# Differential effect of neutral and fear-stimulus virtual reality exposure on physiological indicators of anxiety in acrophobia

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## ABSTRACT

This paper presents a study which explores the physiological and behavioural indicators of anxiety during exposure to a virtual reality environment. Using 10 participants (5 with acrophobia and 5 control) the study aimed to determine whether an increase in heart rate (HR) from baseline to VR exposure is a sufficient measure for effectiveness of a virtual reality exposure therapy (VRET) stimulus, or whether there is a mediating effect of neutral VR exposure which should be taken into account. The participants all explored an immersive cityscape at ground level and at height, and both subjective and objective measures of physiological arousal were recorded. It was found that the VRET was successful in inducing an anxiety response in the participants with acrophobia, and moreover demonstrated that an increase in HR from baseline to VRET on its own should not be considered a reliable indicator of VRET efficacy, but that there should be an adjustment for the effect of neutral VR exposure on physiological arousal.

## 1. INTRODUCTION

Irrational or excessive fear or anxiety is a common problem, with an estimated 40% of the general population suffering from one or more fears of a specific object or situation in the course of their lifetime, with around 10% developing a specific phobia (Van Houtem et al., 2013). Whilst some of these may be the direct result of a traumatic or harmful experience, many others are acquired through transmitted information or observation learning (Rachman, 1977). This can make them challenging to treat, as it is often not just a simple case of addressing the underlying causative incident, but modifying the underlying pathological fear structures (Edna B. Foa, Huppert, & Cahill, 2006).

One of the most common forms of treatment for this type of therapy is gradual controlled exposure to the feared stimulus ("exposure therapy"). Hofmann (2008) reports that exposure therapy involves a cognitive process of the extinction of fear by the absence of harm during exposure, and is at least as effective as the more complex cognitive therapy. Emotional processing theory (E. B. Foa & Kozak, 1986) suggests that exposure therapy may work by breaking the stimulus-fear-avoidance cycle, producing new networks by exposing the individual to the feared stimulus without harm. Indeed, even imagined exposure to the feared consequence strengthens the discrimination between "thoughts about harm" and "real harm" (Edna B. Foa et al., 2006). It is this ability of "imagined exposure" which is of particular interest, as it allows for the possibility of creating controlled virtual environment to support graded exposure.

This "virtual reality exposure therapy" (VRET) is being increasingly used to treat a variety of phobias and anxiety disorders (e.g. Carlin, Hoffman, & Weghorst, 1997; Emmelkamp et al., 2002; Mel Slater, Pertaub, Barker, & Clark, 2006), and has been demonstrated to be effective in reducing symptoms in vivo as well as in VR (Coelho, Waters, Hine, & Wallis, 2009; Parsons & Rizzo, 2008). However, the outcomes are not always consistent, and this may be due to a number of factors, including the individual patient (Krijn, Emmelkamp, Olafsson, & Biemond, 2004; Wiederhold & Wiederhold, 2000), the study protocol (Owens & Beidel, 2014; Parsons & Rizzo, 2008) or the virtual environment itself (Miyahira, Folen, Stetz, Rizzo, & Kawasaki, 2010; M. Slater, Pertaub, & Steed, 1999).

This paper is concerned with the last of these factors, the virtual environment, and the influence this may have on the efficacy of the VRET and hence on the treatment outcomes.

## 2. BACKGROUND

Exposure therapy is a neural reconditioning process, which presents the feared stimulus in the absence of harm, undermining the negative associations and creating a new cognitive network (E. B. Foa & Kozak, 1986). It is plausible that even exposure to virtual stimuli may support this cognitive reconditioning process, and indeed this hypothesis is supported by a number of reviews studying VRET outcomes (Coelho et al., 2009; Krijn et al., 2004; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008). However, studies vary in the reported efficacy of the VRET, and this may in part be due to the ability of the virtual environment (VE) to provide a suitable stimulus for effective exposure therapy.

Owens and Beidel suggest that effective VRET must meet three conditions in order to be consistent with the principles of emotional processing theory. Firstly, the exposure in the VE must be able to be generalised to real-life, secondly, the patient must feel present in the VR, and finally the VE should elicit physiological arousal (Owens & Beidel, 2014). To a certain extent, the first condition can be met by careful design of the VRET application. The second and third are closely associated, as a VE is unlikely to elicit physiological arousal without a sense of presence in the exposure to a virtual fear stimulus, and both behavioural observation and physiological measurement are considered valid measures of presence (Lee, 2004). Thus in order to evaluate the potential efficacy of a VRET application, we can use either behavioural observations or physiological indicators, as well as more traditional measures of presence.

Previous studies have shown that VRET can elicit physiological arousal (Owens & Beidel, 2014; Mel Slater et al., 2006), but this has not generally been correlated to observable behaviour changes or subjective distress. For example, a study which compared reported presence to physiological observations used only a general presence questionnaire, and did not include any behavioural observations (Meehan, Insko, Whitton, & Frederick P. Brooks, 2002). When evaluating such studies, it is difficult to be certain whether the increased physiological arousal can be attributed to a fear stimulus, or to some other factor of the virtual environment. In addition, it is not certain whether exposure to virtual reality can itself trigger physiological arousal, even in the absence of fear or distress.

Slater et al., (2006) demonstrated a significant difference in heart rate (HR) between speaking in an empty virtual room and speaking to a virtual audience, confirming that HR within a virtual environment is dependent on the level of stimulus. However, in the absence of baseline (non-VR) HR data, the level of elevation of HR which would indicate successful fear-arousal is unclear. It has been suggested that an increase in HR >15 bpm is indicative of sufficient immersion for exposure therapy (Walshe, Lewis, Kim, O'Sullivan, & Wiederhold, 2003), but again this study did not examine the change in HR from non-VR to baseline VR, and so could not differentiate between rise in HR due to the fear-inducing stimulus from that induced solely by exposure to VR.

We suggest that in order to evaluate whether a virtual environment meets the conditions necessary for VRET, it is necessary to demonstrate that the fear stimulus has a differential effect on physiological arousal beyond that which may be induced by baseline VR exposure. In this preliminary study we expose both an acrophobic group and a control group to an immersive VR environment followed by a virtual height stimulus. We hypothesise that there will be an increase in HR on exposure to VR, even in the absence of a fear stimulus, and that there will be a further increase in HR when participants are exposed to the virtual height. Further, we hypothesise that there will be a differential change in HR between phobic and non-phobic participants when exposed to height, but not in the other conditions. Finally, we hypothesise that there will be correlations between observed behaviour, reported anxiety and HR in the VR exposure.

## 3. METHOD

The study was a mixed 3x2 factorial design, with one within-subjects factor (VR condition), and one between-subjects factor (acrophobia).

The VR exposure and the acrophobia tendency were the independent variables, and heart rate (HR) was the primary dependent variable. In addition, presence, subjective fear and behavioural observations were recorded.

### *3.1 Participants*

Ten participants were recruited from the School of Creative Technologies. There were 8 males and 2 females, aged from 19-26 (mean age 22). Five participants reported mild or moderate acrophobia, and five reported no fear of heights.

**Table 1.** *Participant demographics.*

| **Participant** | **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Acrophobia** | None | None | Mild | Mild | Mild | None | None | Moderate | Moderate | None |
| **Age** | 21 | 22 | 24 | 20 | 26 | 19 | 21 | 21 | 21 | 21 |
| **Gender** | m | m | m | m | m | m | m | f | f | m |

### *3.2 Measures*

On arrival, participants were asked for a self-rating of their fear of heights. This was coded as none=0, mild=1 and moderate=2. Heart rate data was recorded continuously via a Polar H7 monitor during the pre-exposure, VR-neutral exposure and VR-height phases of the study.

Behavioural observations were made throughout the interaction with the virtual environment. Behaviours were coded from 0 (no signs of anxiety) to 5 (signs of severe anxiety).

A post-test short questionnaire (M. Slater & Usoh, 1993) evaluated the sense of presence during the VR exposure, and participants were also asked to rate their subjective sense of fear during the exposure on a scale of 1-10.

### *3.3 Experimental setup*

As previously discussed, it is important to induce a sense of presence ("being there") for effective VRET. In order to evaluate the differential effect of VR stimuli on HR, we need to use a virtual environment which is optimised to support the induction of presence. Since the visual quality of the environment and the level of interaction available to the user are both important factors in inducing a sense of presence (North & North, 2016), we designed a realistic virtual cityscape and used full body motion capture to support fully immersive interaction.

For the virtual environment to run smoothly during the VR exposure several optimisations had to be made, one of which was combination of low and high polygon 3D assets to ensure that frame rates do not drop below comfort zone of around 75fps. A technique known as *Level of Details* (LODs) was used to dynamically adjust the detail of meshes in the virtual environment depending how close the participant is to the object. The further away the object, the lower the detail it will have and closer you get towards it the sharper the textures and more polygons will be visible resulting in greater overall performance and more pleasant experience.

A 3D model of a cityscape was created in Autodesk 3DS Max and then deployed in Unreal Engine 4. Physical based rendering (PBR) was used in order to create realistic lighting effects. A walkway between two buildings was constructed on the 5th floor, and this was made of a combination of concrete and glass textures. Finally, there was a lookout point on the roof of a seven-story building (Figure 1).

**Figure 1.** *From left to right: Cityscape, concrete and glass walkway and roof lookout point.*

The participants' motion was captured using Vicon T10 cameras and a full-body motion capture suit with 59 markers. A PC was used which was capable of running the motion capture and application in real time at a minimum frame rate of 120fps. Between the Motion Capture hardware and Unreal Engine 4 it was essential to have a solution which streamed the data captured from the body motion, and translate it to a rigged animation in real time. For this we used Vicon's Pegasus retargeting software. This allows us to bridge both technologies seamlessly and result in highly responsive real-time full body control in the virtual environment.

Participants viewed the virtual environment using the Oculus Rift DK2, and their movements were mapped directly onto a self-avatar, with real-time rendering of shadows.

*3.4 Procedure*

Participants were briefed on the study and signed an informed consent sheet. They were also reminded that they could stop the study at any point if they felt uncomfortable or overly anxious. They were then fitted with the Polar H7 monitor on a chest strap, and then donned a motion capture suit. Fifty-nine optical markers were applied at predefined anatomical landmarks (Figure 2), and a calibration sequence of movements was performed. During this time (3-5 minutes) a baseline HR was recorded.

**Figure 1.** *The motion capture suit with optical markers.*

The participants were then fitted with the head mounted display and were able explore the cityscape at ground level. They were given a few minutes to acclimatise to the VR environment and the VR-baseline heart rate was recorded during this time.

Finally, the participants were asked to close their eyes for 10 seconds while they were moved to the elevated areas of the virtual environment. They were given a number of tasks, including stepping onto the bridge, crossing over a glass area, and leaning over the rooftop to look down to the street, which accumulated around 10 to 15 minutes for each participant's total exposure. Again, HR was recorded during this VR-height exposure.

After the completion of the tasks at height (or sooner if the participants requested "escape" from the scenario), the participant completed a questionnaire with 3 questions to score the sense of presence, a Likert score for the level of fear experienced, and a free-text question regarding aspects of the experience which interfered with the sense of presence.

## 4. RESULTS

*4.1 Effect of VR condition on Heart rate*

A repeated measures ANOVA was conducted to compare the effect of no-VR, VR, and VR-height exposure on heart rate (HR). There was a significant effect of VR condition on the mean HR [$F(2,18) = 87.54$, $p = .000$.].

Post hoc comparison demonstrated that HR was significantly lower in no-VR than VR [$t(9)=10.57$, $p=0.00$.], lower in no-VR than VR-height [$t(9)=5.51$, $p=0.00$.], and lower in VR than VR-height [$t(9)=8.19$, $p=0.00$.] (Figure 3).


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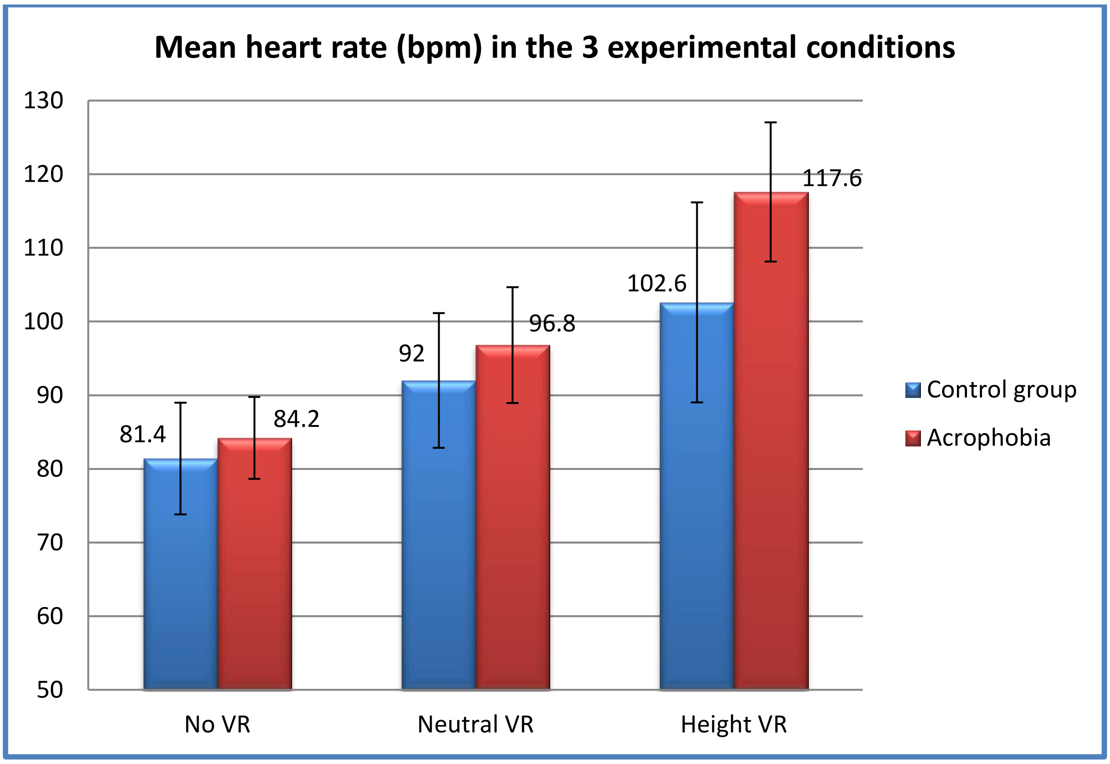


**Figure 3.** *The differential effect of non-VR, neutral VR and VR-height on heart rate.*

### *4.2 Differential effect of acrophobia on HR during fear stimulus*

There was a positive correlation between the level of acrophobia and the VR-height HR [$r = 0.679$, $n = 10$, $p < 0.05$]. There was no correlation between the level of acrophobia and the baseline HR or neutral-VR HR.

### *4.3 Correlation between behaviour, HR and reported anxiety during fear stimulus*

There was no anxious behaviour observed while the participants explored the city street, and all the observed anxious behaviour occurred during exposure to the height stimuli. There was a positive correlation between the observed anxious behaviour and the reported level of fear [$r = .909$, $n = 10$, $p = 0.00.$], between the observed behaviour and the HR at height [$r = .655$, $n = 10$, $p < 0.05$], and between the reported level of fear and the HR at height [$r = .827$, $n = 10$, $p < 0.01$].

## 5. DISCUSSION

This study set out to explore the differential effect of neutral and fear-stimulus VR exposure on physiological indicators of anxiety. There was a significant increase in HR on exposure to neutral VR environments in both groups, with a mean rise of 12 bpm. This rise was not associated with any anxiety behaviour, and was not correlated to the level of acrophobia. Since the suggested indicator for successful immersion for exposure therapy is only 15 bpm (Walshe et al., 2003), it would appear that we run the risk of a false positive evaluation of a VRET if we compare non-VR HR to exposure HR without adjusting for the direct effect of neutral VR exposure on HR.

The exposure to the VR height stimulus elicited a further significant rise in HR in all groups, but this time there was a significant correlation between reported acrophobia and the increased HR, with the mean increase in acrophobia being 19.4 bpm, compared to a rise of 10.6 bpm in the control group. Furthermore, all of the acrophobia group experienced a minimum rise of 15 bpm when moving from the neutral VR stimulus to the VR height stimulus. This suggests that the 15 bpm could indeed be a useful indicator of a successful exposure in a VRET environment *but only when it has been measured from a neutral VR* baseline. Indeed, when the increase in HR is compared directly to baseline, without adjusting for VR exposure, 80% of the control group (no acrophobia) exhibit a rise >15 bpm, without showing any sign of anxiety behaviour or reported fear.

This study is not without its limitations. The initial sample size is small, and does not have an equal gender balance between groups, additionally all participants do come from the School of Creative Technologies which is a clear limitation. Although this may not have influenced the results, a larger sample with a more homogenous


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demographic distribution is needed to confirm these initial findings. Furthermore, activity is known to influence HR, and although the participants were able to move around in all three conditions, it was not possible to completely control for any potential effect of movement on HR. A follow-up study with seated participants would help to identify any movement-artefacts in the recorded HR data. Finally, there were a number of incidents which caused a break in immersion, including "stepping off the edge", hearing other voices in the motion capture room, and "retargeting errors" on the hands of the avatar. For a future study, the participants would be issued with noise-cancelling headphones, and a more robust smoothing algorithm used to maintain consistent movement of the avatar. Whilst there is a good correlation between observed behaviour scores and the respective self reporting of anxiety and the recorded heart rate, the behaviour coding was not a standardised coding system but was created bespoke for the project. The observational data was recorded by the author without prior knowledge of the behaviour coding. The coding of behaviour was then designed by a second member of the team and then applied to the observational data. This was then checked and found to be relatively consistent in its application and interpretation across the participants by a third member of the team. Such an approach, whilst mitigating bias, does have limitations and in future work a blind double coding approach will be applied from the outset. It has been suggested that passive haptics can significantly increase presence in VR (Meehan et al., 2002), and thus the use of a raised surface for the bridge, and a small platform for the roof would be used in future studies

In summary, this study is the first to indicate the need to adjust for the rise in HR in neutral VR before using HR increases as an indicator for successful VRET fear stimulus. It is important to elicit the physiological and behavioural responses of anxiety during exposure therapy in order to achieve successful extinction of fear during the therapeutic process (Owens & Beidel, 2014), and careful evaluation of the VRET stimulus environment before deployment should facilitate more consistent outcomes.

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