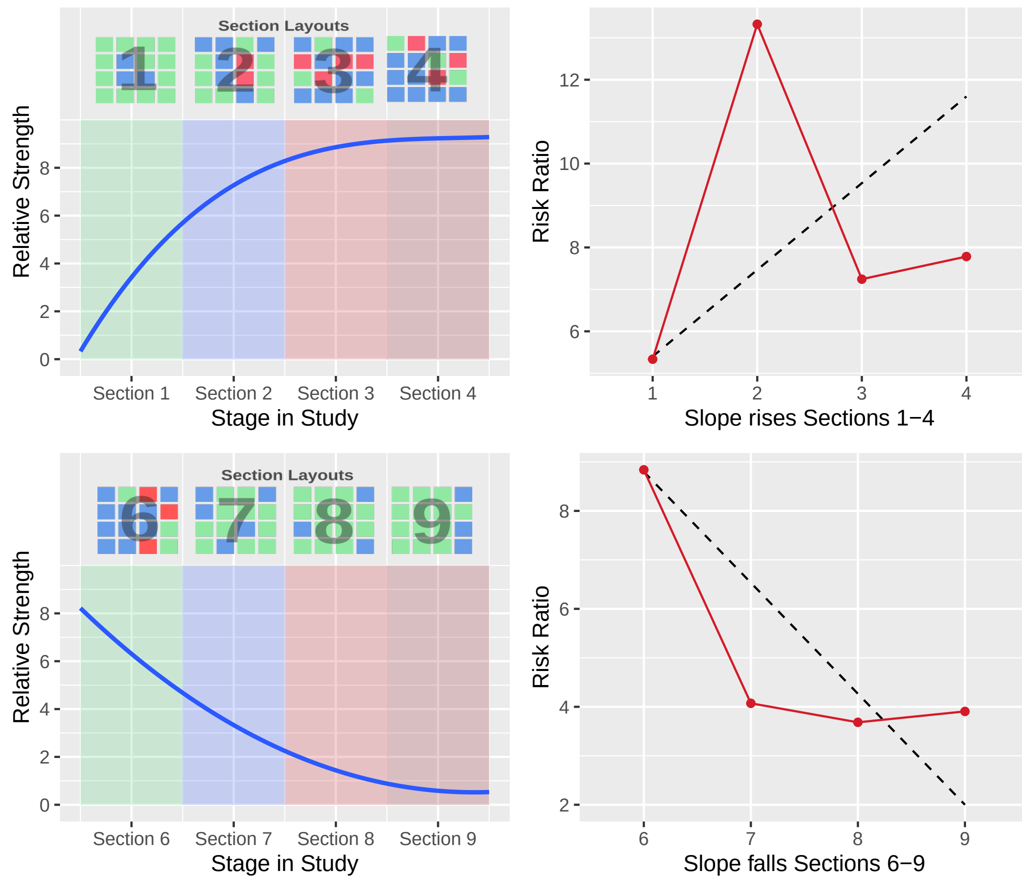

Figure 6.4: Measures of risk aversion and Risk Ratio slope calculations

6.2.1 Research Questions

1. Combine data from selected Sections of Study Three and Study Two to examine additional variables.
2. Can behavioural measures be used to predict participant behaviour.

6.3 Methodology

6.3.1 Measures of risk averse behaviour formal definitions of risk ratio, hesitancy and time on solid blocks

Risk Ratio = (number of Risk Assessments) / (number of Risk Decisions). This measure represents the proportion of one-footed checks (assessments) to two-footed movements (decisions).

Hesitancy = Time taken between two footed Risk Decision movements. This measure represents the amount of time participants took to advance within the VE.

Time on Solid Blocks = Time spent on Solid blocks. This measure represents the amount of time participants spent on the safest interactive threat blocks.

DidFall = Binary value. This measure represents whether a participant did or did not fall within the VE.

zScoreMeanRiskRatio = Risk Ratio averaged and z-scored. This measure represents a z-scored mean value for Risk Ratio and was used in a combined dataset to offset differences in the design of study two and study three.

zScoreMeanSolidTime = Time taken between two footed Risk Decision movements averaged and z-scored. This measure represents a z-scored mean value for time spent on solid blocks and was used in a combined dataset to offset differences in the design of study two and study three.

6.3.2 Data sets

Analysis one describes Risk Ratio slopes calculated from study three. Two slopes were calculated, one across sections 1-4 (increased threat) and a second across sections 6-9 (decreased threat). The number of participants in the analysis was 20. A linear regression was performed where slope 1-4 was the dependent variable and age, neuroticism and openness were the independent variables. A linear regression was performed where slope 6-9 was the dependent variable and age, neuroticism and openness were the independent variables.

Analysis two describes Hesitancy slopes calculated from study three. Two slopes were calculated, one across sections 1-4 (increased threat) and a second across sections 6-9 (decreased threat). The number of participants in the analysis was 20. A linear regression was performed where slope 1-4 was the dependent variable and age, neuroticism and openness were the independent variables. A linear regression was performed where slope 1-4 was the dependent variable and age, neuroticism and openness were the independent variables.

Analysis three describes Risk Ratio slopes calculated from a combined dataset of levels 1-3 of study two and sections 1-3 of study three. Risk ratio slopes were calculated. The number of participants in the analysis was 55. A linear regression was performed where slope was the dependent variable and age, neuroticism and openness were the independent variables.

Analysis four describes DidFall a binary variable calculated from a combined dataset of levels 1-3 of study two and sections 1-3 of study three. The number of participants in the analysis was 55. A hierarchical logistic regression was performed where DidFall was the dependent variable and for the first stage gender, age, neuroticism and openness were the independent variables. For the second stage z-scored mean values for Risk ratio and time on solid blocks was added to the logistic regression model.

6.4 Results

6.4.1 Study Three 1-4 Slopes

A linear regression was conducted using risk ratio slope calculated for sections 1-4 as a dependent variable. Correlation coefficients are provided in table 6.1. The regression was not statistically significant ($F(3, 16) = 2.29$, $p = 0.12$) with an R^2 value of 0.3. Examination of the independent variables indicated a significant positive relationship between trait neuroticism and the value of the slope (See Tab. 6.2).

A linear regression was conducted using hesitancy slope calculated for sections 1-4 as a dependent variable. Correlation coefficients are provided in table 6.3. The regression was statistically significant ($F(3, 16) = 6.89$, $p = 0.003$) with an R^2 value of 0.56. Examination of the independent variables indicated a significant negative relationship between age

Table 6.1: Sections 1-4 Risk Ratio Correlation Matrix

term	Age	Neuroticism	Openness	SlopeS1
Age				
Neuroticism	0.49			
Openness	-0.22	0.22		
SlopeS1	0.21	0.45	0.13	

Note:
†p <.5 *p < .05. **p < .01

Table 6.2: Study Three 1-4 Risk Ratio Model

term	estimate	std.error	statistic	p.value	
Age	-0.03	0.05	-0.59	0.56	
Neuroticism	0.14	0.05	2.49	0.02	*
Openness	-0.02	0.07	-0.32	0.75	

Note:
†p <.5 *p < .05. **p < .01

and openness and the value of the slope and a significant positive relationship between neuroticism and the value of the slope (See Tab. 6.4).

6.4.2 Study Three 6-9 Slopes

A linear regression was conducted using risk ratio slope calculated for sections 6-9 as a dependent variable. Correlation coefficients are provided in table 6.5. The regression was not statistically significant ($F(3, 16) = 1.35$, $p = 0.29$) with an R^2 value of 0.2. Examination of the independent variables indicated a marginally significant positive relationship between age and the value of the slope (See Tab. 6.6).

A linear regression was conducted using hesitancy slope calculated for sections 6-9 as a dependent variable. Correlation coefficients are provided in table 6.7. The regression was not statistically significant ($F(3, 16) = 1.31$, $p = 0.31$) with an R^2 value of 0.2. Examination of the independent variables indicated a significant positive relationship between age and the value of the slope (See Tab. 6.8).

6.4.3 Combined Study Regression

A linear regression was conducted using risk ratio slope calculated for combined study dataset as a dependent variable. Correlation coefficients are provided in table 6.3. The

Table 6.3: Sections 1-4 Hesitancy Correlation Matrix

term	Age	Neuroticism	Openness	SlopeS1
Age				
Neuroticism	0.49			
Openness	-0.22	0.22		
SlopeS1	-0.4	-0.4 †	-0.11	

Note:
†p <.5 *p < .05. **p < .01

Table 6.4: Study Three 1-4 Hesitancy Model

term	estimate	std.error	statistic	p.value	
Age	-1.71	0.41	-4.21	<0.001	***
Neuroticism	1.42	0.44	3.22	0.01	**
Openness	-1.30	0.56	-2.32	0.03	*

Note:
†p <.5 *p < .05. **p < .01

Table 6.5: Sections 6-9 Risk Ratio Correlation Matrix

term	Age	Neuroticism	Openness	SlopeS2
Age				
Neuroticism	0.49			
Openness	-0.22	0.22		
SlopeS2	0.27	0.06 †	0.12	

Note:
†p <.5 *p < .05. **p < .01

Table 6.6: Study Three Risk Ratio 6-9 Model

term	estimate	std.error	statistic	p.value	
Age	0.13	0.06	1.99	0.06	.
Neuroticism	-0.09	0.07	-1.26	0.23	
Openness	0.03	0.09	0.38	0.71	

Table 6.7: Sections 6-9 Hesitancy Correlation Matrix

term	Age	Neuroticism	Openness	SlopeS2
Age				
Neuroticism	0.49			
Openness	-0.22	0.22		
SlopeS2	0.19	0.03 *	0.22	

Note:
†p <.5 *p < .05. **p < .01

Table 6.8: Study Three 6-9 Hesitancy Model

term	estimate	std.error	statistic	p.value	
Age	0.99	0.55	1.80	0.09	.
Neuroticism	-0.44	0.60	-0.74	0.47	
Openness	0.91	0.76	1.20	0.25	

Table 6.9: Combined Data Correlation Matrix

term	Age	Neuroticism	Openness	Slope
Age				
Neuroticism	0.18			
Openness	-0.04 **	0.02 **		
Slope	-0.4	-0.09 *	-0.08 *	

Note:
†p <.5 *p < .05. **p < .01

Table 6.10: Combined Model

term	estimate	std.error	statistic	p.value	signif
Age	-0.07	0.03	-2.57	0.01	*
Neuroticism	-0.01	0.02	-0.41	0.68	
Openness	-0.03	0.03	-1.15	0.26	

Note:
†p <.5 *p < .05. **p < .01

regression was not statistically significant (F(3, 49) = 2.65, p = 0.06) with an R^2 value of 0.14. Examination of the independent variables indicated a significant negative relationship between age and the value of the slope (See Tab. 6.10).

6.4.4 Combined Study Fall Data Hierarchical Logistic Regression

For the combined dataset a hierarchical logistic regression was conducted using DidFall was the predictor variable. There was no collective significant effect for Age, Neuroticism and Openness (F(4, 43) = 2.38, p = 0.07, R^2 = 0.18). There was a significant collective effect for Gender, Age, Neuroticism, Openness, zMeanSolidTime and zMeanRisk Ratio (F(6, 41) = 6.88, p = 0, R^2 = 0.5) (See Tab. 6.11). The individual predictors were examined further and indicated that zMeanRiskRatio [t = -2.41, p = 0.02] was a significant predictor in the model (See Tab. 6.12, 6.13).

6.5 Discussion

6.5.1 Summary of Results

For the extended Study Three analysis Risk Ratio (The sum of Risk Assessment interactions was then divided by the sum of the Risk Decision interactions) slopes were calculated for Sections 1-4 and a linear regression analysis performed on these measures. The Risk Ratio slopes regression for Sections 1-4 showed that Neuroticism was a significant predictor in

Table 6.11: Combined Study Fall Data Hierarchical Logistic Regression

Model	r.squared	adj.r.squared	sigma	statistic	p.value	df	df.residual
1	0.18	0.10	0.47	2.38	0.07	4	43
2	0.50	0.43	0.38	6.88	<0.001	6	41

Note:
†p <.5 *p < .05. **p < .01

Table 6.12: Combined Study Fall Data Hierarchical Logistic Regression 1

term	estimate	std.error	statistic	p.value	
Gender	0.78	0.69	1.14	0.26	
Age	0.27	0.12	2.26	0.02	*
Neuroticism	-0.06	0.05	-1.26	0.21	
Openness	0.07	0.07	0.94	0.35	

Note:

†p <.5 *p < .05. **p < .01

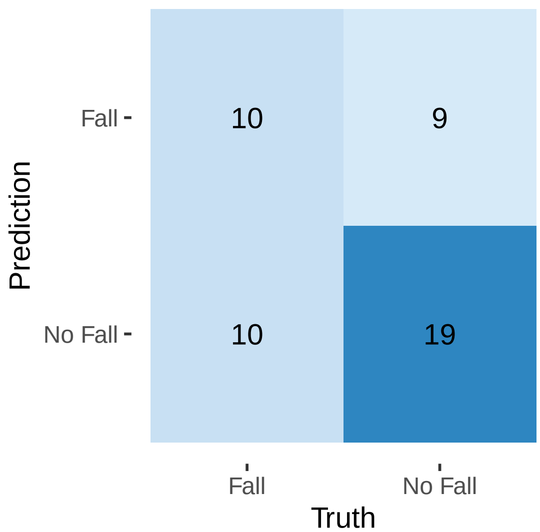

Figure 6.5: Confusion Matrix Logistic Regression 1, Predicted Falls vs. Actual

Table 6.13: Combined Study Fall Data Hierarchical Logistic Regression 2

term	estimate	std.error	statistic	p.value	
Gender	2.89	1.75	1.66	0.10	.
Age	0.64	0.33	1.92	0.05	.
Neuroticism	-0.20	0.12	-1.63	0.10	
Openness	0.36	0.18	2.00	0.05	*
zMeanSolidTime	-0.13	0.68	-0.19	0.85	
zMeanRiskRatio	-5.67	2.36	-2.41	0.02	*

Note:

†p <.5 *p < .05. **p < .01

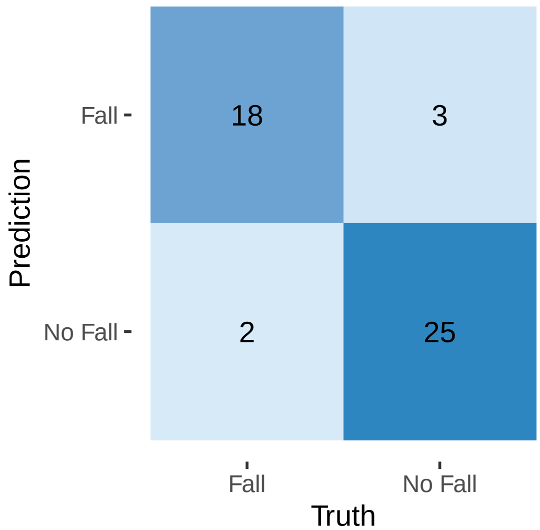

Figure 6.6: Confusion Matrix Logistic Regression 2, Predicted Falls vs. Actual

the model although the model itself was not significant. Analysis of the slopes for this factor showed that at this point in the study participants scoring highly for Neuroticism responded more strongly to increased threat this negativity bias was demonstrated by the positively associated slopes. Hesitancy slopes were calculated for Sections 1-4 and these datas were then subjected to a linear regression. For the Section 1-4 Hesitancy slopes Age, Neuroticism and Openness were revealed to be significant predictors in the model. Analysis of the slopes for these factors showed that older participants took less time to make Risk Decision actions at this point in the study and that participants scoring higher for neuroticism took longer to make two footed decisions on which blocks to advance to, for participants scoring higher for Openness this behaviour was reversed, at this point in the study they made Risk Decision actions more quickly. We assume that neurotic participants may have found the threat of height and increasing number of threatening blocks at the early stage of the study conducive to increasing their speed and decreasing their level of checking behaviour i.e. it may not have been fully clear to participants prone to nervous or panicked responses how to check and decide on which blocks to move to with one footed and two footed movements, we would suggest that at this point in the study and during the task in general participants scoring highly for neuroticism were more affected by the VE threat mechanics.

For the second set of linear regression results slopes were calculated for Sections 6-9 and a linear regression analysis performed on these measures. The Risk Ratio slopes regression for Sections 6-9 showed that Age was a marginally significant predictor in the model although the model itself was not significant i.e. older participants made more risky decisions at this point in the study. Hesitancy slopes were calculated for Sections 6-9 and these datas were then subjected to a linear regression. For the Section 6-9 Hesitancy slopes Age was a significant predictor in the model but the model itself was not significant. Analysis of the slopes for these factors showed that older participants took more time to make Risk Decision actions at this point in the study. At this point in the study the levels of threatening blocks had decreased to a low enough level that it is unlikely that differences in personality scores would have a bearing on participant behaviour. We also assume that older participants may have either been less perceptive of a decrease in threatening interactive blocks within the VE or that they may have been more strongly affected by the previously high levels of threat in the study and sought to rapidly advance to the end goal area thereby reducing their levels of risk assessment interactions.

For the Combined Study dataset (N=53) the cross-study Risk Ratio slopes were subjected to a linear regression. Age was revealed to be a significant predictor in the model. Age had a negative relationship with the risk ratio slope over S1-S3; this finding indicated that younger participants exhibited a higher slope value, i.e., demonstrated a greater proportion of one-foot checks in response to increased threat, although the overall model was only marginally significant. This finding could be due to a natural decline in neuroticism, thus reduction in sensitivity to threat [Ormel, 2000, Roberts et al., 2006, Scollon and Diener, 2006].

The combined Study dataset was also subjected to a hierarchical logistic regression. A binary variable DidFall was generated on a per participant case basis if a participant stood on a fall block during second and third parts of the task where fall blocks were introduced into the task. The aim of this analysis if personality traits and behaviour could predict the likelihood of a fall occurring during the study. Two further variables of z-scored mean time spent on solid blocks and z-scored mean Risk Ratio value were introduced to the logistic regression model in addition to Age, Gender, Neuroticism and Openness. For the first stage of the logistic regression there was no significant effect for Age, Neuroticism and Openness. This first stage of the analysis suggested that traits alone were a poor predictor of fall likelihood with a classification rate of 60.4%. At the second stage there was a significant collective effect for the logistic regression model after the addition of Gender, zMeanSolidTime and zMeanRisk Ratio values. There was a significant effect for Openness and there was also a significant effect for zMeanRiskRatio, i.e. participants' level of risky behaviour and their score for Openness was a significant measure of their likelihood of interacting with a Fall block and being subjected to a virtual fall, the highest level of threat interaction in both of the VE tasks. The second stage of the analysis suggested that behavioural factors were good predictors of fall likelihood with a classification rate of 89.6%. These behavioural traits were significant predictors in fall likelihood, i.e. high Ratio Ratio values indicated more Risk Assessment behaviour reducing likelihood of Risk Decision interactions with Fall blocks. Openness increased likelihood of falling due to less checking of interactive blocks and faster decision making time periods.

6.5.2 Relationship to Background Research

One of the primary goals of Study Three ways to modulate threat by increasing and reducing perceived threat. Individuals scoring highly for Openness may be influenced by reduction in perceived threat within the context of behavioural studies in virtual environments. For the extended Study Three analysis and the combined dataset analysis slopes were calculated by measuring the net effect of variables such as Risk Ratio or Hesitancy across combined Sections of the VE the coefficient of these slopes correlates with an increase or decrease in the change of that variable during a period of the study and can correlate with participant approach avoidance behaviour. Previous research by Riva et al (Riva et al., 2007) showed that virtual reality, via relatively subtle changes to similar VE designs can induce positive and negative subjective responses in participant reactions to those environments. Further studies [Biedermann et al., 2017, Bouchard et al., 2008, Krupić et al., 2020, Robillard et al., 2003] have also shown that medical interventions and personality trait differences can induce different responses to virtual environments. This study has again demonstrated that threat can be induced by a VE and that risk averse behavioural responses can be measured. The slopes of negative gradient calculated by this study also demonstrate that this negative gradient can be modulated by trait neuroticism and that this gradient can also be modulated by openness [Zuckerman, 2008, Larsen et al., 2004]. As previously stated in Chapter 5 To our knowledge no study has sought to modulate responses via manipulation of threat within a single trial, it was hypothesised that evidence for the negativity bias response shown in high neurotic participants may be offset by positivity offset responses in high openness participants when threat in the environment was at its lowest

6.5.3 Limitations and Improvements

Conclusions made by this study have several caveats. Sample size was relatively small even when the datasets were joined together in the Combined Linear Regression and the Combined Hierarchical Logistic Regression and may be underpowered. It should also be noted that combining these two studies together resulted in a dataset that yielded 35 participants who took part in the Study Two trial and 20 participants that took part in the Study Three trial. In order to analyse the additional factors to address additional research program hypotheses it was decided that the maximum possible sample size should be used in the analysis. It could be argued that the study could be improved by attempting to balance the number of participants (N=40) so that results were not biased towards a single dataset. It should also be acknowledged that although the layout of threatening blocks and their number were the same in both of the combined study datasets the design of each study did have several differences. Notably in the first study rows of blocks which had been advanced through were not removed from behind the participant as in the third study. This allowed participants to "backtrack" through previous areas and self regulate the level of threat they were prepared to interact with. The first study was also not at a single level of virtual height and due to lab space restrictions was divided up into three levels such that the experience of threat was broken by safe goal doorways and starting platforms which were unthreatening safe zones. It should also be noted that the distribution of the age of participants within the studies was uneven (low number of older participants).

6.5.4 Future Research

Linear regression analysis also showed that there were correlations between personality score and time taken to make decisions in the trial. Logistic regression analysis showed that data on participants' choices which reflected the level of risk they were willing to engage in during the early part of the study correlated with their likelihood of interacting with the high threat level fall blocks. Future studies could examine both of these measures as a means of adapting a threatening scenario to modulate threat on a per-participant basis tailoring the experience to increase or decrease threat for high neurotic or high openness participants. Using data recorded during Study Three it would be possible to obtain accurate information on how many individual threat block interactions occurred during Sections 1-4 of the VE design. Although there were 48 individual threat blocks within Sections 1-4 the actual number of interactions was likely much less than this for each participant. Future research programmes may also choose to examine the minimum number of interactions necessary to make accurate predictions about participant behaviour within a VE. This research could then be used for therapeutic purposes e.g. treatment of fear of heights or social anxiety. Research into the minimum number of interactions recorded in a room-scale ecologically valid VR environment and the capacity for this metric to make accurate predictions about participant behaviour has implications beyond psychological research into human behaviour and it is also not known if room-scale VR simulations have an impact on the magnitude of the number of interactions needed to make such a prediction i.e. if the plausibility and immersive qualities of VR scenarios can have a bearing on this predictive measure.

No significant effect was shown for positivity offset behaviour in the dataset at Sections 6-9 of Study 3. We suggest that this hypothesis could be studied via modifications to the design of the VE. The Study divides the VE interactive block area into three Stages, Sections 1-3 where threat is increased, Sections 4-6 where threat is increased and maintained at a high level and Sections 6-9 where threat is reduced. This modulation was designed solely to manipulate threat in the context of negativity bias posits of the ESM. The focus on threat and its modulation may be the reason why no positivity offset response was observed. A future study may change the design of the VE by changing the threat modulation at the final three Sections (6-9). The number of threat blocks were reduced gradually to the same extent as they were increased at the first stage of the study but participants were rewarded for exploratory behaviour, via a mechanic that “illuminated’ ’ safe blocks in front of a participant when participants chose to stop checking with one foot movements and make risky “gambles’ ’ with two footed only transfers to blocks risk taking exploratory behaviour would be rewarded within that stage of the VE. This future study could then offset the effects of the previous threatening stages by dividing its participants into two groups, one group would complete a task that increased threat then rewarded exploratory behaviour in the latter stage of the trial, the other group would conduct a task which rewarded exploratory behaviour initially but reduced this reward factor and increased threat in the latter stages. The results suggest that a small portion of a VE’s interactive mechanics could be used to successfully classify human behaviour. This interactive portion used to predict behaviour could be studied in greater detail to determine the ideal number of interactions required to make accurate predictions. Such a measure could have broad implications beyond the scope of this research project. Such a measure could also be studied to determine whether psychophysiological VR experiments are an ideal way to predict human behavioural responses based on personality differences and behaviour within the experimental trial or if this proposed number of predictive interactions is generally applicable to non VR based experimental designs. We have also proposed a future study which would introduce a reward based based mechanic as a counterpoint to the risk taking methods generally used throughout this program of research in order to enhance the capacity of a potential VE to provoke changes in behaviour. It may be possible at a future date to develop a VE that can successfully incorporate all of the Big 5 personality traits as provocation mechanisms to be studied as factors within the context of ESM research.

6.5.5 Conclusion

Psychophysiological studies which modulate stimulus delivery during the course of a room-scale VR scenario can be successfully implemented in controlled laboratory environments. Care must be taken to utilise mechanics within a VE which deliver stimuli in a similar fashion should the researcher wish to combine the datasets of multiple studies at a future date. Results from this chapter suggest that further research is required to develop a VE which can provoke a negativity bias response and simultaneously stimulate a positivity offset response in participants scoring highly in Openness. Although this study had several caveats regarding the combination of datasets we believe it presents interesting possibilities for future research.

Chapter 7

Discussion

7.1 Summary of Findings

In order to summarise the main findings of the research programme we will revisit the project's main hypotheses individually and highlight supporting or contradictory findings.

1. Wearable sensors can deliver equivalent signal quality and sensitivity to independent variables as conventional wired psychophysiology.

When both devices were used during a facial mimicry task in study one (Ch. 3), there were no significant differences between the devices with respect to their ability to differentiate between different facial expressions. This result demonstrated that the Faceteq device could be used in subsequent studies in the research program and that the measures it provided were comparable to established devices capable of wirelessly recording psychophysiological measures such as the BioNomadix device, which was also used in study one and study two.

2. Room-scale VR will enhance emotional reactivity because it induces an embodied emotional state.

Results for the first study (Ch. 3) indicated that the room-scale VR condition elicited a greater level of fEMG response than the sedentary VR condition, which indicates that participants were more emotionally reactive during the former. The difference in fEMG reactivity was due to an increased zygomaticus response, but only for the initial stage of the task. This pattern could indicate that participants experienced a greater level of threat due to virtual height when first introduced to the environment - if the zygomaticus increase is assumed to represent a grimace response.

3. Negative gradient from ESM is observed when potential source of negativity (threat) is increased.

Both studies two and three included a linear increase of threat level as an independent variable. Our analyses of behaviour in study two (Ch. 4) and study three (Ch.5) clearly demonstrated that risk-averse behaviours (e.g., checking with one foot, time on solid blocks, hesitancy) all increased in a linear fashion with higher risk, as described by the negative gradient from ESM [Cacioppo and Berntson, 1999, Cacioppo et al., 2012]. A similar pattern was also observed during study three (Ch. 5) as the block timing data showed that participants spent significantly longer at the final stage of the VE but only at height. This result demonstrated an absence of the negative gradient during the ground condition of study three where no threat of a virtual fall was present.

4. Due to negativity bias, personality traits, such as neuroticism, lead to a more pronounced (i.e. steeper) negative gradient when faced with increased level of threat.

For the second study (Ch. 4) the block interaction analysis revealed that participants with higher scores on trait neuroticism were more risk-averse when the threat level in the environment was highest. These participants also demonstrated a significantly higher number of interactions with solid block types at level one, i.e. minimising risk at minimum level of threat. A combined dataset was generated during the supplemental data analysis (Ch. 6) and our analysis revealed that individual traits moderated the magnitude of the negative gradient (hesitancy), i.e., trait neuroticism increased the negative gradient whereas age and trait openness had the opposite effect. In other words, neurotic participants spent longer making a decision about their next movement, whereas older participants and those who scored highly on trait openness spent less time planning their next movement..

5. If the threat level is reduced from high to low, then we observe a reversal of negative gradient.

The third study (Ch. 5) intended to demonstrate a reversal of the negative gradient during the final part of the environment where threat was suddenly reduced from maximum to minimum levels. We found that risk-averse behaviour was significantly reduced during this transition, i.e., . participants spent less time standing on the safe solid blocks and performed fewer checks.

6. Behavioural outcomes in the VE can be predicted and modelled based on individual traits and risk-averse behaviours.

For the supplemental data analyses (Ch. 6) when risk ratio results were incorporated into a predictive linear model, results demonstrated that measures of risk-averse behaviour (frequency of checking), age and trait openness were all significant predictors of participants' likelihood of experiencing a virtual fall. These findings suggested that it is possible to develop predictive models of behaviour based on individual differences and behavioural monitoring of participants in VR.

For the fourth study (Ch. 6) when risk ratio results were incorporated into the model results showed that the behavioural measures were a good predictor of participants likelihood of falling. These findings suggested that it may be possible to predict participant behaviour based on interpersonal differences and behavioural measures.

7. Corrugator activation will increase when participants perform high threat behaviour compared to low threat. Zygomaticus activation will decrease when participants perform high threat behaviour compared to low threat.

fEMG measures were recorded in an event-related fashion when participants made two-feet movements in the VE to either solid (low threat) or crack (high threat) blocks (Ch. 4 and 5). For study two (Ch. 4), we found a marginal effect of increased corrugator activation when participants stepped onto a crack block instead of a solid block; however, there were no significant effects for the zygomaticus. This pattern was reversed for the third study (Ch. 5) where fEMG data were analysed at pre and post-event, e.g. before and after an interaction with an ice block. There were no significant effects for corrugator activity but zygomaticus increased during the pre-movement period when participants stepped onto a crack block instead of a solid block. We also found a significant effect during the third study where zygomaticus activation was generally higher when participants experienced the VE at height as opposed to the ground level version. These results showed an increase in post event corrugator activity in study two, which was the expected result, but this pattern was reversed with an increase in zygomaticus activity at the pre-event period in study three. These results could suggest inherently ambiguous measures for zygomaticus activity shown by a general increase in zygomaticus activity for height as whole in study three and the rise in activity before a threatening event. The results for fEMG data may also be confounded by verbalisation during the task (See Limitations and Improvements).

7.2 Relationship of Findings to Background Research

Early academic work utilising virtual reality technology was focused on its capability to deliver an immersive virtual environment which generated a sense of presence for a participant [Slater and Wilbur, 1997, Hoffman et al., 1998, Slater, 1999] A sense of presence being dependent on a sufficient level of immersion generated by one-to-one visuomotor synchrony of participant action translated to the virtual environment which also does not interfere with a user's established sense of self e.g. a male participants use of a female avatar [Slater et al., 1995]. Subsequent research allowed the VR user to move within the virtual environment enhancing the sense of immersion and presence [Slater et al., 1995]; additional research demonstrated that accurate body tracking and recorded movement data could provide useful insights into user experience, e.g. measurements of approach towards an avatar [Bailenson et al., 2001]. Further work demonstrated how VR could be used in order to induce different types of emotional experiences for the user [Riva et al., 2007, Felnhofer et al., 2015] and how virtual environments can successfully induce experience of threat [Bouchard et al., 2008, Felnhofer et al. [2014]; Diemer et al., 2015; Montero-López et al., 2016; Allen et al., 2017; Krupić et al., 2020]. This research project has attempted to combine the proven immersive capacity of VR technology whilst also delivering an environment that allows participants to express emotion through whole body movement and behavioural strategy. The project has surpassed standardised protocols for emotional induction which use batteries of static, facile stimuli [DeSteno et al., 2006, Lang, 1995, Quigley et al., 2013, Samson et al., 2016] via the development of a goal-orientated, realistic digital environment, specifically designed to deliver a sense of embodied agency without impeding the accuracy of measures recorded during its operation.

This project was inspired by research conducted that measured participant movement in response to threat as evidence for risk aversive behaviour [Cleworth et al., 2012, Meehan et al., 2002, Peterson et al., 2018], as opposed to using environmental manipulation to induce negative emotion via sedentary VEs [Riva et al., 2007, Felnhofer et al., 2015]. Other research projects modulated participants propensity for avoidance behaviour via administration of psychotropic drugs [Biedermann et al., 2017]. or the modulated the virtual height threat stimulus [Cleworth et al., 2012, Wuehr et al., 2019]. To our knowledge no current research could be considered to fully utilise a room-scale VE in the context of emotional induction research. This research program has continued to develop VEs which incorporate current VR technologies attempting to prove the enhanced capacity of true room-scale VR to increase participant agency, immersion and increasing the interactivity of VEs and their capacity to induce emotional responses for psychophysiological studies. The research project from Biedermann et. al [Biedermann et al., 2017] is most closely aligned to the current research. These authors constructed a VR environment which; manipulated threat, measured resulting changes in participant behaviour and was room-scale, but the virtual environment used was small in scale and consequently the behavioural measures recorded were limited. Biedermann and colleagues also studied the influence of individual differences in traits (acrophobia) on risk avoidance, they also incorporated biological markers of stress (cortisol) into their protocol and moderated avoidance behaviour through administration of anti-anxiety drugs. These studies parallel the work conducted in the current project as we found that trait neuroticism correlates with increased risk aversion (individual differences), and demonstrated that room-scale VR designs can enhance psychophysiological responses associated with increased emotional arousal, which can be manipulated by increasing or decreasing threatening stimuli in a room-scale VE.

To summarise, our findings complement and extend existing research by demonstrating that: (1) A room-scale VE must use accurate tracking methods to allow participants to freely explore an environment. (2) Multiple tracking sensors should be utilised to record full body movement data instead of previous proxies for motion recorded from the position of the headset alone. (3) Wireless technologies should be utilised so that movements through room-scale immersive environments can be performed naturalistically without any feelings of physical restriction that can be experienced with a tethered system. (4) Psychophysiological room-scale studies should use behavioural data in conjunction with physiological sensor recordings to enhance the interpretation of these measures. (5) Behavioural measures in response to threat can be used to predict behaviour.

Previous research has observed discrete patterns of fEMG activity in response to affective stimuli generally delivered in the form of static media (imagery) [Goss, 1963, Schwartz et al., 1976, Cacioppo et al., 1986, Larsen et al., 2003] and that the Corrugator response can be most associated with negative affect, whereas increased activation of the Zygomaticus is associated with positive stimuli. However, there are issues surrounding both the measurement of fEMG activity and the way in which these signals are used to infer patterns of emotional reactivity. Later research has concluded that facial expressions and facial muscle activation due to emotional stimuli can be subject to context and interpersonal variability in intensity of emotional response induced by stimuli [Fernández Dols and Russell, 2017, Fernandez-Dols et al., 1997, Reisenzein et al., 2013] and that interpretation of zygomaticus activation can be a result of a negative grimace response [Burton, 2011, Martin et al., 2017]. This research program concedes that fEMG results through each of the separate studies have yielded inconsistent and partially confounding results; furthermore, we propose that inter-individual variability may have been exaggerated by the level of mobility afforded to participants, which had a negative effect on recorded data (i.e. increased noise in fEMG signal). For example, interactions between the sensor sites and the HMD worn by the participants additionally 'form fit' factors such as the relationship between head size and fit of the HMD, which in turn, negatively affected the robustness of fEMG connection. We do suggest that the specific goal of developing emotionally and physically engaging virtual environments which are specifically designed to encourage individual differences in behaviour may lead to resultant interpersonal differences in fEMG responses was achieved by this research program. We further suggest that as each VE design was focused on providing a threatening environment, the majority of the interactions within each VE were either neutral, conducive of a relief response upon discovery that a negative situation was not activated, or of a solely negative nature and so not conducive to display of positive fEMG responses associated with zygomaticus activation.

Through the course of the research program substantial resources were dedicated to the provision of evidence for a proposed negative gradient which increased in response to environmental threat and decreased as this threat was removed. The negative postulate of the ESM was the basis for this hypothesis. A propensity for avoidance behaviour was translated into a negative gradient, which could be modulated due to individual differences i.e. participants with a higher level of trait neuroticism would yield a proportionally steeper negative gradient. High neurotic personality types have been shown in previous research to have greater sensitivity to negative stimuli [Eysenck, 1963, Drabant et al., 2011, Zelenski and Larsen, 1999].

We believe the research program to have been generally successful in confirming this hypothesis by generating emergent patterns of behaviour that build on previous VR threat research [DeSteno et al., 2006, Khalaf et al., 2020, Krupić et al., 2020, Rosén et al., 2019, Biedermann et al., 2017, Bouchard et al., 2008] Like others, our work has particularly focused on how threatening stimuli can induce low level flight or flight responses that influence higher order behavioural strategies that reflect individual differences [Biedermann et al., 2017]. Our work has supported the ESM conception of negative gradient, but like Eysenck etc., we demonstrated how trait differences associated with negativity bias influence the slope of this negative gradient.

7.3 Limitations & Improvements

The creation of VE's for psychological research creates a technical burden on the researcher which must be considered and respected throughout the program of research, such as the one described in the current thesis. We believe this project to have undertaken a moderate and considered approach during each phase of the research program (See. Ch. 2 Methodology, Virtual Environment Design)in the pursuit of the primary research goals. Unreal Engine has previously been used as a tool to design virtual reality applications in psychological studies [Laak et al., 2017, Lewis et al., 2011, Lin et al., 2017, Wiesing et al., 2020]. To our knowledge, no psychophysiological study has employed Unreal Engine to develop room-scale VR applications with the levels of complexity and interactivity achieved during the current research programme. Unreal Engine was chosen for its adaptability, the node-based BluePrint system employed by UE was well-suited to deliver small scale prototypes in volume for experimental design discovery, and its underlying c++ architecture allows development of custom behavioural data capture libraries that could be reused between separate study designs (See. Ch. 2 Methodology for detail). We note that use of Unreal Engine presented few limitations on the scope of the research project. The research project made use of Unreal Engine 4 (versions 4.24 ~ 4.25) Unreal Engine 5 (scheduled 2021 release) incorporates a completely redeveloped graphics pipeline, Nanite[1] which utilises "virtualized micropolygon geometry". To summarise, established graphics pipelines such as those used in Unreal Engine 4 render 3D objects constructed of static 3D assets. The UE5 Nanite engine scales the rendering of these assets based on their location to the user in real time. This functionality permits highly dense detailed polygonal meshes to be used in 3D applications. We do not believe that the use of Unreal Engine hindered the project in any way and that additional enhancements to this software in the future could increase its utility in VR applications. Particularly in VR studies where assets are subjected to increased and unpredictable detail by the user of room-scale VR applications the advancement of the rendering engine will enhance the immersive qualities and reduce the technical burden on their deployment in room-scale applications.

The capture of fEMG data during room-scale VR experiments also presented several challenges which were not initially apparent without a series of extensive pilot studies at the beginning of the research project. Currently available wireless tracking sensor technologies such as the BioNomadix device (See. Ch. 2 Methodology, Psychophysiological Measures) used during study one and two use unshielded cables for fEMG data capture and are not ideally suited for for room-scale VR applications where full body movement is expected leading to increased noise on the captured signal. Despite considered management of the fEMG sensor cables to prevent contact with the wired HTC Vive headset cable, this aspect of the experimental apparatus proved to be difficult. This problem was exacerbated by the design of study two which required a participant to turn and walk back to a starting position between levels and after a fall block had been activated. During the course of the research the HTC Vive wireless adapter was released commercially and adopted by the project, by which time Emteq, the research partner, had also developed a wireless Faceteq prototype (See. Ch. 2 Methodology, Emteq Faceteq System, Fig 2.29) which we believed offered data capture performance that was at least equal to the BioNomadix system. As previously stated, we believe the use of wireless VE delivery and sensor recording technology to be a necessity for room-scale laboratory environment experimentation and adoption of wireless protocols reduced the issues inherent with tethered VR HMD use.

We found that heart rate data can be difficult to measure reliably in a room-scale VR experiment because of variability in the speed/level of body movement between participants. A heart rate sensor (PPG) was also incorporated into the FaceTeq design but it was not considered robust enough to capture accurate data. SCL's tonic measures were not appropriate for the short time periods that were utilised within the experimental

[1]https://www.unrealengine.com/en-US/blog/a-first-look-at-unreal-engine-5

design, these measures were also affected by the hand controllers used in the room-scale VR scenarios which adversely affected SCL sensor placement. The project integrated additional advanced sensors when they became available to mitigate these issues (See. Ch. 2 Methodology, VR Comparison and Solution, Fig 2.4). There are inherent problems in the measurement of ambulatory psychophysiology in room-scale VR due to confounding caused by increased movement and additional care should be taken at the analysis phase to develop robust protocols to remove signal noise from the data.

One of the primary research goals of this project was to develop VE's that would accurately measure fEMG responses in response to threatening events. The fEMG results obtained by the research program were not consistent with research hypotheses linking negative affect to corrugator activation and positive affect with the activity of the zygomaticus. There are a number of issues to consider with respect to fEMG measurement in VR. We suggest that differences in individual head shape and size can introduce contact issues with fEMG sensors that are integrated into the HMD. This limitation could have been mitigated by a screening process which removed participants whose head dimensions were not within tolerances established by a protocol (i.e. small head circumference = poor sensor contact) that could have been developed at an early stage in the research program. We have suggested that there is evidence that interpersonal differences can affect fEMG responses and that facial expressions associated with negative emotional states, such as the grimace response, can lead to ambiguous zygomaticus data. The focus of the research project on threat response and negative gradient fundamentally reduced the incorporation of interactive stimuli associated with positive valence, which limits the scope for increased zygomaticus activity. We should also state that despite clear instructions to each participant before the commencement of each of the experimental protocols, it was frequently difficult to discourage participants from speaking over the course of the experiment. These vocalisations often occurred at the onset of each trial in the form of participants attempting to use conversation to locate the presence of the observer or in the form of a constant dialogue with themselves as a reassurance measure against the stressful nature of the environment. In most instances severe instances of vocalisation led to those trials being excluded from the dataset but it was not possible to completely eliminate all instances of unwanted vocalisation. To summarise we feel that improved fEMG data capture devices designed for VR use and enhanced laboratory facilities may help to remove some of the issues with unwanted vocalisations; it is unlikely that they could be completely removed from a project of this nature.

We would propose that with further advances in wireless technology it would be preferable to conduct room-scale VR experiments in laboratory facilities that have a sufficient lab space and also incorporate an isolation booth for the observer. We believe that the laboratory space limitation for study two (Ch. 4) reduced the immersive qualities of the VE as participants were often close to the walls of the physical space and were made aware of their proximity to the walls by the VR chaperone safety feature of the Steam VR software. We believe that the use of a larger laboratory space and optimisation of a VE designed for that physical environment improved the validity of the measures recorded for study three and that future utilisation of an even larger laboratory space could improve results. In hindsight it may have been preferable to develop an acclimatisation environment before each study to ensure all participants were familiar with the general effect of VR technology. The majority of fEMG research is based on experimental protocols that are more linearly structured and controlled hence it was expected that more variability in room-scale ambulatory data would be observed, we suggest this is a systemic issue for all research of this nature.

The sample size of the third study was severely reduced (N=20, proposed N=35) due to university Covid 19 measures which resulted in a complete shutdown of all on site premises (March 2020). Further analysis was conducted on a combined dataset (Ch. 6) but the sample size of twenty participants for the third study limited the scope of that analysis.

This sample size constraint could have been addressed by increasing the sample to 200 and only selecting the upper and lower 10% of participants to get a clear and non-overlapping representation of high vs. low neurotics. Additionally participants could have been scored on other characteristics known to influence sensitivity to threat e.g. fear of heights and sensation seeking. For the regression analysis (Ch. 6) where trait neuroticism and openess were included, a larger sample size would have allowed additional personality measures to be added to the analysis. Further work could also examine a wider range of individual differences such as acrophobia [Biedermann et al., 2017] and sensation seeking [Zuckerman, 2008].

With respect to design of the virtual environments that utilised the threatening ice block mechanic. The development of a modular threat mechanic that could be easily tuned at the piloting phase to deliver a measurable rise in threat and allowed for agency on the behalf of the participant required considerable design, development and testing time from the research program schedule. Its delivery depended on 1) room-scale VR foot tracking sensors which allowed participants to cross gaps in a VE design suspended over virtual height and to look over ledges without triggering a virtual fall action 2) A VE environment aesthetic which placed a threat of environmental threat in context 3) Development of 3 individual ice-block templates (solid, crack and fall) which could be modularly placed in a VE and rearranged to scale threat, each individual block having its own effects e.g. sound and transitions between states (crack, fall). The research programmes event based methodology forced the analysis to use short time windows. These windows may not have always clearly distinguished between movements of participants through the VE. Future projects could increase accuracy by considering this in the VE design phase i.e. increasing size of interactive blocks, reducing the chance of overlapping actions. For study two sound effects were also added to the solid block which were different to the sound added for interactions with the crack blocks. This was added to ensure that responses to block interactions were not caused by a response to the sound of interacting with crack or fall blocks vs. the ambiguity of the silent interactions with solid blocks present in study one. Study three improved the design by;

1. Use of a larger laboratory space allowed for the presentation of a longer unbroken VE task, which additionally removed the need for a participants position to be reset between levels, breaking immersion.
2. The Height threat mechanic was broken out into a separate trial condition (Height vs. Ground Task).
3. Back-tracking was eliminated via a falling block mechanic which removed blocks greater than two rows behind the participant's position.
4. Tertiary stimuli e.g. sound on block interactions was unified for all interactions with the interactive block type.

A future research project could utilise the larger lab space to eliminate the turns at Sections 3-4 and 6-7 of study three (See Ch. 5 Methodology for detail). If each Section of interactive ice-blocks were offset at an angle as they appeared when a previous section was completed it may be possible to develop a "looping" version of the study three VE design. Participants could traverse the laboratory in a continuous circular direction, eliminating the need for the transitions between section rows and keeping the number of possible block interactions approximately the same for each Section [Razzaque et al., 2002, Souman et al., 2011, Steinicke et al., 2008]. This could also greatly increase the length of the task allowing for additional modulation of threat (See Ch. 6). Additional mechanics could gradually raise or lower the end goal doorway into a final position to ensure that participants were still goal-orientated and could see how their progress was generally advancing their position during the trial.

During the initial planning phase of the research program a range of VR technologies suitable for use in the project were assessed. Two VR headsets were available at the time.The Oculus Rift and the HTC Vive (See. Ch. 2 Methodology for device specifications). A decision was made to use the Vive device in order to use its more accurate laser based tracking vs. the optical solution used by the Oculus device as it was felt this would be a more flexible solution and allow for greater fidelity in analysis of behavioural data. Shortly after the commencement of the project a third device the Five (Fove Corporation,Tokyo, Japan) VR headset was released which included dedicated in-headset hardware and software for eye tracking. Research has been conducted into interpersonal differences and attention [Hahn et al., 2015, Armstrong and Olatunji, 2013] and the role of gaze fixation on perceived threat in VR [Rösler and Gamer, 2019, Reichenberger et al., 2020]. Accurate eye tracking data may have added a useful behavioural measure to the dataset but use of this headset was again not considered due to its lack of room scale VR tracking capacity. Accurate eye-tracking measures would also have enabled data to be analysed with regards to where a participant intended to move to, allowing additional measures of intent to be studied. Additionally changes in measure of pupil size could have been used to index arousal [Bradley et al., 2008, Partala and Surakka, 2003].

For study one a full body representation of the participant was rendered in the sedentary and room-scale conditions of the plank walk task. Additionally in the room-scale scenario this representation also operated with articulated knee and elbow joints which increased immersion for the user. However the development time required to articulate these joints, it was felt, reduced the time available to construct interactive mechanics for the second study. Also in piloting it was noted that representation of the hands and feet alone was sufficient to operate the ice-block mechanic and participants reported high levels of engagement with the task. Future research projects may wish to include additional separate VR trackers to increase the fidelity of movement data and to create a fully realised representation of participants body position within the VE. In the later stages of the research project untethered headset designs were released commercially such as the HTC Cosmos and Oculus Quest. We believe these devices can greatly reduce the technical demands on a psychophysiological study and can be ideally suited to studies which have no room-scale VR requirement. By the time of their release the project had fully adopted a Steam VR tracking solution attached to participants' feet and this had become an integral component of the design of VE's for this research project. The additional tracking devices were not supported by the HTC Cosmos or Oculus Quest.

We believe that this research program has consistently observed the latest developments in future technologies and integrated developments that would have a beneficial impact in our pursuit of the project's research goals. The project has sought to relocate to physical facilities which allow VE experiments to be increasingly capable of capturing interpersonal differences and applied advances in relevant technologies that permit better capture of this behaviour. We do acknowledge that such advances are ongoing and that the research undertaken poses new questions that cannot be answered fully by the analyses we have undertaken and that theoretical and technological developments should be considered for future research projects.

7.4 Future Work

Future projects may wish to replicate the hypotheses of this research programme substituting the negativity bias for the positivity offset posit of ESM [Cacioppo and Berntson, 1999, Cacioppo et al., 2012]. This behaviour should be observed as risky instead of risk averse behaviour and according to the positivity offset postulate, the counterpart to negativity bias postulate of ESM should be observed for relatively low levels of activation. In a VE designed to emulate study two (Ch. 4) a VE could be designed to stimulate exploration, it's first stage would reward exploratory behaviour in a VE environment with clearly defined boundaries, filled with vibrant interactive stimuli and noisy (non-negative) sounds, subsequent VE stages would reduce the dynamism of the environment filling the VE with a neutral grey fog with only a dull light as a stimulus to provoke movement towards it. The hypothesis being that as stimuli for the promotion of exploratory behaviour were reduced in magnitude only individuals with high trait openness would still show propensity for risky, exploratory behaviour. Future work may also wish to replace the fEMG measure with an EEG system. EEG measurements have high temporal resolution, permit measurement of neurophysiological changes related to emotion and are well-suited to event-based analyses [Djebbara et al., 2019]. This type of data could incorporate more insight into the decision making process before and after interactions within the VE and how participants' decision making is altered by exposure to level of threat and after activation of the highest levels of threat possible in the VE, e.g., interaction with fall blocks.

The logistic regression results from study four (Ch. 6) demonstrated that the behavioural measure of risk ratio was a good predictor for the likelihood of participant interaction with a fall block, i.e. a negative behavioural outcome. We suggest that a future research project may wish to reuse the VE design of study three and conduct a similar analysis that utilises all of the stages of that design. For example, the VE design could be modified to allow participant behaviour during the first stage of the VE to modulate their experience of threat in the remainder of the VE. This would represent a generative form of VE that can adapt to the behaviour of the individual to adjust their emotional experience. For example, the threat level of the VE could be adjusted downwards for participants who are risk averse. For those who are not risk averse, the VE could adapt in the opposite direction, increasing crack/fall blocks to increase threat. In this adaptive VR, the level of threat is calibrated to the individual. Hence it is an ideal mechanism for therapeutic applications of VR, such as treating phobias (fear of heights, fear of crowds) because the adaptive mechanism would acclimatise the individual before adjusting further [Freeman et al., 2018]. We would also propose that further research could be undertaken into the number of interactions required within the study to make accurate predictions about participant's future behaviour and that psychophysiological measures can also be used to drive an adaptive VE mechanism, e.g. [Kosunen et al., 2016].

This adaptive VE design could be further supplemented through the use of simple AI behaviour trees [Dey and Child, 2013, Lim et al., 2010] which are commonly operationalised in many game engines such as Unreal Engine. We propose that a future research project could supplement a real time behaviour tree, active during the course of an ice-block based trial, with live data based on behavioural measures used such as risk ratio. This nonparametric behaviour tree system [Shoulson et al., 2011] would take advantage of the discovery aspect of the ice block VE design i.e. participants are unaware of the nature of the blocks around them until they are interacting with the ones closest to them. The system could then learn from behaviour recorded from each prior interaction and modify blocks the participant has yet to reach (or modify previously triggered blocks). It would be expected that participants, given enough exposure to this system, may become aware that their actions have an effect on the level of threat they will encounter as they progress. The research questions of such a study would be twofold; do personality differences such as high neuroticism affect participants ability to learn from their actions and will participants modify their own behaviour in response to threatening stimuli and can a system which responds in real time to risk averse behaviour modify innate behavioural preferences towards or against threatening stimuli.

In recent decades growth in the mobile device market has continued to pursue innovation driven by consumer desire for larger screen sizes and multiple form factors capable of rendering multimedia content for viewing on high pixel density displays. High density pixel display for smartphone devices mass produced over large economies of scale led to the resurgence in development of VR headsets, and their subsequent adoption in research projects, as these displays could be used to present a high quality rendered graphics from within the housing of a head mounted display. Recently mobile focused system on a chip design (SOC) have progressed to the point where SOCs are capable of rendering the entire graphics pipeline from within a VR headset creating a closed loop system which does not require additional computing power to render VR applications.

Closed loop wearable VR HMD would not have impacted the research goals of this project to a large extent but rapid advancements in sensor miniaturization could offer research benefits to room-scale VR experimentation. On October 23 2020 Apple Inc (Cupertino California) released the iPhone 12 series of smartphones, one of the first devices commercially available with an integrated LiDAR (light detection and ranging) scanner. This integrated sensor system functions similarly to the array of sensors used by the HTC Vive room-scale tracking solution but is integrated within the body of the mobile device. It is likely that integrated LiDAR arrays will be incorporated into HMD technology over the next few years. This would enable highly accurate room-scale tracking. LiDAR also continuously scans an environment and can resolve objects and more complex physical areas potentially removing the need for separate sensors mounted on participants' bodies. A proposed VR/AR tracking device could also mix the physical lab environment with stimuli created and programmed in a 3D graphics package in the same fashion as AR devices are capable of overlaying stimuli with a view of the participants physical environment through head mounted transparent displays. LiDAR scanning technology enhances this capacity by being capable of overlapping real world objects onto created assets in such a way as the participants can physically move around visually obstructive real world objects and "discover" artificial stimuli in an exploratory fashion e.g. user opens physical real world box, the LiDAR enabled device detects the lid of the box being opened and then displays an artificially created interactive element within the real world box. Increased environment scanning fidelity in combination with room-scale methods established for this research program has potential for use to examine positive emotional responses via exploratory movement through an environment and positive stimuli discovery mechanics. Other than the innovation potential in experimentation design closed-loop wearable HMD devices could enable these devices may also allow room-scale VR experiments to be run remotely, increasing the sample size potential and helping to reduce the need for laboratory studies to take place in laboratory conditions which may be jeopardized in a post COVID-19 future, or prohibitively complex to manage.

In summary technical decisions on 3D engine choice must be considered at the earliest possible juncture with consideration to the scope of the research and the timescales upon which experimental studies are to be delivered. We believe that the VE designs proposed and delivered by the studies are representative of state of the art in current VR technology. We also believe that the unique libraries developed for behavioural tracking libraries could be further enhanced to allow for their adaptation in other research projects after due consideration was made to some inadequacies that were encountered during the development of each of the virtual environments. Overall we believe this research project has achieved its main goal in demonstrating the validity of room-scale VR applications to reliably induce threatening stimuli, provoke emotional responses and measure resultant interpersonal differences in risk averse behaviour. We believe it has demonstrated the validity of the use of current technological advancements to measure behavioural responses to a level of fidelity that was not previously possible in psychophysiological studies. We also hope that the work undertaken through the course of this research can serve as a basis to expand on these techniques and develop increasingly sophisticated interactive virtual environments which are ecologically valid and have implications beyond the scope of this current research.

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Appendix

Simulator Sickness Questionnaire

How much is each symptom affecting you right now?

General discomfort:

None Slight Moderate Severe

Fatigue:

None Slight Moderate Severe

Headache:

None Slight Moderate Severe

Eye strain:

None Slight Moderate Severe

Difficulty focusing:

None Slight Moderate Severe

Salivation increasing:

None Slight Moderate Severe

Sweating:

None Slight Moderate Severe

Nausea:

None Slight Moderate Severe

Difficulty concentrating:

None Slight Moderate Severe

Fullness of the head:

None Slight Moderate Severe

Blurred vision:

None Slight Moderate Severe

Dizziness with eyes open:

None Slight Moderate Severe

Dizziness with eyes closed:

None Slight Moderate Severe

Vertigo:

None Slight Moderate Severe

Stomach Awareness:

None Slight Moderate Severe

Burping:

None Slight Moderate Severe

Vertigo Questionnaire

Vertigo is the medical term used for symptoms which patients often describe as feelings of unusual disorientation, dizziness, giddiness, lightheadedness or unsteadiness. Click a number to indicate the degree to which each of the situations listed below causes feelings of vertigo, or makes your vertigo worse.

SCALE: Not at all Very slightly Somewhat Quite a lot Very much Not tried

Riding as a passenger in a car on straight, flat roads:

Not at all 1 2 3 4 5 Not Tried

Riding as a passenger in a car on winding or bumpy roads:

Not at all 1 2 3 4 5 Not Tried

Walking down a supermarket aisle:

Not at all 1 2 3 4 5 Not Tried

Standing in a lift while it stops:

Not at all 1 2 3 4 5 Not Tried

Standing in a lift while it moves at a steady speed:

Not at all 1 2 3 4 5 Not Tried

Riding in a car at a steady speed:

Not at all 1 2 3 4 5 Not Tried

Starting or stopping in a car:

Not at all 1 2 3 4 5 Not Tried

Standing in the middle of a wide open space (e.g. large field or square):

Not at all 1 2 3 4 5 Not Tried

Sitting on a bus:

Not at all 1 2 3 4 5 Not Tried

Standing on a bus:

Not at all 1 2 3 4 5 Not Tried

Watching moving scenes on the T.V. or at the cinema:

Not at all 1 2 3 4 5 Not Tried

Travelling on escalators:

Not at all 1 2 3 4 5 Not Tried

Looking at striped or moving surfaces(e.g. curtains, Venetian blinds, flowing water):

Not at all 1 2 3 4 5 Not Tried

Looking at a scrolling computer screen or microfiche:

Not at all 1 2 3 4 5 Not Tried

Going through a tunnel looking at the lights on the side:

Not at all 1 2 3 4 5 Not Tried

Going through a tunnel looking at the light at the end:

Not at all 1 2 3 4 5 Not Tried

Driving over the brow of a hill, around bends, or in wide open spaces:

Not at all 1 2 3 4 5 Not Tried

Watching moving traffic or trains(e.g. trying to cross the street, or at the station):

Not at all 1 2 3 4 5 Not Tried

Ocean Big 5 Questionnaire

DIRECTIONS: You are now being asked to describe yourself as accurately as possible. Please respond to all of the items using the scale provided. You should indicate your answer by encircling one number on each line. It is essential that your answers reflect how you see yourself in the present time, and not as you would like to see yourself either now, or in the future.

SCALE: Very Moderately Neither Moderately Very

Big 5 Question 1

unimaginative 1 2 3 4 5 6 7 8 9 imaginative

Big 5 Question 2

uncreative 1 2 3 4 5 6 7 8 9 creative

Big 5 Question 3

uninquisitive 1 2 3 4 5 6 7 8 9 curious

Big 5 Question 4

unreflective 1 2 3 4 5 6 7 8 9 reflective

Big 5 Question 5

unsophisticated 1 2 3 4 5 6 7 8 9 sophisticated

Big 5 Question 6

disorganized 1 2 3 4 5 6 7 8 9 organized

Big 5 Question 7

irresponsible 1 2 3 4 5 6 7 8 9 responsible

Big 5 Question 8

impractical 1 2 3 4 5 6 7 8 9 practical

Big 5 Question 9

careless 1 2 3 4 5 6 7 8 9 thorough

Big 5 Question 10

lazy 1 2 3 4 5 6 7 8 9 hardworking

Big 5 Question 11

silent 1 2 3 4 5 6 7 8 9 talkative

Big 5 Question 12

unassertive 1 2 3 4 5 6 7 8 9 assertive

Big 5 Question 13

unadventurous 1 2 3 4 5 6 7 8 9 adventurous

Big 5 Question 14

unenergetic 1 2 3 4 5 6 7 8 9 energetic

Big 5 Question 15

timid 1 2 3 4 5 6 7 8 9 bold

Big 5 Question 16

unkind 1 2 3 4 5 6 7 8 9 kind

Big 5 Question 17

uncooperative 1 2 3 4 5 6 7 8 9 cooperative

Big 5 Question 18

selfish 1 2 3 4 5 6 7 8 9 unselfish

Big 5 Question 19

distrustful 1 2 3 4 5 6 7 8 9 trustful

Big 5 Question 20

stingy 1 2 3 4 5 6 7 8 9 generous

Big 5 Question 21

relaxed 1 2 3 4 5 6 7 8 9 tense

Big 5 Question 22

at ease 1 2 3 4 5 6 7 8 9 nervous

Big 5 Question 23

stable 1 2 3 4 5 6 7 8 9 unstable

Big 5 Question 24

contented 1 2 3 4 5 6 7 8 9 discontented

Big 5 Question 25

unemotional 1 2 3 4 5 6 7 8 9 emotional