The effect of virtual reality in reducing preoperative anxiety in patients prior to arthroscopic knee surgery: A randomised controlled trial

Anitra Robertson
Professor Riaz Khan
Professor Daniel Fick
Associate Professor William B Robertson
Surgical Realities Pty Ltd, Subiaco, Western Australia

Dr DG Rajitha Gunaratne
Curtin University
Bentley, Western Australia

Professor Riaz Khan
Professor Daniel Fick
Dr Shanil Yapa
The Joint Studio, Nedlands, Western Australia

Dr Vanessa Bowden
University of Western Australia
Nedlands, Western Australia

Professor Riaz Khan
Professor Daniel Fick
Associate Professor William B Robertson
Curtin University, Department of Computing
Bentley, Western Australia

Professor Hunter Hoffman
University of Washington, Human Interface Tech Lab
Seattle, Washington, USA

Professor Ramesh Rajan
Monash University
Melbourne, Victoria, Australia

Abstract Preoperative anxiety positively correlates with postoperative levels of pain, analgesic use and length of hospital stay. This preliminary study aimed to determine if the principle of distraction, using a relaxing Virtual Reality (VR) immersion, would reduce preoperative anxiety in patients undergoing arthroscopic knee surgery. Sixty patients were randomised into three groups (Standard care group, Virtual Reality group and iPad group). Anxiety scores (Hospital Anxiety and Depression Scale), Galvanic Skin Response (GSR), heart rate and blood pressure were measured pre and post intervention. The Standard care group received no intervention. The iPad group watched a video slideshow of beaches around the world and the VR group experienced a virtual beach immersion. Guided relaxation audio content (via headphones) was replicated across VR and iPad groups. Planned comparisons showed a significant difference between the average GSR measures at Time 1 and Time 2 between the Standard group and VR group. GSR measures for the Standard care group increased by 54 per cent from time 1 to time 2 and the VR and iPad groups reduced slightly, demonstrating an ameliorating effect on anxiety levels. A marginal difference between the Standard care group and VR group in anxiety change scores was reported. Whilst the VR condition reduced anxiety more than Standard care in both GSR and Anxiety change score measures, it provided no significant advantage over iPad condition. In conclusion, distraction using VR and iPad temporarily reduces self-reported anxiety levels and GSR measures compared to standard care in patients prior to knee arthroscopy. Further study is required to determine how long-lasting these benefits are in a clinical setting. The continuing advancements in VR technology, including immersion quality, present an opportunity to investigate the application of VR as a ‘digital pre-med’.

Keywords—Preoperative anxiety; virtual reality; distraction.

I. INTRODUCTION

Anxiety accompanies numerous physical and psychological conditions and can have a debilitating effect on the wellbeing of patients of any age or culture. The majority of patients admitted for elective surgery experience some degree of preoperative anxiety. The extent of this anxiety is influenced by numerous factors including patient age, sex, their underlying physical and mental wellbeing, the type of surgery, previous experiences with surgical procedures, familiarity with, and willingness to undergo the proposed operation, rapport with medical and nursing staff and personal susceptibility to stressful situations.

In particular, the time spent at the preoperative waiting bay has been identified as the period when most patients are likely to imagine the potential dangers of their surgery, as well as most acutely envisage their pain. These dangers may include a perceived or actual threat of death or physical harm whilst in the operating theatre, the risk of postoperative complications, or factors such as an unfamiliar environment, dependence on strangers, separation from family members and/or a sense of vulnerability.

The emotional response elicited in this pre-surgery environment, results in activation of the sympathetic and parasympathetic nervous systems as well as aspects of the endocrine system. Stimulation of these pathways leads to an overall constriction of blood vessels and an increase in heart rate, blood pressure and diaphoresis (sweating). Furthermore, anxiety can increase plasma adrenaline levels.
by up to forty per cent increasing cardiac excitability and the risk of developing pathophysiological responses\textsuperscript{12} (such as heart attacks). While the triggers for anxiety vary greatly between individuals, the effects of extensive or prolonged states of anxiety are often similar and can include heart sinus tachycardia, hypertension, cardiac arrhythmias, an increase in postoperative pain and analgesic requirements, as well as an increase in time spent recovering both in hospital and in the community\textsuperscript{2,13-16}.

Typically, anaesthetists utilise the inpatient preoperative visit to establish rapport, answer questions and allay any immediate patient concerns, which can help reduce the patient’s anxiety. Despite the well-documented possible adverse effects of preoperative stress on surgery and the recovery period, an increase in patient numbers and time constraints has altered the traditional perioperative routine\textsuperscript{17}. Day surgeries, with same day admission (SDA) and limited pre-anaesthetic clinics (PAC) have become the standard for surgical and anaesthetic practice and dramatically decrease the amount of time available for patients to communicate their concerns.

The prescription of anxiolytic or sedative medications is an often-utilised treatment options for in-patient anxiety\textsuperscript{5}. These medications have a varying efficacy for patients, and can be complicated by factors including addiction, tolerance, polypharmacy, anaphylaxis (a severe allergic reaction), end-organ failure, and rarely, death\textsuperscript{18}. Additionally, it is not uncommon for patients to simply refuse pharmacological agents for anxiety in this setting\textsuperscript{19}.

Distraction is a strategy to divert attention away from a stressor and towards other thoughts or behaviours that are unrelated to the stressor\textsuperscript{31}. They have been shown to be effective during medical procedures\textsuperscript{50}. Virtual Reality is a paradigm shift in how people interact with computers. Instead of looking at a hand held or desk mounted computer screen, the computer displays are head mounted. The user puts on a VR headset, where miniature computer screens are position near the patients’ eyes. Lenses are used to focus the images into the patients’ eyes such that the feel like they are inside the 3D computer generated environment. The current study used one of the early prototypes of commercially available VR headsets. (Samsung Gear VR) whereby a Samsung smartphone is snapped into a lightweight low cost VR apparatus. The smartphone thus act as both the computer and the display for the VR system. This headset is inexpensive, lightweight, highly portable, and easy to use.

Immersive VR focuses directly on the patient’s individual perception of stressful stimuli, attenuating their experience through distraction\textsuperscript{28}. VR immerses the user within an interactive virtual environment; head tracking allows the user to actively view the environment in 360 degrees, while noise cancelling headphones provide a matching soundtrack. The conscious experience of anxiety requires attention, of which we have a limited capacity\textsuperscript{52,53}. The interactive VR environment has been shown to reduce users’ available attentional resources, demonstrating decreased performance on divided attention tasks\textsuperscript{53}. Therefore, it can be hypothesised that in a VR environment, less attention is available to process incoming painful or emotionally stressful signals from the outside world. Consequently, patients have reported that VR results in a reduced experience of pain and less time thinking about pain\textsuperscript{28,34,37,41}. The efficacy of VR has been established in reducing reported pain and distress in patients undergoing burn wound care, chemotherapy, dental procedures, venipuncture and other painful procedures\textsuperscript{23,29,49,51}.

iPad distraction before surgery in children has been shown to be at least as effective at lowering anxiety as traditional pre-op sedatives\textsuperscript{67}. Another study demonstrated that iPad distraction significantly reduced the parent’s perception of their child’s level of anxiety, need for being held, and amount of crying during immunizations compared to no distraction\textsuperscript{68}.

The purpose of the present research is to evaluate the feasibility and clinical potential of immersive Virtual Reality in reducing anxiety in the preoperative setting. VR distraction was compared to iPad distraction and standard hospital care. It is hypothesised that patients who were immersed in the virtual environment during the preoperative period would experience less overall anxiety as shown by subjective and objective measures, relative to the standard care, control group.

II. MATERIALS AND METHODS

A. Inclusion and Exclusion Criteria

Inclusion criteria
- Arthroscopic knee surgery

Exclusion criteria
- Prior surgery in same knee
- Pregnant or actively trying to become pregnant,
- History of vestibular dysfunction or motion sickness
- Phobia of heights (acrophobia)
- History of any psychological disorder
- Parkinson’s disease, Multiple Sclerosis or Muscular Dystrophy
- History of alcohol or substance abuse

B. Research Design and Setting

This study was approved by the Ethics Review Board at Hollywood Private Hospital. Each patient signed an informed consent form. Participants were not compensated for their participation. The study is a single-centre randomised control trial of 60 participants. Informed patients meeting the inclusion and exclusion criteria were given verbal and written details at time of consenting for surgery in the clinic rooms. They were then randomly allocated into one of three groups (Control, VR or iPad) using a random number generator. The project was conducted in the preoperative waiting area at a private hospital in Perth, Western Australia. Participants were not made aware of their allocated group until after their response to the initial Hospital Anxiety and Depression Scale (HADS) questionnaire and initial blood pressure (BP) and pulse had been recorded. The participants then had a Galvanic Skin Response (GSR) sensor with finger cuffs attached (Image 1) and were continuously monitored during the intervention. Post-intervention, patients repeated the HADS questionnaire and had their blood pressure and heart rate recorded again.
GSR is a measurement of skin conductance and is one of the most sensitive markers for emotional arousal. Changes in skin conductance in hand and foot regions are altered by emotional stimulation\(^6\); the higher the arousal, the higher the skin conductance. Skin conductance is not under conscious control. Instead, it is modulated autonomously by sympathetic activity which drives human behavior, cognitive and emotional states on a subconscious level. Skin conductance therefore offers direct insights into autonomous emotional regulation.

C. Materials

Standard hospital blood pressure and heart rate monitors, a GSR sensor with two finger cuffs. Patients allocated to the VR intervention group were asked to wear a Samsung Gear VR Headset and a pair of QuietComfort®25 Acoustic Noise Cancelling® Headphones. The VR headset and headphone were run by a Samsung Note 4 mobile phone. The iPad intervention group watched videos of beaches on an iPad 4 Retina with QuietComfort®25 Acoustic Noise Cancelling® Headphones.

D. Intervention

The control group received standard hospital care. The VR group received 9 minutes of VR immersion of The ‘Perfect Beach’ scenario developed by Patrick O’Luanaigh\(^55\) (Image 2). This experience, set on a tropical beach, included waves lapping against a sandy shore complete with blue skies and birds, overlayed with audio recording of a female narrated progressive muscle relaxation technique. The iPad group watched ‘Beautiful beaches from around the world’ for 9 minutes with the same narrated audio (Image 3). All participants received standard care and monitoring plus attachments of the GSR sensor to their 2\(^{nd}\) and 3\(^{rd}\) fingers of their dominant hand. They were otherwise left to their own privacy for the nine-minute period (Image 4).

E. Outcome

Subjective measurement of anxiety was obtained via the HADS questionnaire. HADS scores were recorded both prior to and following the nine-minute waiting period in the preoperative waiting bay. The HADS questionnaire comprises of 14 questions in total. Each question contains four possible answers, with a score between 0-3. The overall score brackets being normal (0-7), borderline abnormal (8-10) and abnormal (11-21). The anxiety related questions were analysed.

Objective measurement of anxiety included both pre- and post-intervention heart rate and blood pressure recordings as well as the average Galvanic Skin Response recorded over the entire nine-minute waiting period. GSR is non-invasive and non-painful. It involves two finger sensors being attached continuously to each patient. This monitors changes in the electrical properties or autonomic nerve responses of the skin and sweat glands\(^56\). It has been previously shown to detect arousal from a state of relaxation with a success rate of 90.97% and has good reproducibility\(^57\). Participants’ heart rates and blood pressures were recorded using a digital monitor.

F. Statistical Analysis

As we have made clear a priori hypotheses concerning the relationship between VR and the other care options (standard and iPad), in all cases we followed up the one-way ANOVAs with planned contrasts that directly evaluated our specific hypotheses\(^66\). This involved comparing the standard group to the VR group, and comparing the iPad group to the VR group. Descriptive statistics were presented as mean (standard deviation) for all continuous variables and as proportions for categorical variables. Examination of the data revealed no outliers (±3 SDs from the mean) and the statistical analysis was performed using SPSS Software on de-identified data.

III. RESULTS

A total of 60 patients were recruited into the study between September 2015 and February 2016. The mean age of participants was 47 years (range 17 - 82) with 22 females and 38 males recruited. A power analysis suggested that recruiting 60 participants (20 per group) would yield 0.80 power to detect a large effect size (f = 0.41) at a .05 alpha level. Effect sizes for t-tests are estimated using Cohen’s d (small = .20, medium = .50, large = .80). To ensure the random assignment to intervention groups was effective we examined age and gender allocation. A one-way ANOVA showed no effect of group on age (F < 1). A chi-square test also showed no difference in the number of males and females assigned to each group (χ²(2) = 1.87, p = 0.393). Random assignment was therefore considered effective.

The VR intervention was well tolerated by all participants. While mild motion sickness or immediate discomfort secondary to the headset were the two main potential issues explored during the planning phase of the project, none of the participants in this study reported such issues.

Table 1. Means (with standard deviations in brackets) for Standard care, iPad, and VR intervention groups. For all except GSR, change scores are presented as Time 2 score minus Time 1 score. For GSR, a percentage change from Time 1 (30secs – 90secs) to Time 2 (6mins – 7mins) is used. Also presented are p-values for all planned comparisons reported, where significant values (p < .05) is indicated with an *.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Standard</th>
<th>iPad</th>
<th>VR</th>
<th>Standard vs. VR</th>
<th>iPad vs. VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanic Skin Response (GSR)</td>
<td>54.35(113.38)</td>
<td>-3.97(48.81)</td>
<td>-4.79(55.47)</td>
<td>0.048*</td>
<td>0.964</td>
</tr>
<tr>
<td>HADS – Anxiety</td>
<td>-0.32(1.63)</td>
<td>-1.47(2.63)</td>
<td>-1.6(2.33)</td>
<td>0.055</td>
<td>0.875</td>
</tr>
<tr>
<td>Heart Rate (HR)</td>
<td>1.05(5.84)</td>
<td>-2.6(5)</td>
<td>0.16(5.2)</td>
<td>0.618</td>
<td>0.108</td>
</tr>
<tr>
<td>Systolic Blood Pressure (SBP)</td>
<td>1.05(10.84)</td>
<td>-0.44(10.35)</td>
<td>-0.32(11.57)</td>
<td>0.741</td>
<td>0.972</td>
</tr>
<tr>
<td>Diastolic Blood Pressure (DBP)</td>
<td>-0.74(9.67)</td>
<td>-3.89(12.07)</td>
<td>5.06(13.89)</td>
<td>0.152</td>
<td>0.050</td>
</tr>
</tbody>
</table>

A. Galvanic Skin Response – Percentage change from Time 1 (30secs – 90secs) and Time 2 (6mins – 7mins)

A one-way ANOVA examining the effect of group on the Galvanic Skin Response (GSR) percentage change from time 1 (30sec – 90sec) to time 2 (6min – 7min) revealed a significant effect (F(2,51) = 3.36, p < .042). There was a significant difference between standard and VR groups (t(36) = 2.04, p < 0.048), where the VR group showed a greater reduction in GSR compared to the standard group. Although in the predicted direction, there was no significant
difference between the iPad and VR groups ($t < 1$), suggesting that, while the low cost VR reduced GSR more than the Standard treatment, the small advantage it provided over iPad group was not significant.

### B. HADS – Anxiety change

A one-way ANOVA examining the effect of group on the HADS-Anxiety subscale (Anxiety at time 2 (6mins – 7mins) minus Anxiety at time 1 (30secs – 90secs)) revealed no significant effect ($F(2,55) = 1.92, p = .156$). There was a marginal difference between standard and VR groups ($t(37) = 1.99, p = 0.055$, Cohen’s $d = .63$), where the VR group trended towards a greater reduction in Anxiety compared to the standard group. Although in the predicted direction, there was no difference between the VR and iPad groups ($t < 1$), suggesting that, while the VR reduced anxiety more than the Standard treatment, the small advantage it provided over iPad group was not significant.

### C. Heart Rate (HR)

A one-way ANOVA examining the effect of group on Heart rate (HR) change (HR at time 2 (6mins – 7mins) minus HR at time 1 (30secs – 90secs)) revealed no significant effect ($F(2,54) = 2.35, p = .105$). There was no difference between the standard and VR groups ($t < 1$), and no difference between the iPad and VR groups ($t < 1$).

### D. Systolic Blood Pressure (SBP)

A one-way ANOVA examining the effect of group on Systolic Blood Pressure (SBP) change (SBP at time 2 (6mins – 7mins) minus SBP at time 1 (30secs – 90secs)) revealed no significant effect ($F(2,51) = 1.65, p = 0.108$).

### E. Diastolic Blood Pressure (DBP)

A one-way ANOVA examining the effect of group on Diastolic Blood Pressure (DBP) change (DBP at time 2 (6mins – 7mins) minus DBP at time 1 (30secs – 90secs)) revealed a marginal effect ($F(2,51) = 2.53, p = .090$). There was no difference between the standard and VR groups ($t < 1$), and no difference between the iPad and VR groups ($t < 1$). Comparing VR vs. iPad, results were in the predicted direction (a slight advantage of VR over iPad), for both subjective (HADS) anxiety and GRS measures, however there was no significant advantage of VR over the iPad condition.

The positive results in the immersive VR group and iPad group support how an attention-capturing medium such as VR is capable of maximising the amount of attention drawn away from the ‘real world’, allowing patients to tolerate anxious preoperative situations. Our current results show that the pre-surgery waiting bay experience could be improved by the addition of these novel technologies. Furthermore, it also indicates that VR or iPad use could be applied in other stressful situations with similar anxiolytic effects, thereby offering exciting new avenues for research.

Similarly, recent studies utilising functional magnetic resonance imaging (fMRI), a neuroimaging procedure that uses MRI technology to map out brain activity measured by detecting changes associated with blood flow, have provided early suggestions that VR immersion may reduce physiological responses to stressful stimuli (e.g., pain) in addition to the subjective benefit of diverting conscious attention. This may explain the reduced psychological responses observed in the present study.

Both heart rate and blood pressure are generally dynamic markers that can change rapidly in response to various emotional or physical stimuli. These measurements were not recorded with accompanying situational details such as patient movement or contact with medical staff. It is therefore difficult to assess whether the time-specific values observed represented the patients’ overall level of anxiety across the seven-minute period or whether they reflect acute reactions to situational stimuli such as VR or iPad interventions. To help address this in further studies, it is suggested that results across the entire allocated time period are recorded instead of individual measurements at specific time points.

### V. Conclusion

The current study is the first to show the feasibility of using a head mounted VR display in the pre-op waiting bay. iPad use and immersive VR is a distinctive attention-capturing medium capable of maximising the amount of attention drawn away from the ‘real world’, allowing patients to tolerate anxious preoperative situations. This provides support for the growing body of literature in this area of distraction techniques.

Additional research is needed to explore whether patients can tolerate using VR for longer durations, and whether newer, more immersive VR systems coming onto the market are more effective than the low cost VR headset used in the current study. Investigating if (as predicted) reducing presurgical anxiety has any long-term health benefits (e.g., reduced post-operative pain) is also recommended.

With VR technology becoming more compact and affordable, providers are now dedicated to the development of new VR content across numerous fields including education, medicine, psychosocial therapy and general entertainment. VR technology is
currently undergoing major commercialisation. As the quality and variety of VR hardware and software improves, it is anticipated to increase the levels of distraction. Currently VR and iPad distraction both show potential as a cost-effective, safe and non-pharmacological adjunct to current preoperative anxiety management techniques as a ‘digital pre-med’, and further research and development is needed.

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APPENDIX
Image 1: Galvanic Skin Response (GSR): Sensor placement

Image 2: Virtual Reality (VR) content: Perfect beach VR Immersion developed by nDreams

Image 3: iPad video scene of beaches

Image 4: Patient in pre-operative waiting bay
REFERENCES


