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RESEARCH ARTICLE

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Virtual Reality Smart Wearable Technology for Personalized Chronic Pain Intervention

Sarah Katz[1,*]

[1]*Department of Cyberpsychology, Capitol Technology University, USA*

Abstract: While immersive distraction has been explored as a method of chronic pain intervention, fewer studies have assessed how wearable technologies can be leveraged to tailor such experiences to the individual patient. This preliminary qualitative empirical case study of ($N = 12$) chronic pain sufferers investigated how a heuristic algorithm could be used to detect how an individual patient responds emotionally to a visual cortisol stimulus rendered by each of the following images projected through a wearable visor: (A) Happiness (a woman smiling) and (B) Suspense (a rock climber climbing). The results showed that 75 percent of participants cited image A (happiness), while 25 percent cited B (suspense) as providing the most distraction. Participants were then asked to explain their rationale, with the majority of users saying they preferred to feel happy rather than overstimulated or physically strained during an immersive experience. The participants who preferred the Suspense option tended to cite enjoyment of sports they used to practice prior to the onset of the chronic pain condition. Based on these preliminary results, the basic design for a wearable simulation headset tool equipped with heuristic emotional detection was proposed to help personalize the distractive immersion experience for chronic pain sufferers. Such a device would support chronic pain researchers and clinicians to develop less invasive pain management techniques.

Keywords: smart wearables, personalized medicine, pain management, chronic pain, virtual reality

1. Introduction

The increased use of extended reality (XR) in the medical field has heightened scientific curiosity surrounding the benefits of immersive experiences for acute and chronic pain intervention. From cartoons used to decrease fear during blood draw in emergency pediatric settings to virtual reality (VR) headsets used for anxiety management across a variety of medical procedures, distractive techniques offer a new patient care method for both acute and chronic scenarios [1]. Pain as an experience causes a profound impact on the body. When exposed to pain, a part of the endocrine system called the hypothalamo-pituitary-adrenal axis (HPA) activates a feedback loop in the nervous system to increase the stress-regulating hormone cortisol in the blood. If stress is prolonged, as occurs in chronic pain sufferers, the HPA can begin regularly producing cortisol, eventually resulting in lower tolerance to both pain and stress [2]. This response can significantly affect quality of life, prompting research into many pain management methods. Therefore, as the healthcare space explores more technical care strategies, VR has emerged as a technology solution offering the user a complete immersive experience as a distraction from acute and chronic pain. This study seeks to further personalize the distractive experience through a smart headset that tracks the individual user's content preferences.

2. Literature Review

The year 2024 saw over 1.5 billion chronic pain sufferers across the globe, amounting to roughly 20% of the world's population [3]. Moreover, chronic pain has also been identified as a primary cause of both emotional distress and low productivity in the workplace [4, 5]. Although VR was suggested as a tool for general distraction from chronic pain as early as 2014, less focus has been given to specific emotional triggers that yield the greatest levels of distraction on an individual patient basis [6].

Furthermore, while various research has examined the physiological connection between chronic stress tolerance and psychological trauma, less attention has been granted to how chronic pain sufferers already accustomed to their pain might benefit from otherwise stressful stimuli, such as suspense at mild, intermittent exposure levels [7]. This perspective would compare how individuals who generally enjoy suspenseful content or thrill-seeking activities, but whose enjoyment has been hindered by chronic pain, could experience escapism versus those chronic pain sufferers who catastrophize their painful experiences alongside any input that could be considered stressful [8]. In this way, while previous studies have explored the effects of viewing a suspense film on audiences, a dearth of research remains surrounding how such an emotion could provide distraction from an overall negative experience such as chronic pain [9].

While virtual technology has seen many applications in the medical field, few studies have explored how pattern detection algorithms such as heuristics could analyze emotional input to inform personalized audiovisual experiences in patient care using smart wearable technologies [10]. Technology developers and healthcare professionals could thereby collaborate on a unique immersive experience for chronic pain intervention, with emotional inputs ranging from calming to intense following an initial assessment to determine each user's personal preference. Such a

*Corresponding author: Sarah Katz, Department of Cyberpsychology, Capitol Technology University, USA. Email: skatz@captechu.edu

device would use pulse sensing to track fluctuations in user excitation levels in response to a preliminary VR test stage, supplementing preliminary assessment of user preferences toward the virtual experience options. Finally, as previous studies have shown distraction to be more effective for acute rather than chronic pain due to the desensitization aspect in the latter condition, repeated exposure would be intermittent to avoid long-term cortisol release and maintain the novelty of the personalized experience for chronic pain sufferers [11].

2.1. Theoretical framework

This study builds upon previously proposed wearable technology for chronic pain, specifically movement-sensing devices focusing on user activities in the household [12]. However, rather than looking at movement, this study proposes a framework that assesses user reactions to an audiovisual stimulus, such as an image accompanied by a related sound effect. This framework aims to customize the user's experience while using the wearable simulative device.

As the increased heart rate has been tied to negative stress while decreased heart rate has been correlated with a more positive and relaxed state of mind, this device would use sensors to analyze user heart rate in response to viewing each of two images – one evoking positive emotions such as happiness and another evoking more stressful emotions such as participation in an extreme sport [13].

3. Research Methodology

3.1. Research design

Due to the positive results of previous qualitative studies that sought to explore participant preferences in depth, this research adopted a case study approach to enhance the personalized experience [14]. To simulate the preliminary assessment component of the proposed wearable device, participants were invited via email to view a presentation featuring interactive interfaces displaying both cheerful and suspense-inducing visual stimuli.

3.2. Participants

This study included 12 participants, all chronic pain sufferers aged 18–50 from within the Anglosphere. Participants were selected based on a shared common language to help avoid linguistic barriers in responses and the stated age range to account for an inclusive range of non-elderly (ages 65 and older) chronic pain sufferers, given the relatively more scant research in chronic pain among younger than older individuals [15, 16]. Neither gender was targeted for this study, and no gender-related data were collected. Future studies could examine the potential impact of gender on chronic pain experiences during virtual reality use.

The sample size of 12 was used to gain a deeper understanding of the factors driving each participant's emotional response to the VR experience. This small sample size was shown to work well for elucidating participant responses to VR chronic pain management in a similar study which used 15 participants [17].

3.2.1. Instruments

The below images were shown to participants via the interactive presentation, followed by a prompt asking which of the two most distracted them from their pain. As positive emotions are known to support pain management, an image of a person smiling was used as a control (Figure 1) for the more suspenseful image of a rock climber (Figure 2) [18].

Figure 1
Happiness (depicting a woman smiling)

Figure 2
Suspense (depicting a rock climber)

4. Results

As depicted in Figure 3, 75 percent of participants reported the happiness image as more distracting, while 25 percent reported the suspense image.

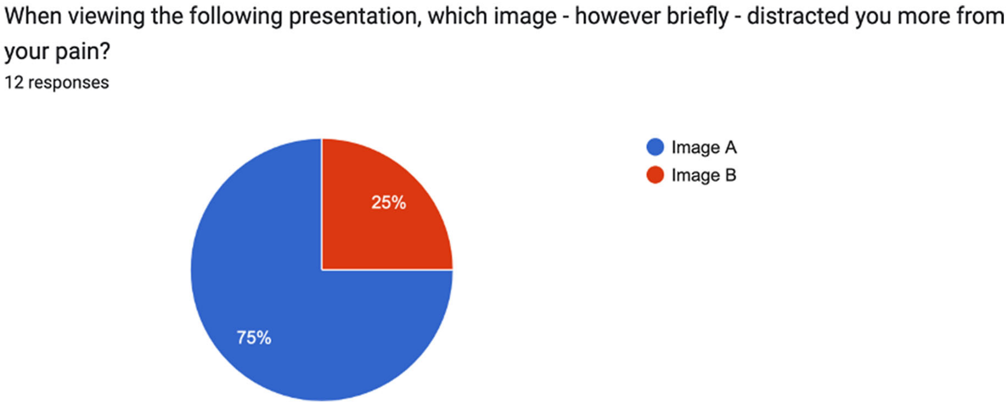
When asked to explain their selections, participants provided the following rationale:

4.1. Happiness

Perceived positive emotion from happiness versus the perceived stress of suspense

1) The happiness image is like a direct image of happiness and makes me feel nice.

Figure 3
User emotional responses to happy versus suspenseful stimuli



2) Happiness, because I feel more attached to what she is experiencing, it's like being home. While suspense gives me vertigo and stress.
3) The girl's emotion in the first one made me feel that for a second whereas the second reminded me of physical exertion and thus my pain.
4) For the climbing image, all I could think was how bad that would hurt. Also, we can clearly see the person's face in the happiness image and they look like they're having a good time!
5) I associate effort suspense with a pain flare-up, so there is no way that could distract me from pain. Happiness looks more like how I'd like to feel. I can't say it distracted me from pain, but it did make me smile.
6) Her happiness feels powerful and contagious, naturally makes you feel happier.
7) I think focusing on someone else's body, especially someone who's not visibly in pain, kinda helped get me out of my own body mentally.
8) Laughing distracts me.
9) Happiness because I feel more attached to what she is experiencing, it's like being home. While suspense gives me vertigo and stressed.
10) The girl's emotion in the first one made me feel that for a second whereas the second reminded me of physical exertion and thus my pain.
11) For the climbing image, all I could think was how bad that would hurt. Also, we can clearly see the person's face in happiness and they look like they're having a good time!

4.2. Image B: Suspense

Escapism

1) It makes me happy thinking about how some people can climb a mountain
2) It reminds me of the outdoorsy stuff I love, even though I hardly get to do any of it anymore
3) Because it reminds me of my childhood.

4.3. Both

I experienced empathetic positive emotion of happiness enhanced by the escapism of suspense.

It was actually both. Being in the wild makes it better for me, mostly, in a green scenery. I clicked on suspense, because I currently practice indoor bouldering and, despite some health difficulties, it has helped me both physically and psychologically.

4.4. Discussion

Most participants who preferred the happiness image mentioned a vicarious experience of happiness from observing the woman's smile. This feedback typically accompanied aversion to the suspense image which they cited as causing stress (from either physical exertion itself or disorientation upon viewing) and even an association with pain. Notably, participants who found the suspense image to be stressful often cited a vicarious experience, only a distressing version stemming from the rock climber's vicarious position and correlation with physical activity they worried could increase their pain.

From a similar vicarious standpoint, those preferring the suspense image tended to have enjoyed physical activity and thrill-seeking experiences prior to chronic pain onset, thus appreciating the nostalgia rendered from viewing the person rock climbing.

Ultimately, while the suspenseful stimulus did not provide adequate pain relief for most, those preferring suspense found positive distraction from nostalgic memories and a sense of escapism. Analgesia of this sort rendered from a distracting visual stimulus typically considered somewhat stressful – such as suspense – suggests that an experience personalized for individuals with thrill-seeking tendencies and perhaps less of a tendency to catastrophize their pain might benefit from immersive experiences focusing on such activities. Healthcare practitioners and technology developers could therefore use an intensity spectrum to analyze individual patient preferences in pain distraction to devise a personalized wearable simulation device.

Given the qualitative nature and relatively small participant pool of this research, future studies could use more quantitative methods such as surveys for a larger sample size in benefits from new and exciting immersive stimuli for distraction from pain. Further research could also differentiate chronic pain sufferers who enjoy thrill-seeking activities from those who do not advance the personalization factor of the immersive experience.

5. Conclusion

Provided the potential for the concept of physical experiences and thrill-seeking activities to help some chronic pain sufferers, healthcare workers focused on non-invasive care could use wearable headsets depicting such content for their patients, particularly for those unable to physically participate in such activities they once enjoyed. By and large, researchers and developers should prioritize the nuance in stimuli to alleviate stress among chronic pain sufferers so as to inform the design of a wearable immersive tool for pain relief across a range of preferences. Given the high number of chronic pain sufferers throughout the world, such personalized treatment using a wearable device equipped for everyday activities could enrich individual quality of life and foster a more productive society.

Given the limitations of both sample size and physiological data in the present early-stage study, future research could entail a larger sample size for more quantitative datasets in assessing the many nuances of individual user preferences and triggers related to and resulting from VR stimuli.

In particular, future studies would examine multiple participant pools based on demographics such as gender, culture, and age. Results for the emotional responses of these users could then be compared and contrasted to assess for any influence age or gender might have on user's lived experiences with chronic pain, with emphasis on how societal expectations impact their susceptibility to stress from audiovisual input and subsequent effects on their perception of chronic pain.

To maintain the depth of insight sought in the present study's qualitative methods, future research could benefit from presenting participants with a similar questionnaire following exposure to the immersive simulation. This questionnaire could begin with additional demographics questions to account for such factors when exploring the rationale behind participants' processing of the immersive content. Finally, given the potential correlation between thrill-seeking affinity and an enjoyment of extreme sport, further studies could incorporate a preliminary question surrounding the participant's feelings toward high-risk sports.

Recommendations

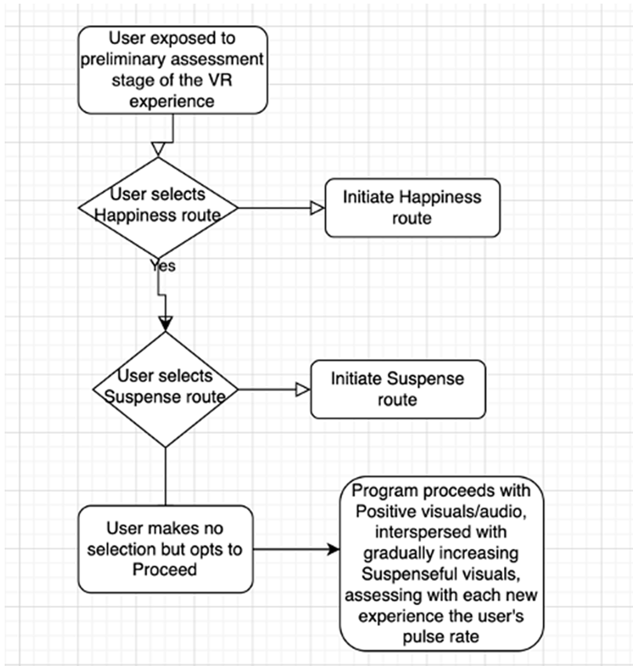
The flowchart in Figure 4 below depicts the basic design for the proposed wearable VR device, detailing how user selections inform the algorithm for how the program proceeds for the personalized experience.

The potential effectiveness of a wearable immersive simulation device for personalized chronic pain management would depend on multiple factors, particularly what type of content causes stress versus enjoyment for the individual patient. For example, a wearable VR headset with a variety of settings ranging from high-risk sports activities to stargazing sessions that generates a personalized experience route could appeal to patients and healthcare providers alike.

The user would begin the experience with a trial wherein the device's heuristic algorithm would collate and analyze responses provided by the user upon viewing images similar to the examples presented in this study. The device would then design the immersive experience based on the individual's preferred content, with the least intense options including seascapes and other calming environments. The spectrum could then continue with widely recognized positive stimuli, such as the smiling woman in the present study or demure-appearing domesticated and wild animals [19]. An audio component could range from ocean waves for the seascape and rainforest sounds for nature visuals.

The more intense options could include lighter sports like football to more extreme, thrill-seeking activities like bungee jumping or skydiving. To help monitor the range of user feedback for the initial trial stage, the device would be equipped with a wristband to measure increase in pulse rate.

Figure 4
Basic functionality design for the proposed VR device



Given the lucrativeness of Python as both a simple language and useful for programming wearable sensor technology as well as simulation programs, this study uses Python for the proposed device's sample code [20, 21].

This early-stage study presents a foundational Python code for the proposed device's main algorithm in assessing a user's emotional predisposition to various stimuli for subsequent personalized immersion. The first set of code informs the heuristic capture of user response to immersive stimuli.

Meanwhile, the next set of code outlines the sensor feature of this wearable device. Based on the individual user's emotional responses to the trial images (positive and stress-inducing), the device would progress the experience to the positive route (Cute) or the stress-inducing route (Thriller). The initial trial stage would begin only if the user does not select either route right away. For insight into both user-supplied input and passively generated physiological data, the pulse sensor functionality would monitor pulse rate alongside active user input provided during the initial assessment stage.

The referenced code can be found in the following GitHub repository [22].

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Ethical Statement

This study was granted an exemption by Capitol Technology University and therefore did not require Institutional Review Board approval.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Sarah Katz: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

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