Remote Medical Diagnosis in Virtual Reality: A Mixed-methods Approach to Understanding the Perceptions of Patients and Physicians

by

Mustapha Unubi Momoh

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

My Contributions: I was responsible for drafting the survey and interview questions, conducting the interviews, and performing all quantitative and qualitative analyses, and building the VR telehealth prototype. I authored the initial manuscript for all chapters and revised it based on feedback from my supervisors and examiners.

Contributions of Others:

Professor Ville Mäkelä helped with the Prolific setup and the recruitment of survey participants and physicians. He assisted with the initial call with the physicians to establish the background for the main interviews and partly coded the open-ended survey questions. He reviewed all manuscript chapters and provided suggestions for edits and restructuring.

Professor Catherine Burns assisted with the recruitment of physicians. She also helped review the resulting manuscript and shared suggestions for improvement, including grammar checks and some changes to the structure.

Professor Daniel Harley read the manuscript and provided valuable feedback for the final revisions including properly attributing my sources, ensuring clarity in the research scope, expanding on the use case example presented, and many other suggestions.

Professor Cosmin Munteanu read the draft and provided valuable feedback, including suggestions to expand the discussion of themes, revise the introduction, and run a structural equation modeling, among others.

Dr. Neil Naik conducted a thorough review of the draft interview questions and provided suggestions for improving the content. He also reviewed our CHI 2024 draft, and some of the ideas from that draft were incorporated into this final work.

Dr. Kevin Samson assisted with reviewing the draft interview questions and the CHI 2024 draft. He made suggestions for improvements and shared a manual for constructing the questions. Some of the ideas from both drafts were used in this final work.

Dr. David Savage assisted with recruitment efforts by connecting us with his network of physicians. He also reviewed our interview transcripts and made some comments for revision. We have applied some of the ideas he shared in this thesis.

Abstract

Global healthcare faces challenges, including physician shortages and resource limitations. Telehealth has offered solutions through services such as text and video chats. Yet, these methods have their issues: they provide only limited opportunities for diagnoses, and they do not foster solid patient-physician relationships. Virtual reality (VR) offers a promising future alternative, which could facilitate real-time patient-physician interactions that resemble real-life visits through realistic 3D avatars. However, understanding patients' and physicians' needs, attitudes, and concerns is crucial for tailoring such VR solutions to healthcare's unique demands. Therefore, an online patient survey ($n = 402$) and physician interviews ($n = 6$) were conducted to understand these needs. Through thematic analysis, common telehealth concerns, including privacy and the limited scope of diagnoses in VR, were identified. Unique elevated concerns, mostly around technology reliability, required expertise, accessibility, and integration with existing workflows, also emerged. Furthermore, the study examined the influence of technology affinity on patients' acceptance of VR telehealth through a Regression Discontinuity Design (RDD) approach. Overall, this study explores the critical concerns in telehealth and proposes evidence-based considerations for developing VR-based telehealth solutions.

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Dedication

This work is dedicated to my parents and siblings.

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List of Abbreviations

3D 3-dimensional iv, 2, 5, 10, 13, 14, 75

AI Artificial Intelligence 2, 12

ANOVA Analysis of Variance 17, 38, 39, 41, 44, 51, 52, 100

ATI Affinity for Technology Interaction 44

CHI Conference on Human Factors in Computing Systems iii

EMR Electronic Medical Records 56, 66, 68, 74, 75, 77, 79

HCI Human Computer Interaction 5

HIPAA Health Insurance Portability and Accountability Act 74, 75

HMD Head Mounted Display 2, 10

NASA National Aeronautics and Space Administration 11

RDD Regression Discontinuity Design 5, 100, 104, 105

RGB Red Green Blue 2

SEM structural equation modeling 50, 51, 100

UML Unified Modeling Language xi, 72, 73

VR Virtual Reality iii, iv, viii, x, xi, 2–7, 9–16, 18–21, 23–39, 41, 42, 44, 45, 48–53, 56, 57, 63–79, 100, 105, 111, 117, 118

VRET Virtual Reality Exposure Therapy 11

VRMedLab Virtual Reality in Medicine Laboratory 12

Chapter 1

Introduction

Access to adequate medical care remains a global issue further aggravated by physician shortages and limited access to specialized care due to geographical constraints and long appointment waiting times [123]. The World Health Organization projects that approximately 930 million individuals will likely be impoverished if they have to pay for telehealth services out of their own pockets [10, 120].

Improving primary healthcare interventions is a key focus for addressing this issue, especially in low- and middle-income countries. The WHO reports that increased government investment in primary healthcare "could save 60 million lives and increase average life expectancy by 3.7 years by 2030" [10, 120]. The need to innovate and adapt in healthcare has never been more evident. The COVID-19 pandemic increased the demand for virtual healthcare services, particularly in rural communities [102]. Platforms like Maple responded to this need by offering the tools to consult via text or video chat [124]. However, these solutions have challenges, including communication barriers, less precise examinations, and difficulty fostering genuine personal connections [62, 59]. Widespread telehealth adoption also faces hurdles such as regulatory constraints, reimbursement policies, interoperability issues, and gaps in digital literacy [1, 58, 21].

To overcome the challenges of current healthcare, human-computer interaction (HCI) researchers are increasingly studying telehealth's limitations and the potential for emerging telehealth technologies to improve medical treatment, training, and health education [63]. In this regard, several studies have attempted to understand the perceptions of telehealth among care providers and patients. One recent study examined patients' perceptions of telemedicine and its use [68]. While the study provides recommendations to overcome the challenges that hinder telemedicine uptake, it primarily focuses on patient perspectives on

video-based visits. A similar study has explored patient preferences for video-conferencing compared to face-to-face care in the post-COVID-19 era [140]; however, it lacks patient and physician perspectives on VR telehealth.

VR is quickly growing as a potential solution to some of the limitations associated with existing telehealth platforms. One of the unique appeals of VR is its potential to enhance patient engagement and understanding through immersive visualization. Healthcare providers could use 3D models to illustrate complex medical information interactively to improve patients' comprehension of their own conditions and treatments [43, 11]. For instance, a doctor might use VR to show a patient how a surgical procedure will affect specific areas of their anatomy or even simulate physical therapy exercises that a patient can follow from home. Recent applications of VR in healthcare have demonstrated its effectiveness in pain management and mental health support. A recent clinical trial involving cancer patients showed that brief, ten-minute VR sessions greatly alleviated pain, with relief lasting up to 24 hours post-intervention [87]. Similarly, interventions with elderly populations using VR-enabled activities like virtual hiking and revisiting familiar places have been associated with reduced feelings of isolation and improved mental well-being [34].

Although VR technology is advancing rapidly, its potential to enhance remote patient diagnosis through improved telepresence has not received adequate attention in the existing literature. By replicating valuable qualities of in-person visits — leveraging techniques such as 3D reconstruction, full-body tracking, and 3D sound spatialization — VR could significantly improve the remote healthcare experience. Telepresence itself is not a new concept, having been studied alongside telecommunications for over four decades [107]. Recent developments include the "AI-mediated 3D Video Conferencing" system [167], which enables 3D collaboration using 2D video capture and streaming. This system requires minimal hardware, such as an RGB webcam, and renders 3D content on specialized stereoscopic displays, like the "Looking Glass display"[1] or the "Dimenco" 3D display[2]. Although these stereoscopic displays eliminate the need for HMDs, they tend to be more expensive and less portable than wearable devices. A related study by Huang et al., [72] proposed a telepresence application focused on 360-degree video streaming in VR. While effective for "unidirectional" observation, this system does not support bidirectional interaction, which is vital for scenarios requiring patient-physician communication. An ideal VR system for remote patient-physician interaction should at least support bidirectional interaction and provide a real-time faithful representation of each participant. Advancements such as "Pixel Codec Avatars"[100], "Relightable Gaussian Codec Avatars"[153], and "metahumans" [56] suggest promising directions for future highly immersive VR systems in telehealth.

[1] https://lookingglassfactory.com/

[2] https://www.dimenco.eu/

However, the technical feasibility of a technology does not necessarily guarantee user adoption. Research has shown that preferences for telehealth interfaces may vary by demographic and can be influenced by the type of information patients wish to access or share. A study by Sin et al. has shown that older adults may prefer speech-only interfaces for accessing general healthcare information, whereas video calls may be favoured when seeking specific information [160]. Thus, understanding the perceptions of potential users of the proposed VR telehealth, especially in light of existing telehealth solutions, can provide helpful information. The insights can inform designers about desired features in the proposed telehealth, predict how various demographic groups might respond to the technology, and identify specific use cases where VR telehealth may be particularly effective.

This work collates and analyzes some of this information from perceptions regarding VR telehealth, specifically around its potential to facilitate remote diagnosis. The work presents the concept of photorealistic telepresence and lifelike avatars in VR to participants to gather insights on how VR's potential to replicate some of the features that make face-to-face visits appealing might shape user experience in virtual consultations. It compares VR telehealth with traditional telehealth and in-person care from the perspectives of physicians and patients and examines how the emerging capabilities of VR can meet the needs of patients and physicians while addressing the limitations present in current telehealth practices.

Therefore, this work analyzes both patients' and physicians' perspectives on telehealth through the following research questions:

- **RQ1:** What are the perceptions of patients and physicians about VR telehealth, as opposed to perceptions regarding in-person healthcare and traditional telehealth?
- **RQ2:** How can VR telehealth respond to the needs of both patients and physicians to improve their experience with telehealth?

An online survey was conducted with 402 patients ($M = 202, F = 200$), and interviews were conducted with six physicians ($M = 4, F = 2$) to learn about their current experiences (including perceptions and concerns) with in-person healthcare and traditional telehealth, as well as their perceptions, concerns, and needs regarding VR telehealth. Survey participants were recruited through Prolific, drawing from an international pool across nineteen countries, with the majority from the United Kingdom, the United States, and Canada. All of the physicians who were interviewed are located in Canada. The study identified a range of patient and physician needs that VR telehealth should address. Statistical analysis of the survey data revealed significant differences in perceptions of comfort and

confidence in telehealth diagnosis across groups based on telehealth experience, technology affinity, level of VR experience, dependent status, age, income level, employment status, and education level. Participants with prior telehealth experience reported higher average comfort and confidence levels in traditional and VR telehealth than those without such experience. Also, participants showed a statistically significant preference for accessing VR telehealth from home or other private locations compared to shared spaces.

Further analysis using causal inference — that is, the average treatment effect — suggested that patients with above-medium technology affinity might exhibit increased comfort levels in sharing medical information in VR. However, the observed effect was not statistically significant. Thus, readers should remain cautious of the interpretation as further validation is required.

The study also identified common barriers to telehealth adoption among patients and physicians, including concerns about privacy, security, broadband connectivity and limitations in conducting comprehensive examinations remotely. Unique needs also emerged for each group. Patients emphasized the importance of provider transparency — such as the ability to verify the healthcare provider's expertise — which could improve their comfort and set appropriate expectations for virtual meetings. On the other hand, physicians strongly expressed the need for faster reimbursement procedures, payment parity between in-person and telehealth services, and smooth integration of the proposed VR telehealth with existing workflows and electronic medical records.

These findings suggest considerations for designing an effective telehealth platform. To ensure provider transparency, the platform should enable patients to verify provider credentials before each telehealth session. Additionally, patient data from VR sessions should automatically update existing medical records to minimize tedious manual entry and ensure continuity in care documentation. Furthermore, VR telehealth should allow the integration of remote monitoring devices to provide real-time access to patient's vital signs, aiding comprehensive virtual diagnoses by providers. Moreover, incentives for physician adoption will require reforming the current volume-based billing and refining reimbursement processes. Ideally, government-backed public awareness and technology literacy programs should advocate for understanding the benefits and limitations of VR telehealth to dispel unfounded fears and correct misconceptions about telehealth. Clinical care providers should not rely solely on VR telehealth — or any telehealth — as a substitute for in-person visits. Instead, they should adopt a hybrid approach consisting of in-person consultations for initial diagnoses and virtual visits for monitoring and follow-up care whenever appropriate.

1.0.1 Major Contributions

- Combining Qualitative and Quantitative Methods: To the best of our knowledge, this research is the first to combine qualitative and quantitative methods to study patients' and physicians' perceptions of in-person consultations, traditional telehealth, and the potential VR telehealth. Both methods can reveal insights that a purely quantitative or qualitative study might miss.
- Causal Understanding of Users' Perceptions of VR Telehealth: this work is the first to explore the causal understanding of patients' perceptions of VR telehealth through Regression Discontinuity Design (RDD). This approach has allowed the measurement of the possible influence of certain demographic factors on user comfort in VR telehealth. This understanding might be helpful for developing strategies to improve these perceptions and for making VR telehealth design choices.

This work provides a fact-based understanding of telehealth perceptions from both care providers and patients, which may guide the medical and HCI communities in developing VR solutions to address the unique demands of telehealth. Similarly, this work may guide the promotion of VR telehealth and educational strategies to address unfounded concerns and misrepresentations of the technology while responsibly educating the public on the limitations of VR telehealth.

1.0.2 Thesis organization

This work has four chapters:

- **Chapter 1 — Introduction:** This chapter begins with a brief overview of the current issues faced in healthcare and the rise of telehealth as a solution to these challenges. It also highlights gaps in the current telehealth research, followed by a presentation of the research questions. Finally, it outlines the approach undertaken to answer these research questions and presents the study's main contributions.
- **Chapter 2 — Background:** This chapter presents the study's background. It starts with an overview of the current challenges with traditional telehealth methods, such as video conferencing. Next, it presents the advances in virtual reality applications in healthcare, the recent telehealth opportunities enabled by digital humans and chatbots, the challenges associated with using digital humans, and the case for human-driven 3D avatars for VR consultations.

- **Chapter 3 — Methodology and Results:** This chapter details the steps to gather qualitative and quantitative data through online surveys and interviews. It presents the results of both studies, followed by a use case example of the potential VR telehealth system. Finally, it discusses the nuances and commonalities in the perceptions of patient and physician respondents.

- **Chapter 4 — Discussion and Conclusion:** This chapter discusses the results in the context of the research questions and explains the potential connections between the findings and results from past research. Moreover, it discusses the study's limitations due to the chosen methods, the sample size, and the sampled distribution demographics. The chapter concludes with a brief recap of the research scope, key findings, and considerations for designing VR telehealth that could address some of the needs of both healthcare providers and patients.

Chapter 2

Background

Definitions

This section presents specific definitions of standard terms central to the discussions on health information technology explored in this study. The following definitions provide the meanings associated with the terms used in this work.

Telemedicine: The World Health Organization defines telemedicine as providing healthcare services remotely. It includes healthcare providers consulting with other providers for clinical advice (provider-to-provider telemedicine) or patients accessing health services from healthcare providers at a distance (client-to-provider telemedicine) [122].

Telehealth: Telehealth is closely associated with telemedicine but utilizes a broader range of technologies for consumer outreach, remote learning, and "electronic communications and information technologies" to enhance healthcare services [122].

Traditional Telehealth: Traditional telehealth is about all telehealth except those using virtual reality devices to replicate face-to-face visits between a patient and a care provider or between two care providers. Traditional telehealth care delivery may include any or all of the five delivery mechanisms outlined in the 2006 American Telemedicine Association (ATA) issue paper: "networked programs, point-to-point connections, direct patient-to-monitoring centers, web-based e-health patient service sites, and health provider-to-home connections" [5].

VR Telehealth: VR Telehealth refers to telehealth delivered through VR devices where communications between the healthcare provider and the patient occur remotely

in a virtual 3-dimensional space, similar to in-person real-time consultation in the exact physical location. The care delivery mechanism is "health provider to home connections".

In-person Care: A care delivery method in which both the patient and the provider are in the same physical space.

2.1 Current State of Healthcare and Telehealth

The current state of healthcare, characterized by challenges such as a lack of family doctors, high medical expenses, and lack of access to medical facilities due to distant location of health facilities, has necessitated an increased focus on telehealth as a solution. Many countries transitioned from in-person medical consultations to telemedicine during the pandemic, using mobile apps, text messaging, phone calls, and video conferencing [184]. Consequently, remote health care has rapidly expanded in most sectors of the world. The measures implemented to control COVID-19 transmission through physical distancing have also yielded benefits "beyond the pandemic", such as improving healthcare access and "lowering costs for both healthcare systems and patients" [51]. While the current telehealth technologies offer many benefits, including bridging geographical barriers and reducing costs, they also present challenges owing to their nature. Some of the challenges are:

Limitations in Comprehensive Physical Examinations: One of the primary concerns of traditional telemedicine is the lack of tactile feedback. Many medical conditions necessitate hands-on examinations, such as palpation, to discern abnormalities or assess symptom severity. The tactile interaction, central to several diagnoses, is absent in video consultations. This limited interaction can lead to potential misdiagnoses or delayed treatment, as certain conditions require physical touch to be assessed accurately [161]. For instance, detecting lumps, assessing skin texture, or evaluating joint movement is challenging without direct physical contact[42].

Additionally, the inability to perform specific diagnostic tests, such as auscultation with a stethoscope, further limits the effectiveness of current telehealth in providing comprehensive care[89]. Moreover, the absence of physical examinations can impact the doctor-patient relationship. Physical touch is crucial in building trust and rapport between healthcare providers and patients. The lack of this interaction in telehealth can make patients feel less connected to their providers, potentially affecting their overall satisfaction. This situation is particularly significant in geriatrics and pediatrics, where physical presence and touch are essential components of care [159].

Visual Limitations in Video Conferencing: Additionally, even the most advanced video conferencing tools are characterized by visual limitations. Despite high-definition capabilities, they might miss subtle signs crucial for diagnosis. The depth perception offered by live video conferencing is constrained, making evaluations of three-dimensional issues challenging [69]. For example, in assessing a patient's gait, capturing all angles and nuances through a video session is difficult since the view is typically limited to the camera's fixed perspective. Moreover, video conferencing often suffers from latency, poor lighting, and limited field of view, which can further hinder accurate clinical assessments [161].

VR telehealth can address some of these limitations by providing an experience closer to real-time face-to-face visits. VR can potentially support full three-dimensional patient representation, enabling clinicians to observe and interact with patients from multiple angles and perspectives. Evaluations that require physical interactions, such as manual muscle testing, can now be performed using robotic exoskeletons worn by patients. These exoskeletons are equipped with sensors that digitize the patients' movements, which can be transmitted remotely to the physician. As a result, when VR is utilized this way, it can improve the accuracy of these assessments [22].

Lack of Personal connections and communication challenges: Traditional telehealth such as text messaging and telephone consultations are often considered impersonal forms of telehealth. They fall short in fostering a genuine connection between patients and physicians. While they can sustain pre-existing relationships, experts argue that forging new ones can be more challenging in a virtual setting [41]. In the research by Donaghy et al., the authors explain the lack of physical presence can make it challenging for healthcare providers to establish rapport with new patients [41]. Non-verbal cues, such as body language and eye contact, are essential aspects of interaction but are often missing in text messaging and telephone consultations. Thus can lead to miscommunication or a lack of empathy. While video conferencing addresses some of these issues, patients often find it challenging to share sensitive information through video, and they may favor face-to-face visits as a result. VR telehealth may be better suited to situations where sensitive information, including sexual health or upsetting news about diagnosis, is to be shared since it can more closely replicate the personal nature of face-to-face visits than traditional telehealth. Providers have also expressed that they often need to exert more effort to extract information from patients during virtual consultations, likely due to patients feeling less comfortable or less inclined to share certain sensitive information in a video call [41].

Conversely, patients have reported that healthcare providers ask fewer questions during telehealth appointments, requiring them to advocate for their care more proactively. Studies suggest that patients often feel rushed in virtual consultations, which can result in significant health issues being overlooked or not fully addressed [159, 60]. The situation

is particularly problematic for patients with chronic conditions that require a detailed and ongoing treatment.

2.1.1 Virtual Reality in Healthcare

As the limitations of traditional telehealth platforms become more apparent, the healthcare industry is turning its attention to emerging technologies that can address these challenges. VR is one of the fast-growing technologies that may see increased use in telehealth.

Classes of Virtual Reality Technologies

Three classes of VR technologies exist: fully immersive, semi-immersive, and non-immersive systems [149]. Fully immersive VR systems deeply engage users by projecting them into a simulated environment using a combination of VR headsets, HMDs, controller devices, and motion detectors. These systems provide a holistic three-dimensional experience, allowing users to view and interact with the virtual world. By simulating human senses, these advanced VR systems offer a realistic and encompassing experience, limited only by the available computing power and content. Semi-immersive virtual reality systems utilize high-performance computing to generate 3D graphics, typically displayed on large monitors or projection screens. These systems offer a partially virtual experience, often used for educational and training scenarios, like flight simulators for pilot training.

On the other hand, non-immersive virtual reality systems are more common. They are characterized by a computer-generated environment on a standard monitor controlled via a keyboard and mouse. Video games are a classic example of non-immersive VR, where users remain aware of and can be influenced by their physical surroundings [149, 57]. The VR telehealth referred to in this study is fully immersive.

2.1.2 Role of Virtual Reality in Healthcare

Virtual reality has proven highly useful in healthcare. Popular application areas include clinical care, training and education.

Clinical care

Several telemedicine interventions have leveraged VR to deliver clinical care. One of the earliest is a virtual environment that allows physicians to gather data remotely from pa-

tients with movement disorders, specifically spinal cord injuries [144, 145, 147]. Virtual reality exposure therapy (VRET) is another common area in which VR has been applied, although mostly in clinical settings. It is an extension of exposure therapy, which involves immersing patients in a simulated environment to treat mental health conditions, including anxiety disorders [30]. Several studies have documented VRET's effectiveness in areas including treating anxiety [15, 162] and increasing the availability of exposure therapy for patients [162]. In a study to measure VRET's effectiveness in managing anxiety, an analysis using "random effects" showed a significant effect size with VRET compared to the waitlist [23]. Similarly, an effect size ranging from medium to large ensued with VRET compared to "psychological placebo conditions". These results replicated across different anxiety disorders, suggesting that VRET is a practical exposure therapy method [23].

While the majority of VRETs happen in clinical settings under the direct supervision of a doctor, tele-based VRETs are now available. This remote option makes VRET accessible for patients who cannot attend in-person sessions. *XRHealth* is one of those companies that supports remote VRET, where licensed therapists conduct remote sessions using "Amelia by XRHealth app" to treat conditions such as anxiety and stress in environments VR [185].

Other studies in VR for clinical care include the management of irritable bowel syndrome [168], neurorehabilitation based on the patient's embodiment of virtual avatars [163], the use of illusions of virtual body ownership to manage different types of chronic pains [104, 105], and correcting the perception of body size and shape for patients living with anorexia nervosa [156]. Neurorehabilitation that combines remote interaction with the care provider has also been explored. In the study by Daniel Perez-Marcos et al., the authors devised a system that uses remote body embodiment, "multimodal interaction" at distance, and a physical patient model in a hospital to aid remote interaction [133]. These referenced studies demonstrate that VR can meet various medical needs. It is useful for telemonitoring and accelerating patient recovery through various rehabilitation strategies. Additionally, VR shows promise as a primary method for delivering exposure therapy, as it overcomes challenges associated with imagining scenarios — particularly in older patients — and allows the control over a patient's imagination in therapy [52].

Training and Education:

VR in training and education has grown over two decades. One of the earliest and most common applications is remote visualization for training. An example application is the *Atomic VisualizeR* used in academic environments to understand anatomical structures interactively [70, 146]. Another early application includes the *Cyberscalpel* by NASA for planning and practicing medical surgeries [150, 146]. NASA has more recently built an

environment for training astronauts. This fight simulator utilizes virtual environments, "motion stimuli", and "spatial rotor sounds" to provide an immersive cabin experience during training. The simulator gathers data on passenger comfort to aid the design of ergonomic future air taxi services [45, 182, 181].

VR has also been used to build collaborative environments where physicians at a distance can collectively share and use "medical volumetric databases" in real-time [4, 146]. The VRMedLab is an early example enabling this collaboration. This project supports interactive visualization of three-dimensional models, such as the polygonal model of the human brain, built to allow introspection of the organ from different perspectives. It includes an option for potential virtual collaboration [20].

In a study by Pedram et al., VR for psychotherapy was explored by comparing VR to other remote mediums of delivering therapy. VR outperformed Skype as a therapeutic tool, the VR sessions were reportedly closer to reality, and participants felt a greater sense of telepresence when using VR [131]. VR has also been used in medical education to aid the residents' understanding of fracture anatomy and in the training of clinical residents in the medical intensive care units (MCU) to improve their fundamental clinical education [78, 55, 17]. Several motivations have spurred the interest in VR for facilitating studies utilizing inanimate objects. These include enhancing patient safety in surgeries, addressing ethical concerns, and considering costs. It is safer for residents to receive simulation-based training such as in VR before carrying out intervention on patients [183]. Simulation can be highly useful in "hemodynamic monitoring and mechanical ventilation" [183]. These training sessions will provide residents with near real-life experiences in the operating room, aiding the effective transfer of the acquired skills [158, 126].

Although VR simulation can serve as an effective complementary training tool, limitations in the quality of the "haptic feedback and interactive tissues" limits simulators [152] Regardless of the quality of the simulator, VR simulation is not a replacement for the training in the real environment [108, 155].

Digital humans and chatbots for healthcare services

Chatbots and digital humans have long been explored for various use cases, especially in automating repetitive tasks. They have grown in concert with the rapid advancements in artificial intelligence. Some digital humans incorporate advanced AI capabilities for human-like interactions. Studies suggest that people relate better to digital humans with a more realistic appearance, which exhibits non-verbal cues and shares sentiment [67]. One of the earliest examples of virtual humans is the "SimSensei system" developed by

researchers at the University of Southern California. Like its virtual human predecessors, "SimSensei" can connect intimately with people. However, it was specifically designed to improve existing "self-assessment questionnaires" by providing measures of user behaviour related to emotional distress [109].

As Steve Lazer notes in [92], digital humans can potentially serve several other uses, including language translation services that enable communication in the patient's native language, with the potential for the integration of computer vision-based sign language. Text-based communication in the preferred language can also assist patients with speech difficulties. They may provide post-procedure support and engagement through virtual physical therapy, encouraging aftercare compliance and reducing the likelihood of patients neglecting follow-up care. They can also alleviate stress and anxiety related to patient education by helping patients understand upcoming procedures and processes.

The potential applications of digital humans in healthcare are seemingly endless; however, their dependence on pre-programmed responses may limit their ability to handle complex, real-time interactions. Patients may still find it challenging to connect emotionally with digital humans.

Thus, human-operated, drivable photorealistic 3D avatars may be more appropriate in scenarios requiring complex interactions than fully autonomous digital humans. Since actual humans drive these avatars, they can respond more fluidly, and patients might form better connections with them. The interactions can also feel more natural since the avatars utilize advanced tracking technologies to mirror the movements and expressions of human operators in real-time. In addition, patients may be more willing to disclose information than in in-person visits if the system evokes the belief of being autonomous [109].

2.1.3 State-of-the-Art Drivable Avatars for VR Telehealth

Codec avatars and metahumans represent two significant advancements in human-drivable avatars that may find use in VR telehealth.

Codec Avatars

are deep generative models designed to create highly realistic 3D human faces. Codec avatars use a computationally efficient model, enabling real-time rendering of multiple avatars on devices with limited computational power, such as the Oculus Quest 2. Codec avatars such as the Pixel Codec Avatar (PiCA) allow for multi-person communication [100],

making it *potentially* suitable for VR telehealth applications. One of the prevalent challenges of codec avatar is the complexity of implementing the technology. It is still under research and development and unavailable to the general public. Moreover, preparing a codec avatar requires costly specialized capture equipment and time-consuming post-processing efforts. Current facilities for full body capture are only available in select well-funded research laboratories. An example is the capture facility at the Meta reality lab in Pittsburgh [90]. To put things in perspective, one of the capture chambers, Mugsy, uses 171 video cameras and hundreds of lights to record and capture people's faces, generating about 16 terabytes of data. Another chamber at the same facility, Hearsay, uses 120 microphones embedded in silicon ears to capture people's voices from every possible angle. The Sociopticon chamber comprises a large circular room with 253 cameras to track the entire body's movements. Given the current state, interested users or developers would have to visit the facility and undergo hours of testing and capturing to create the needed personalized avatars. This situation makes codec avatars less convenient for users and infeasible for VR telehealth unless future advancements allow users to scan their appearances, voices, and facial expressions more conveniently from their homes.

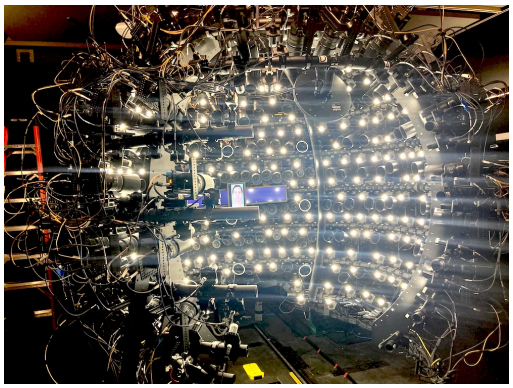


Figure 2.1: Meta's Mugsy [76]



Figure 2.2: Codec avatars [86]

MetaHumans

Metahuman is a complete framework developed by Epic Games, allowing creators to design and use fully rigged, photorealistic digital humans[56]. Metahumans are designed to be user-friendly and accessible, even for those with limited technical expertise. Users can quickly scan their 3D models with mobile devices and use the mesh-to-metahuman feature in Unreal Engine (UE) to generate their metahuman avatar. Therefore, creating an avatar



Figure 2.3: An interface of VR telehealth prototype showing a patient metahuman in a virtual clinic. The avatar can be driven in real-time using motion capture data from a VR device.

with metahuman is less complicated than codec avatars. Metahumans can also be embodied and driven in real-time using the movement data from a VR headset. An interface of a prototype for a VR telehealth application that utilizes metahumans is presented in Figure 2.3.

Both codec avatars and metahumans have unique strengths and potential applications in VR telehealth. While metahumans may be ideal for situations where high visual fidelity is needed, such as patient consultations, codec avatars may be better suited for applications requiring nuanced facial expressions and real-time emotional feedback, which can be critical in therapeutic settings. In the future, choosing between metahumans and codec avatars for VR telehealth would depend on the specific requirements of the telehealth application, including the desired level of realism, ease of integration by developers, performance constraints, and the importance of facial expressiveness.

This chapter briefly discussed the state of telehealth and the opportunities enabled by recent developments. The existing literature that studies the perceptions of telehealth by patients and care providers leaves several areas for improvement. For one, the literature on telehealth, particularly VR telehealth, reflects the technological capabilities of the time and is not up-to-date with the broader opportunities afforded by the current state of technology. Many recent studies on user perceptions of telehealth have primarily focused on video visits and other traditional methods, often neglecting VR telehealth and its potential to enhance telepresence. Moreover, due to these limitations, most of the findings are not generalizable, as they either focus solely on patient or physician perspectives or are limited to specific geographical areas, such as rural settings. This study addresses some of these gaps by examining the underexplored aspects of VR telehealth and comparing it with other telehealth methods. It qualitatively and quantitatively analyzes the views of both patients and physicians on in-person care, traditional telehealth, and VR telehealth.

Chapter 3

Online Survey of Patients and Remote Interviews with Physicians

3.1 Study I: Online Survey of Patients

A total of 402 respondents took part in an online survey designed to address the research questions. The following sections describe how the survey was designed and conducted. Before proceeding with the study, the University of Waterloo's research ethics board reviewed and approved the ethics application ($REB\#45343$).

3.1.1 Sample size calculation

Since the survey aimed to capture participants' overall attitudes and assess group differences using t-tests and ANOVA, the sample size calculation was based on a 95% confidence level and a 5% margin of error. Using the Qualtrics sample size calculator [1] with an assumed population size (of $N = 100,000$), an ideal sample size (of $n = 383$) was obtained. To account for potential dropouts — or, if none occurred, to support subgroup analyses — the sample size was increased by 19 participants, resulting in a final target of 402.

[1] https://www.qualtrics.com/blog/calculating-sample-size/

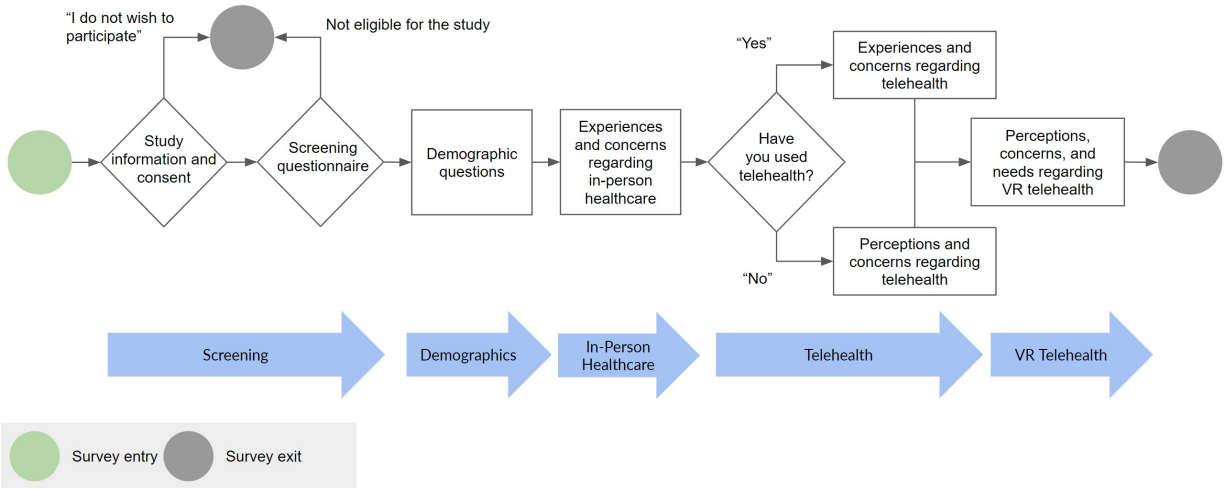


Figure 3.1: Flowchart of survey questions.

3.1.2 Participant recruitment

Prolific [2] was used to recruit all the study participants. The survey was first prepared on Qualtrics and then linked to Prolific. Before launching the study, prescreening criteria such as preferred language and minimum age were defined. Participants had to be at least 18 years old and capable of reading and writing in English. Additionally, the target population size was set to 402.

3.1.3 Survey Design

The survey included questions about the participants' experiences, perceptions, and concerns regarding in-person healthcare services, traditional telehealth services (e.g., text chats, video conferencing, and phone consultations), and VR telehealth. The overall flow of the survey is in Figure 3.1.

Consent and Screening

The participants were presented with the information letter and a consent form. Participants who agreed to the terms moved on to the screening questionnaire, where they

[2] https://www.prolific.co/

reported (1) how old they were and (2) if they had experience or interest in using telehealth. Eligible participants must be 18 years older, have prior experience with telehealth, or be interested in using telehealth in the future. After screening, they moved on to the primary survey. Participants who disagreed with the terms or were not eligible were asked to exit the study.

Survey Content

The primary survey comprised of the following topics:

Demographic questions This included country of residence, education, employment status, annual income, internet access at home, dependent relatives and children, VR devices ownership, level of VR experience, and technology affinity.

Experiences and concerns regarding in-person healthcare. Participants were asked about the frequency of in-person doctor's visits, comfortability and confidence regarding diagnoses and sharing medical information, and concerns about in-person healthcare.

Experiences and concerns regarding traditional telehealth. An explanation of telehealth was provided to participants, various examples of telehealth, and questions regarding their experience using any telehealth service.

Participants with telehealth experience answered questions about the frequency and type of telehealth consultations, comfortability and confidence regarding diagnoses and medical information, the importance of personal connections in telehealth, privacy, and concerns about telehealth,

Participants without telehealth experience answered questions about why they had not used telehealth and similar questions to those with telehealth experience. There was only a slight difference in the wording of these questions (e.g., "If you were to use telehealth in the future, how would you estimate...").

Perceptions, concerns, and needs regarding VR telehealth. VR telehealth was described, and an example of a VR encounter where a patient and physician meet in a virtual doctor's office (Figure 3.2) was provided. Participants were asked about their expected comfortability using VR telehealth from home and a shared VR installation (in private), the comfortability of sharing medical information, the importance of realism, anticipated needs for VR features, and concerns about VR telehealth. All respondents answered the same questions in this part.

On average, participants took 15 minutes to complete the survey, and they each received $6 CAD for their participation. Section 3.1.4 gives a detailed description of the participants.

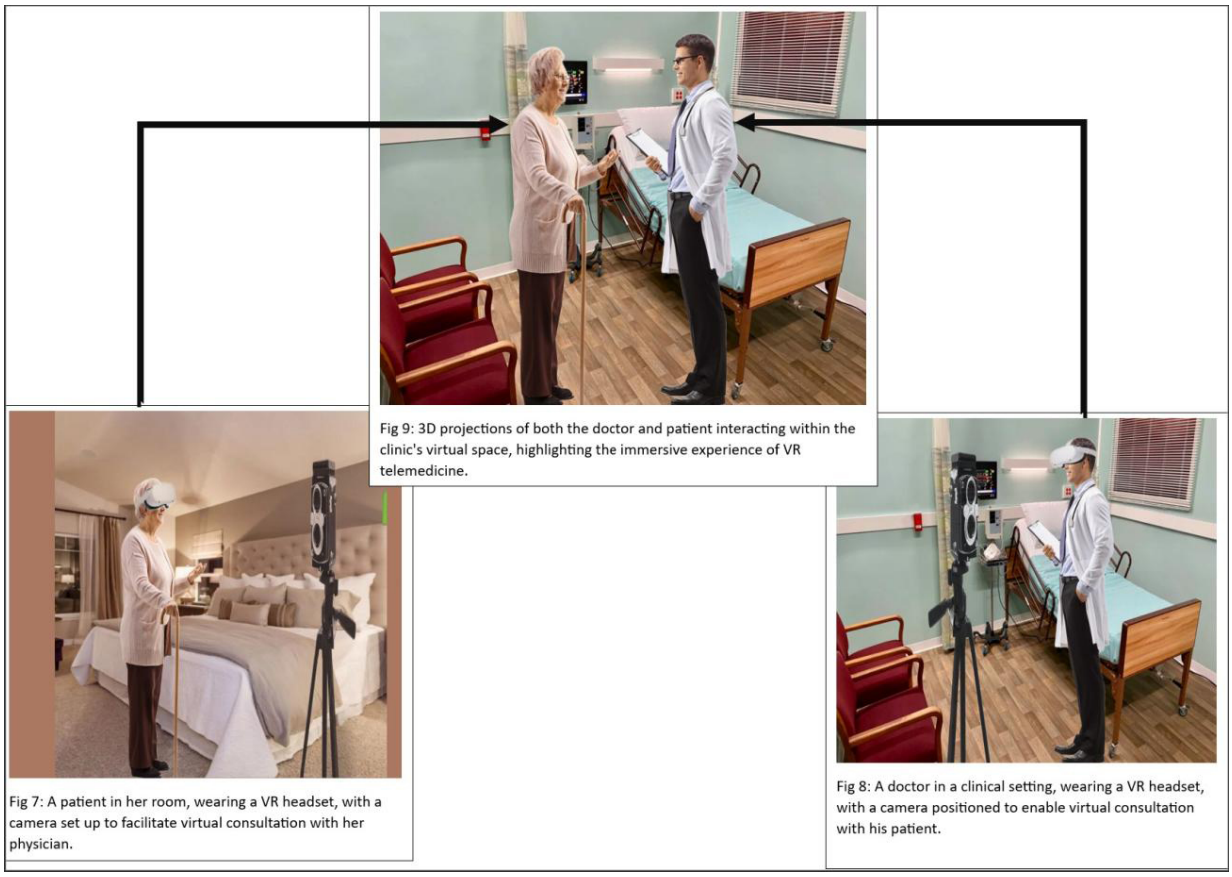


Figure 3.2: An example of a potential future VR healthcare service provided to study participants.

3.1.4 Analysis of the Survey Results

Participants' Demographics and Distribution

The survey participants consisted of 202 men and 200 women. The average age of the participants was 32 years and ranged from 18 to 68 years. The majority of participants were in the 23 to 37 age bracket. Figures 3.3 and 3.4 present the distribution of the participants across different categories, including telehealth experience, country, education level, employment status, and familiarity with VR. More than half of the participants had prior experience with a telehealth platform or service. The majority held a bachelor's degree (41%) and were employed full-time (48%). Additionally, a significant number of participants had direct or indirect experience with VR, either having used it themselves or having observed it being used by others (92.2%), frequently or a few times. Only a tiny proportion (7.7%) reported having no form of experience with VR.

Grounded Theory: Coding the Open-ended questions

Grounded theory open-coding was applied on all open-ended questions, following established procedures [28, 33]. Two researchers first analyzed 40 randomly picked responses (10% of the data) and generated an initial set of codes. Then, both researchers independently reviewed the responses and assigned codes to them. Each response received between one and five codes. Afterward, researchers compared their coding and discussed the responses where the coding did not match (around 15% of the data) and responses where one or both researchers had trouble assigning a code (around 2%). Two more codes were generated at this stage, and two existing codes were combined. The researchers then again did an independent coding round, after which the results were discussed and decided on together to produce the final coding.

Concerns and Challenges

All 402 respondents shared their perspectives on VR telehealth. Of these participants, 295 who had experience using traditional telehealth expressed their concerns about its use for remote patient diagnosis. Another 105 participants, unfamiliar with telehealth, voiced their anticipated challenges.

Details of the concerns are presented in Figure 3.5. Notably, 47 participants found no issues with VR telehealth. Similarly, 108 of those experienced with traditional telehealth

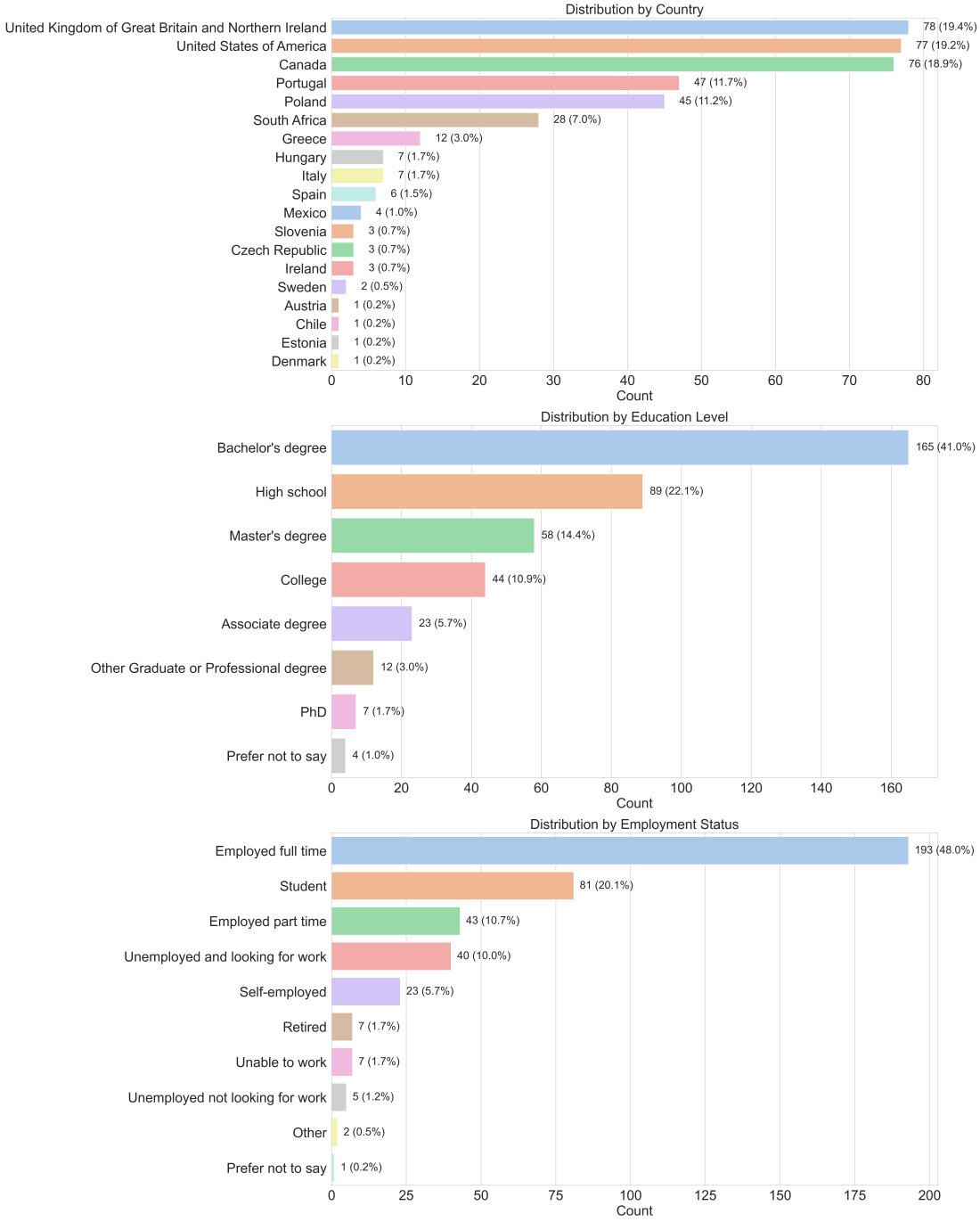


Figure 3.3: Participants' country of origin, education level, and employment status.

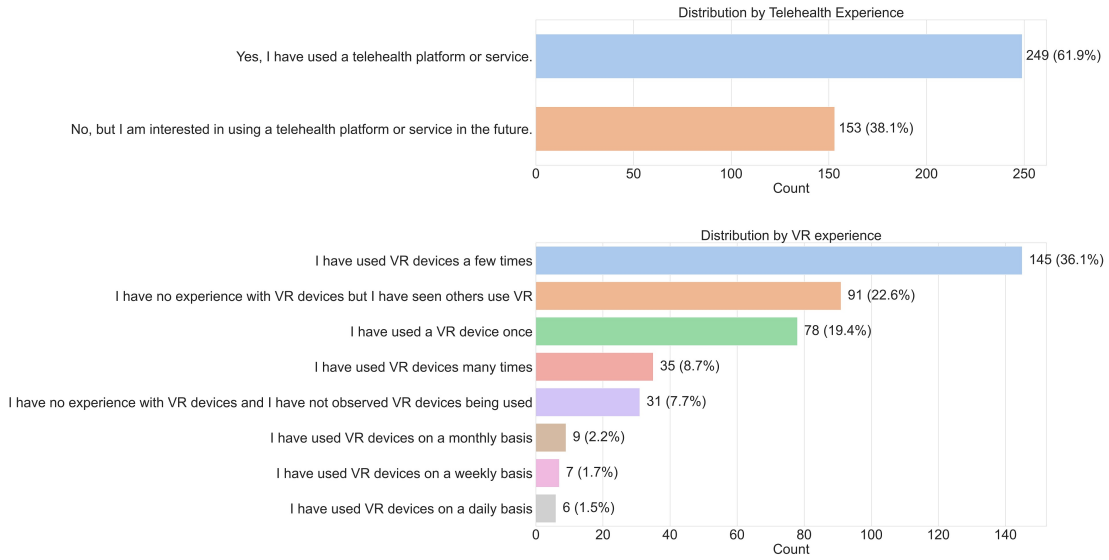


Figure 3.4: Familiarity with telehealth - traditional telehealth and VR telehealth

had no concerns, while 20 participants without prior telehealth experience expressed no challenges or couldn't think of one.

Some of these concerns in VR telehealth are presented below:

- *Limited Diagnosis:* This tag deals with concerns that physicians are unable to conduct sufficient examinations or diagnoses in VR. Certain kinds of examinations, such as physical examinations, are challenging to conduct in telehealth. One of the patients noted,

  "That the doctor won't be able to see my physical condition"

  (patient62, 25 years old, has telehealth experience)

  Another patient expressed worries about the physician's capacity to evaluate specific health issues remotely:

  "My physician being unable to inspect or assess the area of concern virtually, such as a painful body part or taking of vitals"

  (patient88, 35 years old, has telehealth experience).

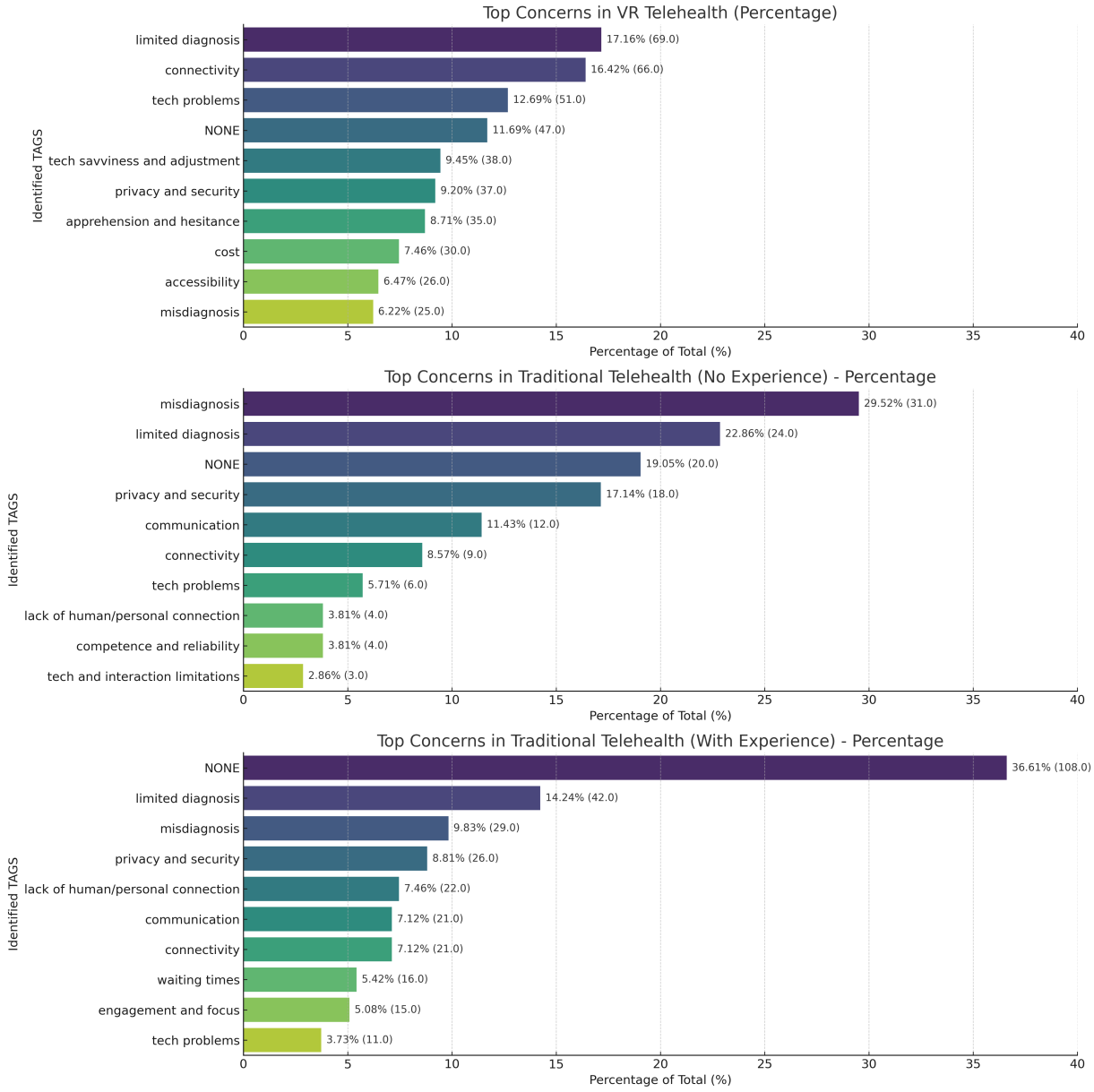


Figure 3.5: Participants' reported concerns, issues, and challenges regarding VR telehealth and traditional telehealth, with the latter being divided into those who had prior experience with telehealth and those who did not.

Some of these concerns have been studied in existing literature. For instance, Lee et al. emphasize face-to-face meetings might be more appropriate when a patient requires any form of examination due to the challenges of replicating the thoroughness of in-person physical examinations in telehealth [94]. Although, "virtually adapted examination" is possible, it is still not completely safe or feasible [94]. Indeed, the challenges of conducting specific physical evaluations remotely limit the quality of care provided through telehealth [46]. Addressing these limitations requires the integration of advanced technologies. For instance, remote monitoring devices that enable real-time access to patients' vital signs can greatly improve the effectiveness of remote diagnosis, as care providers would have more critical information to work with. However, some types of care that require physical contact with critical organs, such as medical surgery, must still be performed in person until technology advances to make them feasible and reliably safe remotely.

- *Connectivity:* Internet connectivity is one of the primary barriers to telehealth adoption, as unstable connections can lead to interruptions that can significantly diminish the quality of care in telehealth. Approximately 16% of the participants expressed concerns about losing connection in the middle of a telehealth consultation or lacking the required stable internet bandwidth for a telehealth visit. One of the patients remarked:

  "Internet connection issues. I'm not able to get in contact with my doctor, and simply the platform does not allow for me to"

  (patient16, 30 years old, has telehealth experience)

  Another patient noted,

  "In my country, South Africa, we have load shedding; electricity is off most times of the day, sometimes at night; it is unpredictable, so my session could be interrupted at any moment"

  (patient127, 46 years old, has telehealth experience).

  Studies have shown that internet connectivity issues are predominant concerns in telehealth. For example, "no internet use" among other factors such as old age has been reported to be associated with decreased odds of using telemedicine [26].

  Developers should consider VR telehealth that can adapt to varying internet speeds and are resilient to power outages. For instance, the platform can utilize adaptive streaming technologies to maintain communication quality even with fluctuating

bandwidth. Additionally, backup power solutions like power banks, when bundled with VR devices by manufacturers, could help ensure uninterrupted sessions in the event of a power outage.

- *Tech Problems:* This addresses the technical issues that users may experience during their appointments. The potential technical issues identified include VR software or hardware issues, such as technology glitches, audio transmission issues, and other asset glitches. About 12.7 percent of the participants reported concerns about tech problems. One of the patients remarked about the unanticipated disruptions that could compromise the effectiveness of the appointment.

  "There could be tech problems that ruin the appointment."

  (patient62, 25 years old, has telehealth experience)

  Specific apprehensions related to the audio-visual aspects of VR were also reported.

  "regular technical difficulties. VR not working or sound not working"

  (patient77, 29 years old, has telehealth experience)

  Another participant with prior telehealth experience was worried about potential technical issues that could affect both communication and orientation in the platform, which may impact the effectiveness of the appointment.

  "I would anticipate experiencing technical difficulties such as not being unable to hear or see the doctor, or I might not be able to orient myself in the right direction, all of which will waste my time with the doctor"

  (patient189, 22 years old, has telehealth experience).

  These *tech problems* are consistent with findings in the existing literature. In a study by Ftouni et al., similar technical issues, including a potential breakdown of the telemedicine platform, disruptions resulting from software upgrades, poor audiovisual quality, and other issues often requiring "in-person technical support" were reported to hinder communication and often led patients to prefer in-person care [53]. Most of the identified issues relate to system reliability and could potentially be mitigated through comprehensive system testing and the establishment of troubleshooting protocols. Addressing these *tech problems* is essential to improving user confidence in telehealth, especially in its reliability.

- *Tech Savviness and Adjustment:* This concerns potential issues from lacking knowledge or experience with VR technology. It also deals with the challenges of learning or adjusting to a new technology. About 9.5 percent of the participants expressed related worries. Some patients worry that the significant adjustment required for VR telehealth could hinder communication with their healthcare provider. One of the participants with no prior telehealth experience noted,

  "It may be too big of an adjustment for some people, and that could interfere with how that patient may interact with their healthcare provider"

  (patient43, 23 years old, no telehealth experience)

  Using an unfamiliar technology, especially one like VR, which is not as straightforward to set up as telephone calls, can be daunting, especially for a sick patient who is not skilled at technology.

  "The familiarity of the platform could be an issue for many people who are not tech-savvy"

  (patient28, 26 years old, no telehealth experience)

  The rate of adjustment to new tools may differ among demographics. Older patients may struggle more with the technology than younger generations [6], and the situation can become more frustrating in the event of technical issues if they and their healthcare providers are new to VR technology.

  "Older people won't be as tech savvy, so that they won't be as accustomed to VR compared to the younger generation"

  (patient55, 18 years old, no telehealth experience)

  "It might be difficult to learn how to work with a new technology. Since the patient's information needs to be private, no one can help with the technical side when consulting with a doctor. This might affect older people more than younger, but I still see it as an issue"

(patient251, 22 years old, no telehealth experience).

Implementing technical training programs, providing ongoing support to care providers and patients to aid the transition to VR telehealth, and ensuring the interface is easier to navigate could help the adoption of this technology.

- *Privacy and Security:* Participants expressed concerns regarding privacy, data collection and usage, and data security in VR telehealth. Some of the concerns are about potential eavesdropping while sharing sensitive information in telehealth, the risk of data breaches, and the potential of malicious actors gaining access to sensitive health data. Privacy issues may be amplified in the context of VR due to the potential to collect extensive data, including movement patterns from full body tracking, biometric data, and ambient audio. The potential involvement of third-party technology providers in delivering VR telehealth services also raises questions about data ownership, consent, and/or the possibility of using the data for purposes beyond healthcare. Patients shared apprehensions about their health data being processed by external entities.

  One participant commented on whether accessing this technology will require them to link their healthcare information with social media accounts and the potential for these data to be used for targeted advertising.

  "I would have privacy concerns because I own a Quest 2, a headset created by Meta. I do not trust Meta with my healthcare information. I would want to avoid associating my healthcare information with my Facebook account. And I wouldn't want Meta to use my healthcare data to advertise to me"

  (patient177, 35 years old, has telehealth experience)

  Moreover, the confidentiality of remote meetings cannot be overemphasized. Participants specifically expressed uncertainty about who might be present on the other end of the virtual meeting, questioning whether an outside party or an unauthorized individual might participate in the session without their knowledge.

  "How would I know the doctor is alone in the room"

  (patient332, 25 years old, no telehealth experience)

  Similarly, another participant expressed worries about privacy in their own environment during VR sessions:

"Not realizing when someone has entered the room I am in, which would violate the privacy between my doctor and I"

(patient150, 22 years old, has telehealth experience)

Concerns about data breaches and cybersecurity threats were also raised:

"There is a high chance of cyber attacks and data theft in such a setup"

(patient305, 31 years old, has telehealth experience)

The issue of data confidentiality has been previously investigated in many studies and is reportedly one of the major barriers to the adoption of telehealth [157, 165, 170, 111, 71]. Some considerations to address these concerns include "obtaining informed consent" from patients before a session similar to in-person consultation and based on the country's legislation [53, 80, 178]. Also, care providers should ensure that proper data privacy agreements with involved third parties are made and notify patients about the use of any third-party applications [53].

- *Apprehension and hesitance:* Participants expressed concerns regarding their comfort, attitudes, and expectations regarding using VR for telehealth consultation. About 8.7 percent of the participants expressed worries indicative of apprehension and hesitance, which could impact their ability to feel at ease and engage fully during consultations.

  One participant stated,

  "I would feel awkward"

  (patient20, 20 years old, has telehealth experience)

  Similarly, another participant noted this feeling of awkwardness and a perceived lack of authenticity of interactions in virtual environments:

  "Feeling awkward and taking the appointment seriously as it feels like not a real human-to-human interaction"

  (patient136, 31 years old, has telehealth experience)

VR uses synthetic representations of the real world, such as avatars for humans. This can lead some patients to perceive the consultations as artificial, which can impact the perceived seriousness of the interaction.

"Looking too much like a virtual environment, making one lose sense of how serious the situation is"

(patient121, 22 years old, has no telehealth experience)

The lack of the comfort of face-to-face confidentiality and the perception that digital technologies like VR telehealth are less secure can make patients hesitant to share certain information during a telehealth visit. The reluctance to disclose sensitive information in VR was expressed by one participant,

"I would not want to show the doctor certain parts of the body that are causing issues. In-person, however, I would be willing to"

(patient217, 25 years old, no telehealth experience).

The hesitance to disclose in telehealth can be associated with the challenge of developing the doctor-patient relationship or rapport that is common in face-to-face visits [53]. However, if VR telehealth can foster a similar level of rapport or replicate the human touch of in-person visits — for instance, with enhanced telepresence — its adoption among patients might improve. This enhanced telepresence can make it easier to connect emotionally during remote appointments, helping patients feel more at ease and truly understood. When patients see their healthcare providers as caring and genuinely involved, they're more open to sharing information, which can result in better diagnostics [39].

- *Cost:* This concerns the financial implications of adopting VR telehealth, particularly the expenses associated with purchasing and maintaining the necessary equipment and services such as VR headsets and internet connectivity. One of the specific worries was the return on investment for individuals who may not require frequent medical consultations. One of the participants captured this sentiment in the explanation,

  "The cost of owning a VR headset just for accessing health care alone might not be worth it for some"

(patient186, 32 years old, has telehealth experience)

Besides cost, another concern raised by participants is obsolescence. With the rapid advancement of technology, users may find themselves needing to replace their devices after a relatively short period. This uncertainty about the long-term viability of the hardware investment can hinder VR telehealth adoption.

"The price of the head-mounted set might be the biggest obstacle because I assume one will have to buy the headset and then also spend money for the doctor's consultation, yet I might only get sick twice a year, and by the time I get to next year, another version of the head-mounted set will be recommended. Almost as if you are buying new phones"

(patient117, 22 years old, has telehealth experience)

Alleviating concerns about cost and obsolescence requires providers and policymakers to consider the economic barriers patients may face when implementing VR telehealth solutions. Strategies such as offering rental programs for equipment, installing necessary facilities and equipment at centralized community centers like libraries for public use, and subsidizing equipment costs could help mitigate these financial challenges.

- *Accessibility:* Participants expressed concerns regarding the accessibility of VR telehealth, citing potential barriers to adoption. Approximately 6.5% of the respondents noted issues related to the availability and usability of VR technology.

  One participant stated,

  "Not everyone has access to VR"

  (patient19, 38 years old, has telehealth experience)

  This submission emphasizes how the digital divide among users — which can influence differences in access to the needed technologies — can hinder the reach of VR telehealth services. A study by Karimi et al. shows that access to digital health technology is associated with the odds of having telehealth visits, [82]. Thus, access limitations can widen the existing gaps in access to care.

  Another participant noted a similar access concern, suggesting the need for community-based access so that users who can't afford the necessary VR equipment can still utilize telehealth services through digital health resources available at community

centers. This strategy could help bridge the digital divide and ensure equal access to healthcare.

"Access to equipment, and if equipment can be accessed through public means"

(patient50, 24 years old, has telehealth experience)

Addressing VR accessibility concerns due to technology limitations will require several considerations, including providing affordable alternative telehealth options. Studies show that audio-only telehealth may be adopted as an alternative to mitigate disparities in technology access [82].

- *Misdiagnosis:* This tag addresses the potential of being misdiagnosed due to the limitations of VR telehealth when compared to in-person care. Misdiagnosis is a significant concern as it can lead to incorrect treatment and potentially worsen a patient's condition. The limitations of VR telehealth, such as the inability to perform hands-on examinations, can contribute to this issue. Key evaluations such as measuring vital signs like blood pressure or listening to a patient's lungs and skin examinations to diagnose dermatological conditions at face-to-face appointments may be complex to perform accurately in telehealth [99]. Other assessments that require palpation for tumours, cysts, or lumps in various body parts, as well as feeling joints and muscles to detect swelling due to arthritis, depend heavily on the clinician's ability to interpret tactile sensations. This is challenging to replicate in a telehealth environment [178]. Some remarks from participants regarding misdiagnosis include:

  "My only concern is being misdiagnosed because I feel like when you're in person with the healthcare provider, you can have a more hands-on visit to be able to have your pain locations correctly identified"

  (patient84, 29 years old, no telehealth experience)

  This comment specifically points to an area where telehealth might be deficient, such as assessing pain locations, which often require the "hands-on" approach of in-person visits. Some participants with telehealth experience expressed informed concerns. One participant pointed out that while remote medical devices can provide real-time vital data to aid assessments, not every patient owns such devices or can operate them without external help.

"Making it so the doctor could get an accurate diagnosis of you when he's not really there, like how he would get your blood pressure so you would probably have to strap something to you correctly, which you might not have at home or at a library or you would put it on wrong"

(patient149, 38 years old, has telehealth experience)

While integrated remote medical devices can provide vital information to aid assessment in telehealth, it is also essential to consider other strategies to minimize the risk of misdiagnosis. Healthcare providers are encouraged to refer patients for in-person evaluations whenever there is any indication that a virtual examination lacks comprehensiveness [143]. Also, involving additional medical professional(s) like "a nurse or physician assistant" in sessions — when possible — can help ensure that nothing is missed during virtual consultation [143].

Expected Features and Capabilities in VR Telehealth

Participants also responded with expected features or capabilities in VR telehealth that would improve their experience during a VR consultation. Ten themes emerged from the responses. These include Clarity and Detail, Communication & Bond, Privacy & Security, Provider Transparency, Uncertainty, Skepticism, Record & Review, Familiar Environment, Interactive Diagnosis, and Purpose & Utility.

a) Clarity & Detail: Participants expect the VR environment to provide clear imagery and detailed examination capabilities. They expect realistic representations to ensure no visual detail that could have helped with the diagnosis is missed. Besides having a lifelike representation of the doctor, they also expect the platform to show a realistic representation of themselves so the doctor can better assess conditions that are symptomatized in visual forms.

   One of the patients stated,

   "The ability to see more of the facial expressions rather than just a model moving its lips to represent the doctor's words"

   (patient96, 22 years old, has telehealth experience)

   Another patient explains why a faithful visual representation is desired in VR telehealth,

"Be able to see my whole body to ensure I could properly display what part needs attention"

(patient46, 30 years old, has telehealth experience)

In essence, VR can enhance telehealth by providing realistic environments, enabling interactions in a "high-definition three-dimensional" conferencing [77]. A faithful visual representation can strengthen the sense of presence and connection between patients and healthcare providers.

b) Communication & Bond: A stable connection and clear audio for effective communication are both important. Besides the technical aspects, participants emphasize the importance of establishing a bond with the healthcare provider. This expectation suggests the need to integrate haptic technologies that can facilitate the transmission of tactile feedback to replicate physical touch.

As one participant explained,

"I imagine that if you were discussing something sad or needed comfort, this would be helpful because a Doctor could put his hand on your shoulder or give an indication or something that will provide comfort like they were in person."

(patient31, 58 years old, has telehealth experience)

c) Privacy & Security: In an age of increasing digital breaches, participants are concerned about data security. They expect the VR platform to have robust measures to protect their personal and health information from nefarious actors.

One participant specifically recommended data encryption and adherence to the country's privacy laws.

"Encrypted Data and a system that adheres to the Privacy Laws of Canada as well as the Medical Privacy Rules and Laws"

(patient101, 31 years old, has telehealth experience)

d) Provider Transparency: Knowing the specialization and expertise of the healthcare provider can enhance patients' comfort. It helps build trust and set the right expectations for consultation.

One participant with no telehealth experience communicated this need,

"Some sort of visual of the provider and what they specialize in to enhance one's comfortability in this virtual environment"

(patient1, 23 years old, no telehealth experience)

Past research on patient preferences for backgrounds in video conferencing corroborates this expectation. In one study, patients preferred video visits where the environment had the physician's certificate on display [114].

e) Uncertainty: Some participants were unsure about the specific features they'd expect in a VR healthcare setting. This tag indicates a potential lack of familiarity or uncertainty about the technology's capabilities. The visual illustration of the proposed VR platform presented to the participants might not have sufficiently conceptualized the system for some participants. An interactive prototype would better demonstrate the functionality of the system.

   This need is captured by the comment,

   "Can't think of anything yet. I'd need to try VR in this format before being able to make that determination"

   (patient111, 32 years old, has telehealth experience)

f) Record & Review: Having the capability to record consultations for future reference is highly valuable since traditional note-taking can be challenging in a VR environment. Patients also expect their medical history to be readily accessible to their healthcare providers. Automatically keeping a record of each visit is also beneficial for physicians as it reduces the burden of manual data entry and supports continuity in care documentation.

   One participant with telehealth experience simply expressed the need for the platform to make their medical record available to the physician whenever it's needed,

   "For them to be able to access my records..."

   (patient39, 31 years old, has telehealth experience)

   Another patient expressed a similar need,

"When considering this process, I have several questions that come to mind. However, I expect that my medical history and other personal information will need to be readily available to them"

(patient52, 37 years old, has telehealth experience)

g) Familiar Environment: To make the experience more relatable, participants prefer the VR setting to resemble a traditional doctor's office. A study by Houchens et al. suggests that patients prefer telehealth visits that display traditional backgrounds adorned by the physician's diploma [114]. Furthermore, patients expect the interactions and exchanges common in face-to-face visits to be reasonably replicated.

One of the participants noted,

"It would have to look like the doctor's office, and not a random office"

(patient80, 22 years old, has telehealth experience)

Another participant stated,

"I would expect that it would be comfortable just like being in person or maybe not just like but a little more like being in person you can see your doctor across from you, where you're sitting, you feel like you're in the exact same environment. I don't know about being able to pick up a prescription because it's not like you could take it from the 3-D image and have it in your home— that would be cool, but if something like that existed, it's not going to happen in my lifetime probably "

(patient31, 58 years old, has telehealth experience)

h) Interactive Diagnosis: A two-way interaction where patients can share their concerns, answer the provider's questions, and possibly undergo a virtual physical examination is essential. There is a need for integrating advanced haptic sensing technology that cannot only accurately replicate human touch but also transmit feedback data to the physician.

A participant expressed the need for such a feature in VR telehealth,

"The only thing that would make it better is if the doctor could feel the patient. Say the patient feels they have a lump. The doctor would need to be able to physically assess that"

(patient15, 31 years old, has telehealth experience)

Moreover, participants also demanded that VR telehealth support comprehensive diagnosis, suggesting the need to integrate the system with remote medical devices in order to provide physicians with real-time access to vitals.

"My doctor to be able to take my vitals right then in there remotely and them to be able to pull them up my environment to be able to be interactive may be able to show my doctor or visually appear in front of my doctor showing anything that I will need to show being my doctor being able to manipulate my body and in any kind of way that they would need to see any kind of issues that I would be having"

(patient29, 35 years old, has telehealth experience)

i) Purpose & Utility: Some participants question the real application of VR in healthcare. They feel the technology might be better suited for entertainment than medical consultations.

This participant stated,

"I don't see the purpose. It seems like this technology would be better used for entertainment purposes"

(patient5, 40 years old, has telehealth experience)

It is important that VR telehealth is designed to cater to specific needs. Although it is not a panacea for all telehealth challenges, there are particular areas where it can offer unique benefits, such as patient education, training for medical surgery, and telehealth visits that require a personal connection with a physician, like therapy sessions. Providers should communicate the limitations of VR in telehealth to users.

j) Skepticism: Some respondents question the relevance and feasibility of VR in healthcare. They think there is no valuable benefit VR can offer beyond what is possible in traditional telehealth, like video conferencing.

As this participant notes,

"I don't see how having a VR environment would make me any more comfortable than a basic video call online. I think it overcomplicates the process and makes it more uncomfortable."

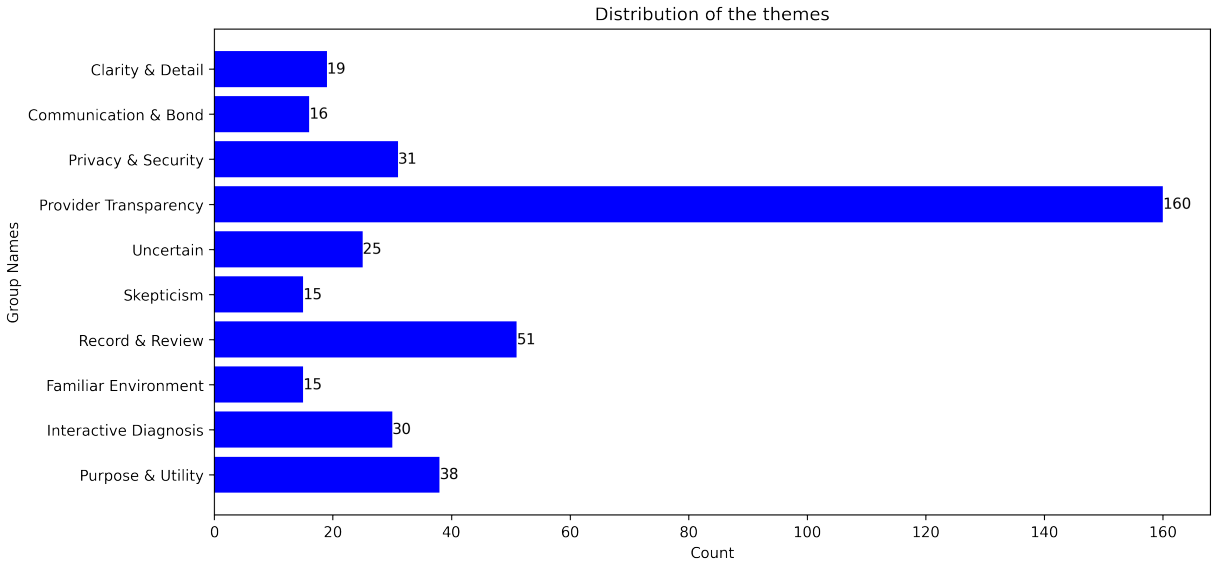


Figure 3.6: Themes that emerged in participants' responses when asked what kinds of features or qualities they might expect to see in a VR telehealth system

(patient142, 31 years old, has telehealth experience)

Comparing Participants' Comfort with Health Services, Confidence in Diagnoses, and Perceived Importance of Personal Connections in Telehealth

A recent study by Chang et al. suggests a significant association between a patient's age and preference for a telehealth type. At the same time, other attributes, including education, race, or income, showed no such relationships with the likelihood to prefer any of "video or audio-only visits" [26]. Other studies examining the effect of demographic factors on telehealth use found differences in the likelihood of receiving telemedicine among races [49]. Another study assessing the differences in perceptions by demographic factors found that geographic location and age influence telehealth perceptions among patients and physicians [36]. Similar to the above studies, this section assesses participants' perceptions of care delivery methods to find out if they differ based on telehealth experience, level of VR experience, income level, employment status, education level, age, technology affinity, dependent status, or country of residence. ANOVA was applied to compare differences among the groups, whereas pairwise t-tests measured the differences between pairs

where appropriate. Figures 3.7, 3.8,B.2,3.9,B.9,B.7,B.6, B.8 show resulting plots from the perceptions aggregated by the groups. The following perceptions were compared.

1. Confidence in the accuracy of in-person Diagnosis
2. Confidence in the diagnosis received via telehealth
3. Comfort level in receiving diagnosis via telehealth
4. Comfort level in sharing medical information in telehealth
5. Comfort level in sharing medical information in person
6. Comfort level in sharing medical information in VR
7. Importance of establishing a personal connection during a telehealth visit

Figure 3.12 presents the ANOVA results across the demographic groups. The observations from plots in Figures 3.7, 3.8,B.2,3.9,B.9,B.7,B.6, B.8 and the p-values at 95% confidence level presented in Figure 3.12 are:

- *Ratings aggregated by Telehealth Experience:*

  The average ratings by participants with telehealth experience (*n=249*) were consistently higher across the six variables in 3.1.4 than the ratings by participants without telehealth experience (*n=153*). However, ANOVA results (3.12) show only four out of the six variables present differences that are statistically significant between the two groups, i.e., between participants that have telehealth experience and participants that have no telehealth experience. These four variables that show statistically significant differences are *Confidence in Diagnosis received via telehealth*, *Comfort level in receiving diagnosis through telehealth*, *Comfort level in sharing medical information in telehealth*, *Comfort level in sharing medical information in person.*

- *Ratings aggregated by Level of Experience with VR devices:*

  The average ratings provided in *plots A - F* in Figure 3.8 show that participants who had used VR devices daily are most comfortable receiving diagnosis via telehealth, are most comfortable sharing their medical information in traditional telehealth and VR, are most confident in the diagnosis received via telehealth, and think most highly of personal connection in a telehealth consultation. Conversely, participants who had no experience with VR devices nor observed VR devices being used are the least



Figure 3.7: Ratings by Telehealth Experience

comfortable receiving diagnosis via telehealth and sharing their medical information via telehealth.
However, based on the ANOVA result, only the *Comfort levels in sharing medical information in VR* show statistically significant differences among the various VR experience levels.

- *Ratings aggregated by income levels:*

  Figure 3.12 suggests that only three variables *Confidence in Diagnosis received via telehealth, Comfort level in sharing medical information in telehealth*, and *Comfort level in sharing medical information in person* show statistically significant difference among the income groups.

- *Ratings aggregated by employment:*

  Even though all the average ratings differ across the various employment statuses (figure 3.9), only *Importance of establishing a personal connection during a telehealth visit* show statistically significant differences among the employment groups.

- *Ratings aggregated by education levels:*

  The education levels show that participants with advanced degrees such as a PhD are most comfortable receiving diagnoses in traditional telehealth, most comfortable sharing their medical information in-person, in traditional telehealth and VR, and place the most value on personal connection in telehealth (B, G D, F, E, respectively, in Figure B.9). Those with an associate's degree were the most confident in the diagnosis received via telehealth. These groups' higher comfort levels and ratings might reflect a greater familiarity with digital technologies or trust in the system due to their educational background or more exposure to advanced healthcare systems. Moreover, the distribution of educational levels by telehealth experiences shows 85.7% (i.e., 6 out of the 7) of participants with a PhD have telehealth experience, whereas 69.6% of the participants with an associate degree have telehealth experience. Lastly, 75% of the participants who preferred not to state their degree had no telehealth experience. These percentages are shown in Figure B.10.

  Moreover, Figure 3.1.4 suggests telehealth experience is positively associated with participants' comfort levels in receiving diagnosis through telehealth and comfort levels in sharing medical information via telehealth. Further, the ANOVA results in Figure 3.12, indicate only the differences in average ratings for *Comfort level in sharing medical information in telehealth, Comfort level in sharing medical information in person, and Importance of establishing a personal connection during a telehealth consultation* among the education levels are statistically significant.

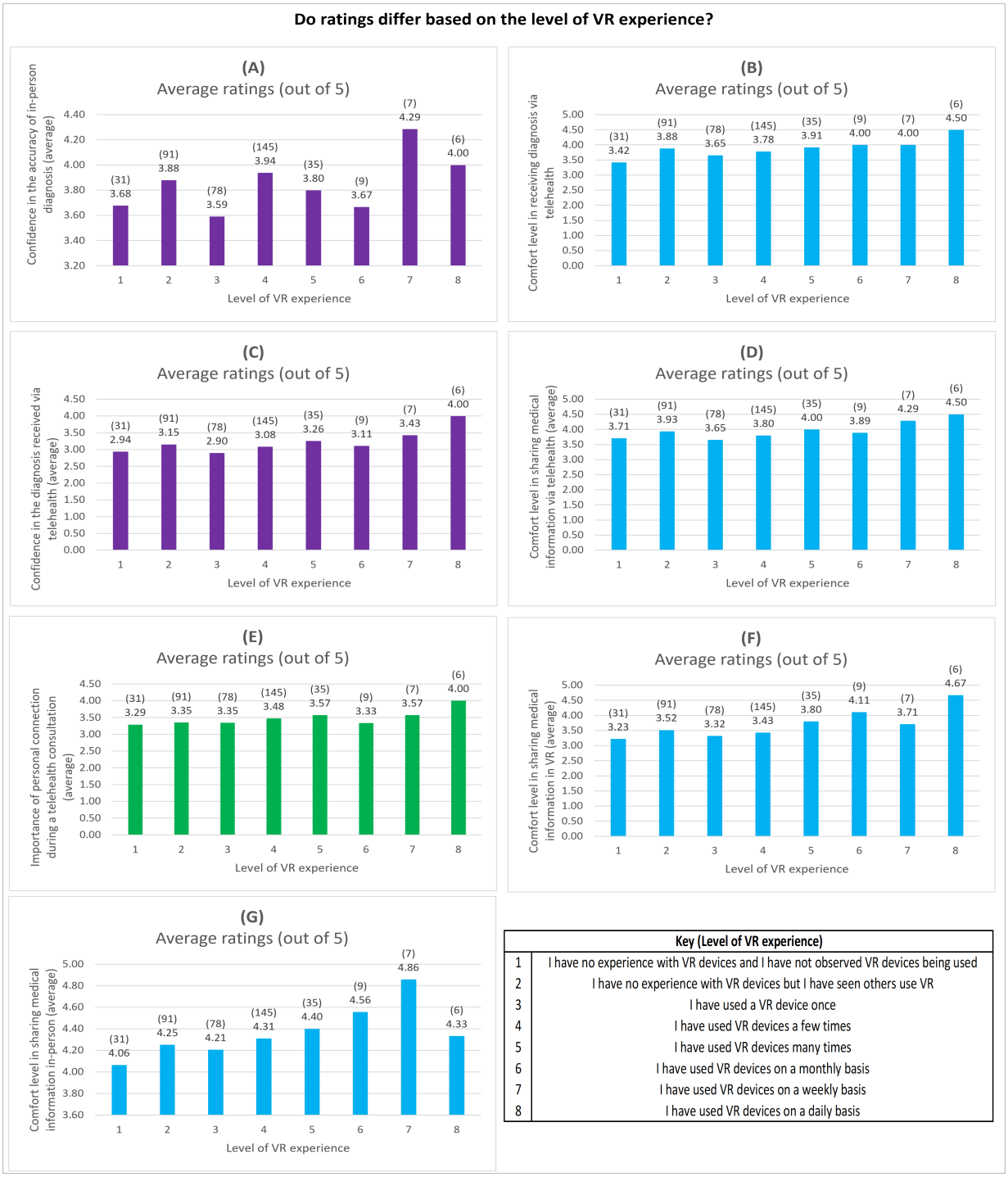


Figure 3.8: Ratings by Experience with VR devices

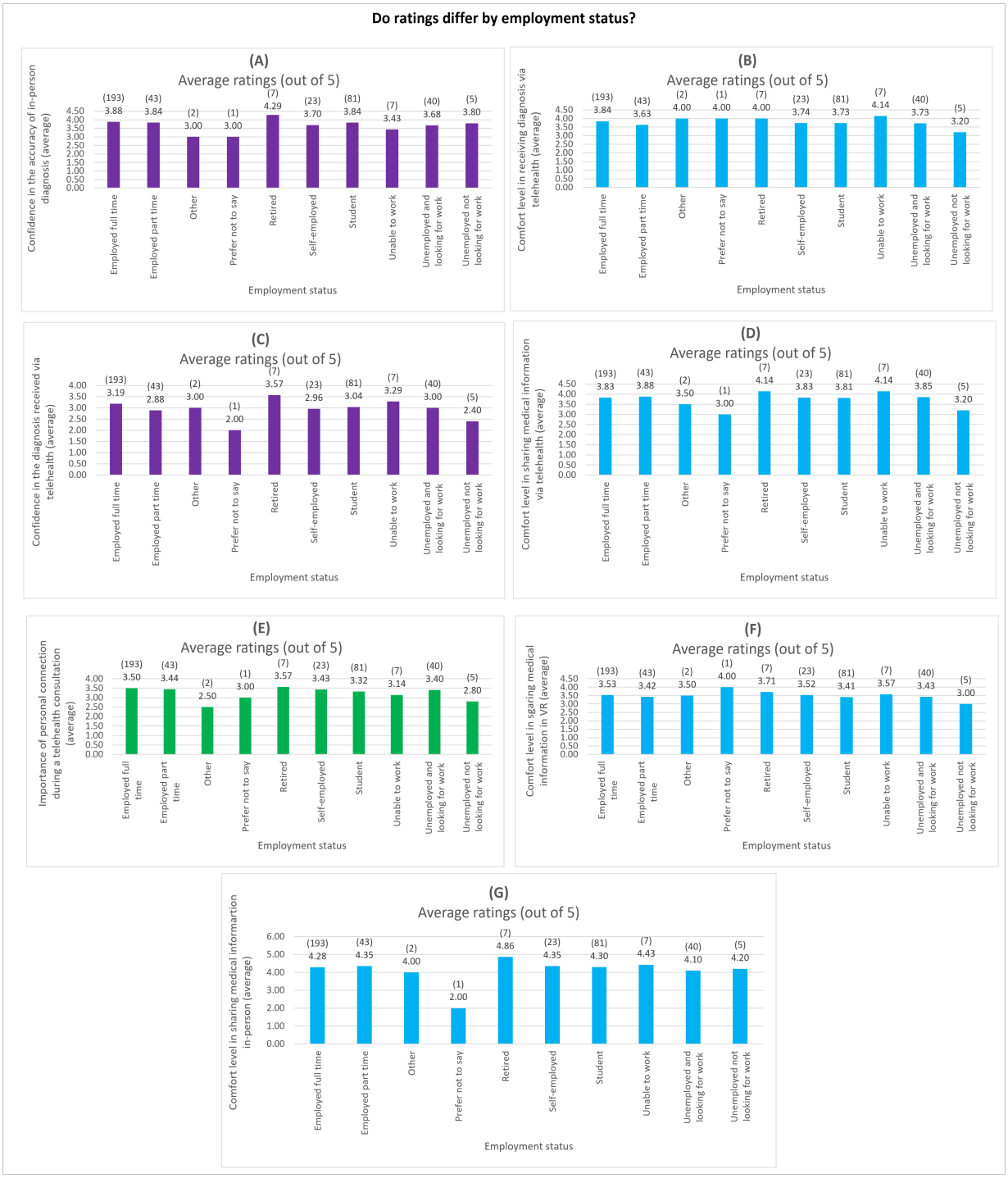


Figure 3.9: Ratings by Employment status

- *Ratings aggregated by age:*

  The age-based ratings in Figure B.7 suggest the differences in *Comfort level in sharing medical information in person* are statistically significant across the age groups. This difference is reflected in the p-value in Figure 3.12. While average ratings show that all groups are comfortable sharing their medical information in-person, the older participants (*55 - 64 years and* $\geq$ *65 years*) might be more comfortable. However, older participants are less comfortable in receiving diagnoses via telehealth (for ages 44 years, average comfort levels show a continuous decline).

- *Ratings aggregated by dependence status:*

  The average ratings in Figure B.8 and the ANOVA results in Figure 3.12 show the differences in *Confidence in the Accuracy of In-person Diagnosis, Confidence in Diagnosis received via telehealth, Comfort level in sharing medical information in telehealth, Comfort level in sharing medical information in-person, and Importance of establishing a personal connection during a telehealth visit* are statistically significant between participants with dependent relatives and the participants without dependent relatives.

- *Ratings aggregated by Technology Affinity:* The affinity for technology interaction (ATI) refers to an individual's inclination to deeply and actively immerse themselves in technology usage, viewing it as a vital personal asset for managing and adapting to technological environments [175]. Reliability analysis of the ATI scale based on respondents' responses showed that the scale was suitable for measuring technology affinity based on the obtained McDonald's omega of 0.81 and an average inter-item correlation of 0.41. Moreover, results indicate that participants have a high affinity on average (*mean=4.12, SD=1.32*). Other detailed results can be found in Figure B.5.

  Additionally, ANOVA results showed the *Comfort level in sharing medical information in VR* and *Importance of establishing a personal connection during telehealth visit* have statistically significant differences across the participants based on their technology affinity level. Specifically, there is an upward trend in the average *Comfort level in sharing medical information in VR* beyond medium affinity. This relationship between participants' *Technology affinity* and *Comfort level in sharing medical information in VR* is examined further in Section A.1.

- *Ratings aggregated by Country of Residence (top 5 Countries)* The participants' perceptions also vary by country of residence. The analysis of these perceptions across the top five(5) countries (that is, the United Kingdom, the United States, Canada,

Portugal, and Poland) shows the participants from the United Kingdom have the least comfort in sharing medical information in both VR and traditional telehealth, and the least confidence and comfort in telehealth diagnosis. Most participants from these top countries had prior telehealth experience, and their sizes were not significantly different (refer to Figure 3.10). However, there is a statistically significant difference in the reported comfort levels in telehealth diagnosis, in the *Confidence in diagnosis received via telehealth*, and in the *comfort level in sharing medical information via telehealth* among the five countries. The differences in healthcare delivery models in these countries, the participants' digital literacy level, or the quality of their prior telehealth encounters could have influenced the reported levels of comfort and confidence in telehealth.

For instance, in the United Kingdom, the National Health Service (NHS) has been slower to integrate telehealth into routine care like face-to-face consultations [73, 118]. This slower adoption of telehealth may contribute to less favourable perceptions among patients, who may view it as less thorough than in-person care.

Pairwise Comparisons of the Comfort levels

Pairwise comparisons were conducted to investigate how participants perceived different modes of receiving care in terms of comfort with sharing medical information.

- *Comfort levels accessing VR telehealth at home versus in a shared space* A t-test was conducted to examine how comfort levels in accessing VR telehealth differ based on the location in which telehealth is accessed, specifically between private homes and shared spaces.

  This test examined patients' considerations about the future accessibility of VR telehealth, where affordability could be a barrier to personal device ownership. If VR telehealth systems were available in public health centers; it raises the question of whether patients would feel comfortable accessing such services in shared spaces.

  The question relates closely to patient privacy and the convenience telehealth is generally expected to provide. Research has shown that privacy concerns significantly influence telehealth acceptance, with patients expressing hesitancy in environments where others may overhear sensitive information [7]. The potential need for VR hardware to be made publicly accessible in shared spaces like community centers might compromise perceived privacy. Additionally, the convenience of telehealth might be diminished if patients must travel to a specific location — to be able to

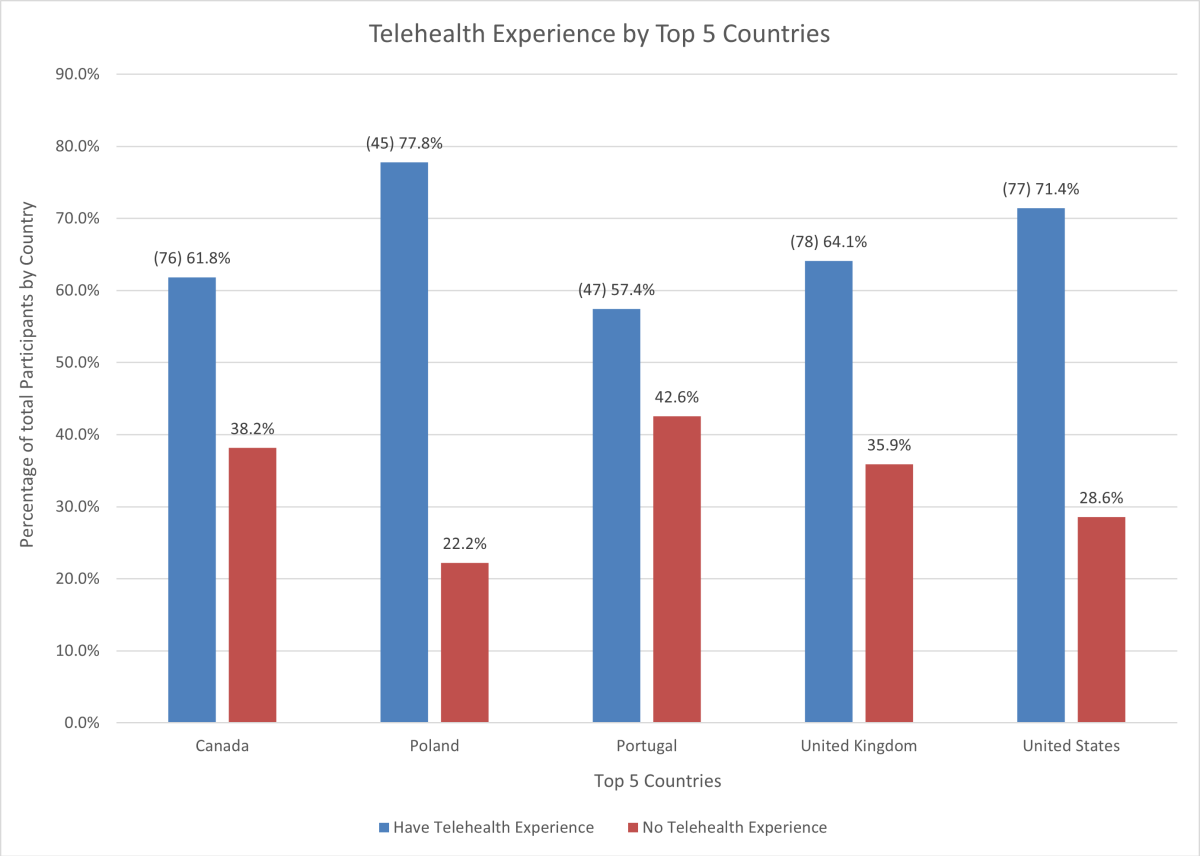


Figure 3.10: Telehealth Experience by Country

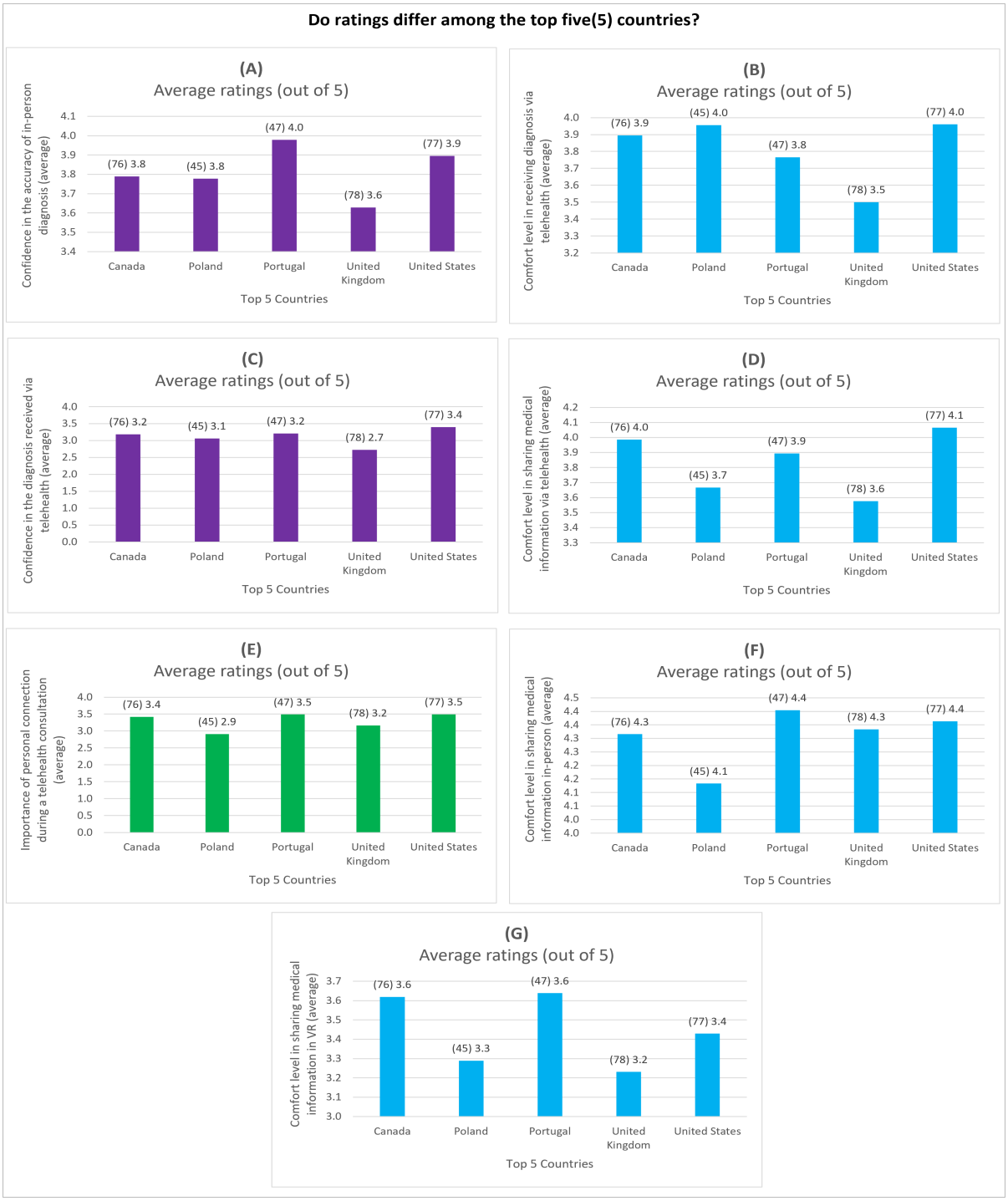


Figure 3.11: Ratings by Country of Residence (top 5)

	Summary of statistical test results (p-values) at 95% confidence level - ANOVA						
	Confidence in the Accuracy of In-person Diagnosis	Confidence in Diagnosis received via telehealth	Comfort level in receiving diagnosis through telehealth	Comfort level in sharing medical information over telehealth	Comfort level in sharing medical information in-person	Comfort level in sharing medical information in VR	Importance of establishing personal connection during telehealth visit
Telehealth experience	0.754254635	1.86754E-05	0.001125402	0.005759468	0.040491683	0.198479844	0.965438901
Level of VR experience	0.137794837	0.351889972	0.136463614	0.162497417	0.081583346	0.000716473	0.792919559
Income level	0.748852818	0.020188607	0.089756343	0.007274116	0.011335073	0.198401882	0.466276626
Employment status	0.347427273	0.620110525	0.889664883	0.868307882	0.134730405	0.993374648	0.022615726
Education level	0.936075393	0.727151753	0.380318735	0.013968069	0.004532244	0.279699081	8.78824E-05
Age	0.525732052	0.271624132	0.573152396	0.368574424	0.031674468	0.140340737	0.055252666
Dependent relatives	0.011321091	0.017549847	0.066101052	0.007238771	0.032813058	0.094000133	0.011610786
Affinity for Technology interaction	0.169898419	0.123526221	0.064748397	0.39783166	0.057860606	0.009735084	0.003562919
Country	0.139642238	0.000639722	0.018977537	0.010337762	0.360435291	0.156231213	0.00536781

Figure 3.12: Analysis of variance (ANOVA) in the ratings among participant groups

access it —- particularly, the ill, elderly, and disadvantaged might struggle with such arrangements.

The test results (see Figure 3.13) show a statistically significant difference in participants' comfort levels based on where the VR consultation is received. The result also indicates a high effect size, suggesting a significant difference between the means of the two groups compared. On average, participants tended to be more comfortable receiving VR telehealth consultations from their private homes than in a shared space.

- *Comfort levels sharing medical information in-person, traditional telehealth, and VR telehealth*

  Prior research suggests that patients feel more comfortable discussing sensitive issues or disclosing personal information such as sexual health in face-to-face meetings than in telehealth like video conferencing [41] or are more open with healthcare chatbots [164]. Likewise, another study showed that patients may be more inclined to "disclose" if they believe they are interacting with a fully automated virtual human, possibly because these interactions lack direct human presence, thus reducing fears of judgment [109, 98].

  These findings suggest a need to investigate participants' comfort with sharing their medical information in different care settings. Thus, independent t-tests were conducted at 95% confidence level to compare participants' comfort levels in sharing medical information in in-person care, traditional telehealth, and VR telehealth.

  The results, as presented in Figures B.3 and 3.14, show statistically significant differences exist between comfort levels in sharing medical information in the various modalities. Specifically, participants reported higher comfort levels sharing medical information in-person (*n=402, average=4.28*) compared to traditional telehealth

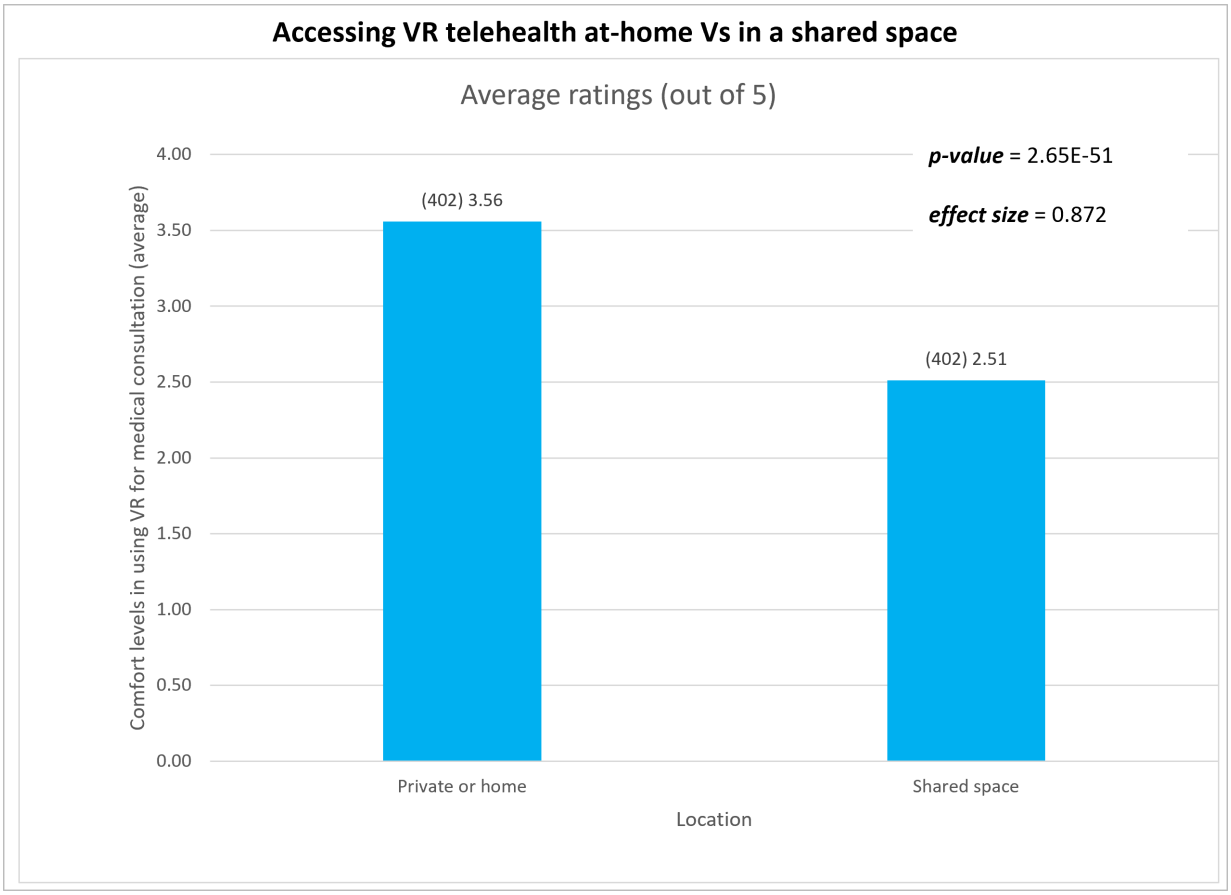


Figure 3.13: Comfort ratings: VR Telehealth at home vs shared space

(*n=402, average=3.83*) and VR telehealth (*n=402, average=3.48*). This preference for sharing medical information in person over both traditional telehealth and VR telehealth is statistically significant. Also, the preference for sharing medical information in traditional telehealth over VR telehealth is statistically significant. In addition, the reported comfort levels in traditional telehealth and VR telehealth are positively correlated (see the correlation matrix in Figure B.4. This suggests that individuals comfortable sharing their medical information in traditional telehealth are similarly comfortable using VR for the same purpose, or users open to one form of technology-driven health communication might be receptive to other forms.

Test for statistical significance (2 tailed, type 2: Comfort level in sharing medical information in different modalities)			
	In-person	Traditional telehealth	Virtual reality
In-person		2.64E-11	4.95E-27
Traditional telehealth	2.64119E-11		3.83632E-06
Virtual reality	4.95E-27	3.84E-06	
Test for statistical significance : Effect sizes (Cohen's d)			
	In-person	Traditional telehealth	Virtual reality
In-person		0.47687	0.78796
Traditional telehealth	0.47687		0.32816
Virtual reality	0.78796	0.32816	

Figure 3.14: P-values and Effect sizes: In-person vs. Traditional telehealth vs. VR Telehealth

Influence of VR Exposure and Technology Affinity on Comfort in VR Telehealth: A Structural Equation Modeling Approach

The preceding section on participant demographics 3.1.4 revealed that most participants had prior experience with VR devices, raising the question of whether this characteristic influenced their comfort and confidence ratings in VR telehealth. Additionally, the analysis of variance of participants' technology affinity levels based on VR experience showed statistically significant differences, suggesting that both prior VR exposure and technology affinity are potentially associated with perceptions of VR telehealth.

To investigate these questions, structural equation modeling (SEM)[85, 16] was conducted using the *level of VR experience* and *average affinity scores* as exogenous variables, with *comfort level in sharing medical information in VR* as the dependent variable. Given the ordinal nature of *level of VR experience* and *comfort level in sharing medical information in VR*, a Diagonally Weighted Least Squares (DWLS) estimator[95, 113] was applied.

The SEM analysis results suggests that *average affinity scores* is a significant predictor of *comfort level in sharing medical information in VR*, with a standardized estimate of

0.212 and a p-value of less than 0.001. This finding suggests higher technology affinity is associated with greater comfort in sharing medical information in VR. On the other hand, based on the same model, the result indicates that the relationship between *comfort level in sharing medical information in VR* and *level of VR experience* is not statistically significant ($p = 0.129$), suggesting that VR experience does not significantly contribute to explaining the variance in comfort levels beyond what is already explained by affinity scores.

However, when *level of VR experience* was tested alone as a predictor, a statistically significant relationship with *comfort level in sharing medical information in VR* ($p = 0.008$) ensued, with a standardized estimate of 0.146. This suggests that when considered in isolation, *level of VR experience* does have a significant association with *comfort level in sharing medical information in VR*. However, the effect size is smaller compared to *average affinity scores*.

Causal Analysis of Technology Affinity and Comfort Levels in VR

Following the results of the ANOVA and SEM, further exploration to understand the causal impact of technology affinity on participants' comfort with sharing medical information in VR was carried out. Results suggest a trend toward higher comfort levels among individuals with above-medium technology affinity compared to those with medium or lower affinity scores. However, this treatment effect is not statistically significant, as the 95% highest density interval (ranging from -0.035 to 0.13) includes zero, implying the effect may be due to chance. For more about the results, see Section A.1 and Figure A.8.

3.1.5 Discussion of Survey Results

This study has shown, through various analyses, patients' perceptions of in-person healthcare, traditional and VR telehealth care, and the relationship between some demographic factors and patient perceptions. On user concerns, while most participants (29.52%) without prior telehealth experience are primarily concerned about misdiagnosis, very few participants (9.83%) with prior telehealth experience share similar apprehension. In contrast, the most participants (36.61%) shared no concerns. Other prominent concerns include technical problems, which may be due partly to system complexity and were more commonly cited for VR telehealth (3.73%) than traditional telehealth (12.69%). The concerns common to both platforms include privacy, security, and internet connectivity

issues. Most participants concerned about connectivity issues mentioned worries regarding the heavy network demands of streaming and rendering of VR content VR telehealth will require. Some privacy concerns stem from participants' discontent over sharing sensitive medical information over the internet, whether in private or shared spaces. Similar privacy concerns have been previously reported as barriers to telehealth adoption [83]. To alleviate the concerns of ease of use, designers of VR telehealth systems should prioritize the user-friendliness of the interface to minimize the effort needed to set up the system. They should also offer straightforward onboarding tutorials.

The participants also outlined specific details about VR telehealth that would improve their experience of receiving care through the platform. Most of their suggestions centered on provider transparency and the ability to confirm the expertise of their healthcare provider in VR settings. They also emphasize the need to support recording consultations as an alternative to traditional note-taking. Other expectations include the security of medical information and a stable internet connection.

Previous studies [27, 31, 139] have shown that demographic factors play a significant role in shaping perceptions of telehealth. The study explored the relationships between specific demographic characteristics and participants' perceptions of comfort level in telehealth and their confidence in the diagnosis received via telehealth (section 3.1.4). Notably, having telehealth experience, earning a higher income, or having a higher education level were associated with greater comfort and confidence in telehealth. Previous studies by Chang et al. [27] have reported that individuals with prior telehealth experience generally report higher comfort levels as familiarity with the technology reduces anxiety and increases the likelihood of positive experiences. Lower-income individuals often face barriers such as limited access to reliable internet and devices, which can affect their comfort in using telehealth services. However, those with access tend to appreciate the cost savings and convenience [187]. Educated individuals are also more likely to understand and navigate telehealth platforms effectively [29]; hence, this can influence their comfort ratings. Furthermore, while the ANOVA results and the boxplot in Figure A.1 suggest a relationship between user comfort levels and technology affinity, the result of the regression discontinuity design in section A.1 indicates that although technology affinity appears to influence user comfort in VR positively, the effect is not statistically significant.

3.1.6 Conclusion

This study provides an understanding of patients' perceptions of in-person healthcare, traditional telehealth, and VR telehealth and the demographic factors that influence these

perceptions. The findings highlight the importance of addressing technical issues, privacy, and security concerns in VR telehealth and emphasize the need for provider transparency, user-friendly interfaces, and stable internet connections. By prioritizing these factors, designers or developers can create VR telehealth platforms that meet patients' needs and expectations of telehealth. Additionally, considering demographic factors that influence comfort and confidence in telehealth — such as prior experience, income, education level, and technology affinity — can guide the development of targeted interventions and strategies to promote equity and inclusivity in telehealth access. To enhance the appeal of VR telehealth, designers should aim to make it affordable, accessible, and capable of extending the current capabilities of existing telehealth.

3.2 Study II: Interviews with Physicians

In the second study, physicians were interviewed to gather their experiences and opinions on VR telehealth, traditional telehealth, and in-person care delivery. The study was approved by the University of Waterloo's Ethics Board ($REB\#45343$).

3.2.1 Interview Structure

The structured interview (see complete interview questions in section C.3) consisted of three sections: demographics, traditional telehealth, and VR telehealth. The demographics section included basic demographic questions such as the participant's age, gender, highest level of education, years of experience, and medical specialty.

The traditional telehealth section consisted of questions to gather information about participants' experiences with telehealth and their concerns. Participants without experience providing telehealth services were asked to state their primary reasons for not doing so.

The VR telehealth section gathered participants' thoughts about using VR devices to deliver healthcare services.

3.2.2 Participants Recruitment

Only the participants who met the inclusion criteria (see consent form in section C.2) were recruited for the study. These criteria include:

- Physicians who are currently practicing and have an active license
- Physicians who have experience with telehealth services through direct provision or their healthcare institution.
- Physicians willing and able to participate in a one-on-one interview, which will be conducted virtually.
- Physicians who can communicate effectively in English, as the interviews will be conducted in this language.

Eligible candidates were invited for a Zoom interview via email (see section C.1). The study was conducted with six primary healthcare professionals in Canada between August 2023 and January 2024.

Four participants were male, and two were female, with ages ranging from 33 to 62 (the average age was 43). All six participants hold medical degrees. They include four family medicine physicians, one pediatrician, and one cardiologist. Three physicians have been practicing for 11 to 20 years, two have 5 to 10 years of experience, and one has been practicing for over 20 years. These physicians have worked in diverse settings, including urgent care, long-term care, walk-in clinics, group practices, solo practices, and community-based primary care. The detailed characteristics of the participants are presented in Table 3.1.

3.2.3 Interview Procedure

The structured interviews with the physicians were conducted over Zoom. Consent for data collection and recording was obtained at the beginning of the interview, followed by the questions. A copy of the consent form is provided in section C.2.

The demographic questions were administered through a form, and the main interview questions were administered orally.

All the interviews were conducted in English by the same interviewer. The participants were sampled to ensure maximum variability in socio-demographic characteristics such as age, gender, length of work experience, and the practice setting [128].

The interviews were conducted until a significant repetition of themes ensued; however, data saturation was not fully achieved. Specifically, following the definition of data saturation from the grounded theory standpoint, that is, the point in coding when no new codes occur in your data [176]. By the fifth interview, the responses mirrored those from the

Characteristics	Category	Number (percent)
Gender	Male	4 (66.7)
	Female	2 (33.3)
Primary Care Professional	Family Medicine Physician	4 (66.7)
	Cardiologist	1 (16.7)
	Pediatrician	1 (16.7)
Age	<35	1 (16.7)
	35 - 50	4 (66.7)
	>50	1 (16.7)
Education	Doctor of Medicine (MD)	6 (100)
Years of Experience	5 - 10 years	2 (33.3)
	11 - 20 years	3 (50)
	20+	1 (16.7)

Table 3.1: Physician Characteristics

previous four interviews. To confirm data saturation, a primary care professional (a pediatrician) belonging to a different category than the earlier respondents was interviewed. During this sixth interview, additional insight was noted regarding the difficulty of working with children via telehealth. Consequently, both theoretical saturation [154] and data saturation [79, 66, 64] were not fully achieved. However, due to practical constraints, data analysis was conducted while acknowledging this limitation.

3.2.4 Thematic Analysis of the Interview results

Thematic analysis under the constructivist framework was applied to develop the codes and themes from participants' responses. In constructing the themes, the inductive approach, where themes are created from data, was followed. Following the six-step framework of Braun and Clark, [19], the main insights from the physician interviews were extracted and refined. Codes were developed only after reviewing the interview transcripts. The

final codes and themes (code clusters) fall under the broad categories of the two research questions. NVivo software was utilized in the coding process. The specific steps taken in the theme development after reviewing the transcripts are presented as follows:

a. Parent codes or containers were adapted from the research questions. These parent codes are *Physician Perspectives across Telehealth and In-person modalities* and *Feature Considerations for VR telehealth to meet users' needs*, developed from the first and second research questions, respectively. The parent codes served as containers for the subsequent child codes.

b. Child codes were developed under each parent container after reviewing the transcripts. To accurately address the research questions, the codes were constructed from the transcripts with the research questions in mind.

c. All the codes were exported from NVivo to an Excel spreadsheet for theme development.

d. Next, the codes were grouped based on their shared relationships. Nine (9) tentative clusters were derived from thirteen (13) codes from the first research question. Next, the clusters that exhibited commonality in their codes were combined before the resulting clusters were named appropriately. For example, clusters 3 and 6 were merged under a new theme *User Interaction* to broadly represent concerns related to the ease of use of the technology and the physical limitations of telehealth. Clusters 4 (Billing system) and 5 (Affordability) were merged under *Economic factors*. In contrast, cluster 7 (technological reliability), cluster 8 (change management and acceptance), and Cluster 9 (Integration with EMRs and other systems) were retained as separate themes. Similarly, eleven (11) initial clusters were formed from the 15 codes within the second research question. These clusters were refined into six (6) broad themes. Some of the resulting dominant themes (by the number of codes) include *Technical Infrastructure and Data Security*, *Functional Versatility, Economic and Regulatory considerations*, and *Accessibility and Inclusivity*. Physicians' suggestions for the VR telehealth use cases, such as follow-up meetings, mental health examinations, patient education, and simulation training, were grouped under the theme *application areas*. Whereas, suggestions about the benefits of telehealth, particularly over in-person healthcare, were collectively named *benefits of telehealth*. Both *use cases* and *benefits of telehealth* were tentatively recorded under a parent container *Others*.

e. After an independent review of the codes and themes by a second researcher, the themes *use cases* and *benefits of telehealth* were moved from *Others* to *Physician*

Perspectives across Telehealth and In-person modalities on the account that this container encompasses the perspectives on current telehealth and in-person modes of care delivery, except the design considerations for VR telehealth. This merge necessitated a change in the structure of the thematic network from *research question* ← *themes* ← *codes* to *research question* ← *themes* ← *sub-themes* ← *codes*. Moreover, the theme *user interaction* from the second thematic network was discarded, and its single child code *convenience* was moved to theme *accessibility and inclusivity*.

3.2.5 Codes, Sub-themes, and Themes

The themes in the first research question present the participants' perceptions of telehealth and in-person care under *use cases*, *benefits of telehealth*, and *concerns*. Whereas the themes in the second research question specify the *functional* and *non-functional* design requirements of users of the proposed VR telehealth platform. The existence of non-functional requirements reiterates the belief that the system's evaluation extends beyond its functional capabilities to include its social sustainability [35]. Figure 3.16 presents these requirements as codes or themes. The functional requirements for the VR telehealth system appeared under various themes, mainly within the theme *functional versatility*, with some participants highlighting the need for patient mobility and tracking during a virtual session and the system's support for comprehensive diagnosis. The code containers in Figure 3.16 were color-coded to reflect the associated requirement. Some of the *nonfunctional requirements* include the need for easy integration with current physician workflow (1a in Figure 3.16), reliable *Internet Connection* (1e in Figure 3.16), being affordable (4a in 3.16), convenient (3c in Figure 3.16), and passing regulatory approval (4b in Figure 3.16), among others. All the themes have been defined below.

3.2.6 Physicians' Perceptions of Traditional Telehealth and VR Telehealth

The perceptions are grouped under three major themes, which include *Use cases*, *Benefits of Telehealth*, and *Concerns*.

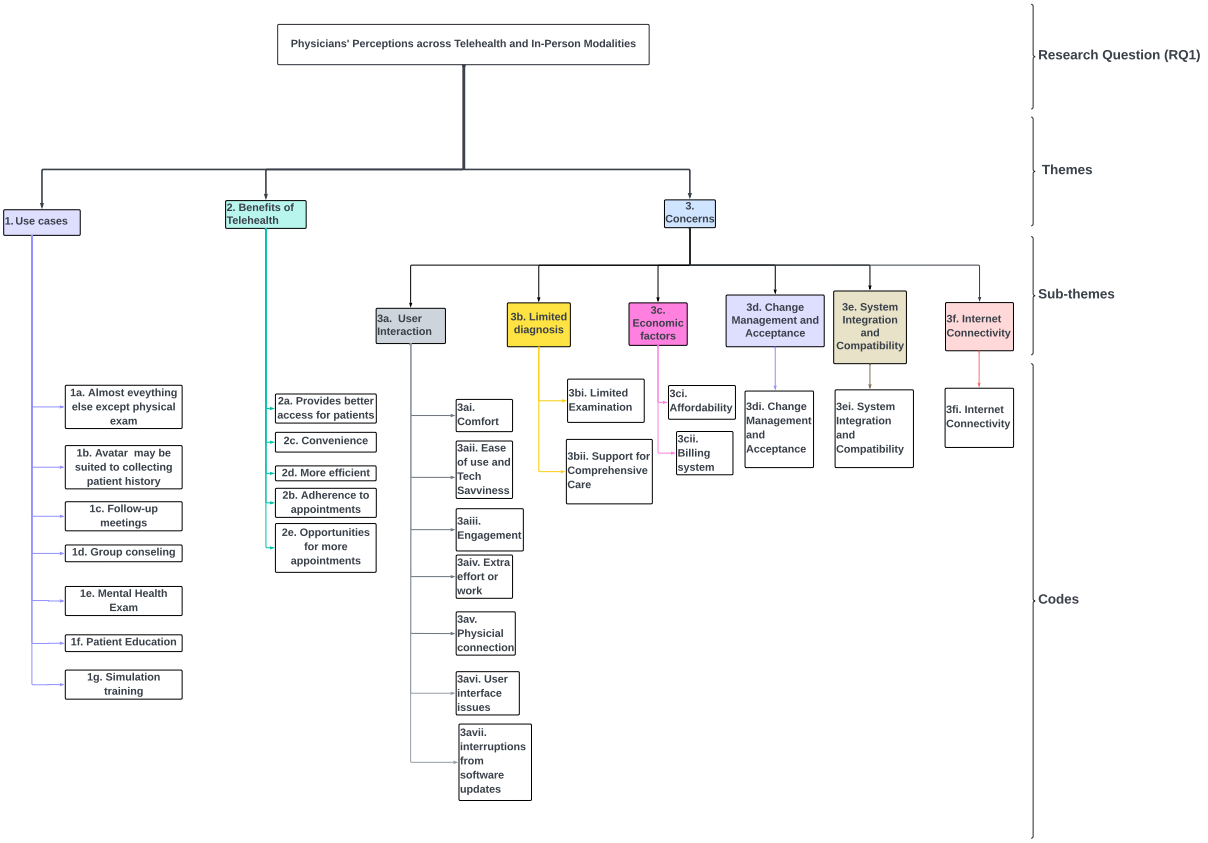


Figure 3.15: Thematic Network based on Physicians' Perceptions of Telehealth and In-person Care

Concerns:

The concerns shared in the interviews were grouped under six(6) codes, including user interaction, limited diagnosis, economic factors, change management and acceptance, system integration and compatibility, and internet connectivity.

User Interaction

User interaction concerns relate to the physical limitations of telehealth systems, such as the difficulty of establishing personal connections, sustaining engagements with patients, and using the technology. They also include unplanned events such as software updates and interface glitches that could impact the experience of a patient and a physician on the platform. The participants shared important insights regarding user interaction concerns.

> *"Video conferencing I find to be challenging because sometimes people don't have the bandwidth or find the link confusing. And the other thing is that we weren't recording the visit in our chart. It was being recorded on this other device, we were typing in another place, and we were copying and pasting, and so anything that creates more steps for me, like with so much burnout, I'm less likely to want to engage in."*

He also highlights why having to learn how to use the technology might hinder adoption by a sick patient:

> *"ease of use of the platform, like if they have to, you know, orient themselves to a platform and do some education or some tutorial, that seems to me to be a barrier for some patients who are sick or who are alone or suffering or, you know, or if they're depressed, they can't really concentrate and necessarily pick up new skills very easily."*
>
> *(male, 37 years old, family medicine physician)*

Moreover, another participant highlighted additional challenges when using telehealth with children. Besides establishing a connection, she noted the particular challenge of holding their attention. She described the situation as follows:

"I think for children, it is harder. The parents, not so much, but for young children, it is hard to establish a connection by video. it's very different in pediatrics because the kids aren't just sitting in one place; they're all over the place, so just being able to connect with your patient sometimes in pediatrics."

(female, 42 years old, pediatrician)

Limited Diagnosis

Limited Diagnosis includes concerns about the inadequacy of telehealth for use in comprehensive diagnosis and care. Telehealth was noted to be lacking in support for comprehensive visual assessment since a physician can only see a window of the patient in a video; likewise, physical examination is currently impossible in telehealth.

One of the physicians states:

"There are medical conditions that clinicians pick up by seeing the person where the patient themselves does not know that they are sick. The classic example is that you can shrink in height as you get older. And so, as we're seeing that in our clinic, or if they become more and more bent over, that usually triggers us to think about fractures of the spine, about autoimmune conditions. We're noticing that somebody is going pale. I had one patient where we were able to capture anemia. It was so gradual that the patient didn't even notice. Those things are missed in telehealth visits because you can modify how I look using online platforms and video consults. I don't get to see how poorly you can walk."

(male, 33 years old, family medicine physician)

The submission suggests how telehealth can limit a provider's ability to spot subtle physical changes important for diagnosing conditions that may go unnoticed. Similarly, regarding the lack of support for physical examination,

"You know it's limited if you want to have a good visual of your patient, so like rashes or to do any assessment, I just don't think that's currently appropriate to do in that platform. You can't do a physical exam."

(female, 42 years old, pediatrician)

Economic factors

Economic factors cover concerns related to the costs of the devices and the internet necessary for communication in telehealth, as well as billing arrangements for the service providers, i.e., physicians.

One participant objected to using a system in which billing responsibilities are not clearly defined in advance. Specifically, he notes:

> *"Nobody will use a system where the clinician doesn't get paid. I'm not going to do it for free, so as a result, either the patient's paying for it, their insurance company's paying for it, or the government's paying for that service. So, for the ones where the government defunded, like secure messaging, almost 90 percent of clinicians stopped using that service because we're not getting paid for our time."*
>
> *(male, 33 years old, family medicine physician)*

Similarly, another physician points out the need to encourage telehealth adoption through billing incentives:

> *"The primary challenges are the incentives around billing currently are volume-based, so seeing lots of patients fast works better if patients are there waiting for me in the room. So, during COVID, you saw the birth of all these telehealth companies like Rocket Doctor, Maple, and Dialog. Still, they've changed the billing codes, so we're paid about a third for telehealth consults or phone or video consults instead of in-person."*
>
> *(male, 37 years old, family medicine physician)*

The cost implications for both patients and physicians were another concern shared.

> *"A lot of these hardware pieces tend to be more expensive and, as a result, create a barrier. For example, one of our hospitals here in town uses remote patient*

monitoring to monitor heart failure patients. Each device is about $10,000 CAD. I have a handful of patients who can't afford internet at home. We have a handful of patients who can't afford a phone or a laptop. So, as a result, the question ends up being, who are we trying to serve? Are we trying to serve the rich who can drive, the rich who can have a laptop, the rich who can have internet? Or are we trying to serve everyone? Or are we trying to serve the under-served? And at what priority level? So if we're going after the under-served, the sickest, telehealth has to be funded".

(male, 33 years old, family medicine physician)

The high cost of telehealth equipment and the lack of affordable internet access thus create barriers for both patients and providers, particularly impacting underserved populations. Therefore, cost barriers raise concerns about equity and accessibility in telehealth services, suggesting that without proper funding and support, telehealth may further widen the healthcare gap between socio-economic groups.

Change Management and Acceptance

Change Management and Acceptance deals with how patients and physicians manage the shift from in-person healthcare interactions to virtual platforms, as well as the willingness of both parties to adopt new methods of delivering and receiving care.

"Change management, because people aren't used to doing it, and patient resistance and there are all kinds of social terms of health that are barriers for patients to receive care virtually."

(male, 33 years old, family medicine physician)

System Integration and Compatibility

System Integration and Compatibility covers concerns related to interoperability of telehealth systems, that is, the ability to integrate with other systems or share information and services with other systems.

"If we had more integration of systems, virtually, electronically, that would be a lot helpful, you know, embedded."

(male, 35 years old, cardiologist)

Internet Connectivity

Internet Connectivity encompasses latency issues and interruptions resulting from a weak internet connection. A solid and stable internet connection is essential for the smooth transmission of audio-visual data in telehealth. Some physicians suggest that patients living in underserved areas may find it challenging to use telehealth due to weaker connectivity. All six physicians remarked that losing internet connection or bandwidth quality often impacts patient connection.

Use cases

The use cases entail the suggested areas where VR telehealth might be most used. These include *follow-up meetings, group counseling, mental health examinations, patient education, simulation training, and collecting patient history.* While all the physicians ($n = 6$) agree that VR physical examination is challenging in VR, more than half of the physicians favour using it for mental health visits or therapy. Physicians believe patients would feel more comfortable in their environment and are likely to feel more heard during a VR visit than in traditional telehealth like online text messaging.

Two physicians suggested that VR telehealth might be best suited for simulation training for medical procedures, patient education, and even for engendering patient satisfaction from telehealth consultation since communicating in VR telehealth can make them feel more heard.

As one physician emphasized, there is a potential of VR in simulation training:

"simulation training regarding the procedures we do. It's been, again, done recently for a specific product, but what's to say it can't be used in training for ablation procedures? It's like a video game. When you're in the lab, the more practice you have with it, the better you'll get."

(male, 35 years old, cardiologist)

" I think there's a big role for VR in patient education, especially when, you know, people are on dialysis and things like that, and they need a lot of teaching or diabetics for their insulin. We should think of protecting the physician's health care mental bandwidth by making the patient feel heard through VR. I think that would improve society, the physician process, and the medical consultation process. And I think VR is perfect for that."

(male, 37 years old, family medicine physician)

Regarding the use of VR telehealth to deliver group counselling, mental health exams, and follow-ups, one participant describes why it might be best suited for such applications.

"Group counseling is probably your easiest one, very similar to how Minecraft you did virtual concerts, and we do group meetings in terms of hey let's teach you about diabetes, let's teach you about cancer screening right that's your easiest one you can tackle. It's like a Zoom meeting with 1500 people. The second one is psychiatry. Can I do counseling with you in a virtual reality where you feel comfortable in your environment As I mentioned earlier, the third one is to follow up on the testing. I don't need to examine you, I don't need to palpate you, I don't need to do anything to you, I need to tell you these are your results, and this is where our next steps are. That makes up a good solid 25 to 50% of my day."

(male, 33 years old, family medicine physician)

As pointed out, follow-up appointments represent a promising opportunity for utilizing VR telehealth. Physicians who object to using video conferencing for follow-ups involving the sharing of sensitive diagnoses — due to concerns about feelings of disconnectedness and diminished empathy [41] — might consider using VR telehealth for this purpose. VR can provide an illusion of presence to both the patient and physician, thus easing the process.

Benefits of telehealth

Benefits of telehealth represent the likely benefits that VR telehealth can offer patients and physicians. These include better access to care for patients, adherence to appointments, convenience, efficiency, and the opportunity for physicians to cater to more appointments. Telehealth can be convenient for both parties, as three physicians suggested.

"It allows me to care for patients outside the city. And also in inclement weather, like this week on Wednesday, I just made my whole office virtual because the weather didn't look good"

(female, 42 years old, pediatrician)

"Yeah, so in terms of telehealth services, what you allow for is patient satisfaction in terms of they're not having to take a day off to come visit me."

(male, 33 years old, family medicine physician)

"Yeah, well, it's mainly convenience because the patients I see are very far away. It allows a lot of convenience and flexibility on my part. I don't necessarily need to stop it. I don't necessarily need to be in the hospital to provide services, too, so that gives me some flexibility."

(male, 35 years old cardiologist)

It is essential to state that these points regarding convenience are not unique to VR but could apply to other forms of telehealth.

VR telehealth can also reduce no-show rates, allow for more harmonious conversations, and allow physicians to see a higher volume of patients in a day.

"I think the benefit is more adherence to appointments. So when someone needs follow-up, they are unwilling to take time off. We saw more no-shows in those situations or a lack of follow-up, which put a lot of pressure on our staff to keep calling. So this way, I think there's a convenience factor. It can sometimes help get another extra appointment or two, particularly around transition times."

(male, 62 years old, family medicine physician)

"So it allows for a more harmonious conversation where they can see and Google things simultaneously as I talk to them. I can see a higher volume of patients per day."

(male, 33 years old, family medicine physician)

3.2.7 Feature Considerations for VR Telehealth to meet Provider needs

The physicians responded with expected features when asked,

"*To make such a VR telehealth platform viable and beneficial for your work, and to support your workflow, what kinds of functionalities do you foresee that such a VR platform should have? For example, in what ways would you need to be able to interact with the patient and the virtual environment?*".

These anticipated features are presented in Figure 3.16.

Most of these expected features of VR are not unique to VR but apply to telehealth in general. Expectations involving economic and regulatory considerations, such as the need for reimbursement parity between in-person and VR telehealth, are not new but existing telehealth needs. The general argument is that a new digital health technology like VR if it were to be favoured, must not perpetuate the existing limitations of telehealth.

Technical Infrastructure and Data Security

Technical Infrastructure and Data Security are concerned with the effectiveness and security of the VR platform. The theme addresses the hardware and software infrastructure needed to support telehealth services and safeguard sensitive medical data. It broadly focuses on interoperability, connectivity, privacy, and compliance. Most physicians stress the need for the VR solution to integrate seamlessly with their current workflow.

> *"To me, the main thing is that it's integrated with the technology I'm currently using. For example, the EMR. If I have to come out of the patient's chart and type in their name and health number, go to some platform, log in, give it my password, and then set it up and click go, that will not fit into any workflow. It has to be integrated into whatever systems I'm currently using and not something separate that requires more effort."*
>
> *(male, 62 years old, family medicine physician.)*

Another physician notes,

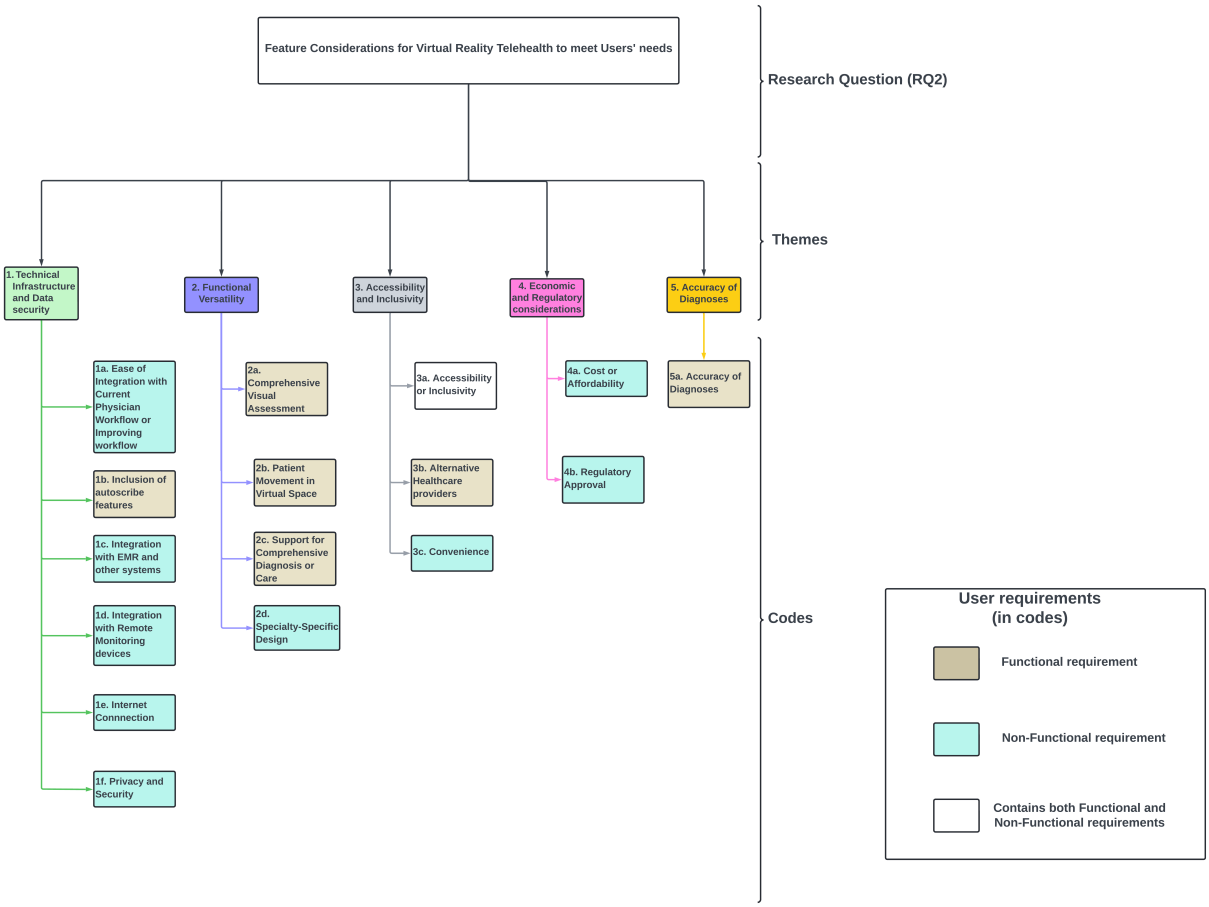


Figure 3.16: Thematic Network based on VR Telehealth requirements by the Physicians

"Yeah, and if I have the patient history and their vitals before a visit, I think that would be advantageous, and I would use that. Now, it needs to be integrated into my EMR. It needs to be populated in my note. So again, workflow is important."

(male, 37 years old, family medicine physician)

"if the vendors did some of the hard work on the workflow piece and demonstrated the value to doctors besides sort of it being a cool technology, but like, increasing the efficiency of work. I think that that would be something that would be important for me."

(female, 48 years old, family medicine physician)

Other subthemes include the need to consider *specialty-specific design*, address *privacy and security concerns*, and ensure better *internet connectivity*.

"Our consultations are specific to the reason for the visit. So, while VR may be appropriate for a mental health visit where we don't need an examination, it may not be as relevant if I need to look at a rash or if I need to feel a rash or things like that. So I think when building VR, the visit reason or different specialties, there needs to be some thought put into, okay, this is what we're catering to."

(male, 37 years old, family medicine physician)

"We need a private space to do this. I suppose, you know, in an exam room, we've got an exam room anyway, but the patient and the provider both need a private space appropriate for doing a VR visit. For example, I've had patients do video visits with me on their phones in their car in their driveway because they're not comfortable talking to me in their homes, in a public library, or wherever else they might be."

(male, 62 years old, family medicine physician)

One respondent specifically requested the inclusion of a real-time auto-scribe feature.

> *"if you could do an auto scribe feature where I'm talking to the patient virtually, but it records my conversation, and auto transcribes what we're saying and summarizes it, I mean that would be like, you know.. next level. I mean, there are platforms like that, but to be able to do that real-time would save me many minutes and allow me to see more patients and provide better care"*
>
> *(male, 35 years old, cardiologist)*

Functional Versatility

Functional versatility reflects the need for a VR telehealth platform to support various functions. As suggested by the participants, these functions include *support for comprehensive visual assessment, comprehensive diagnosis or care, and support for patient movement and tracking* in the virtual space.

When asked *"To make such a VR telehealth platform viable and beneficial for your work and to support your workflow, what kinds of functionalities do you foresee that such a platform should have?"* One participant voiced two needs in their response.

> *"It would be nice if you could do an exam or parts of an exam, I guess, the visual parts. So, seeing their facial expressions and body language is also helpful. And I think you would get more out of seeing the whole person rather than just getting a heads up about mental health visits, which would probably add something. If a patient, particularly a child, wants to move around, such as playing on the floor, the system should allow us to follow their movement within the room. It's important that the system can track them without requiring them to stay in a fixed spot."*
>
> *(female, 48 years old, pediatrician)*

Similarly, two of the respondents shared their interests in being able to read vitals, view internal organs, and study patient movements on the platform.

"We need a way of listening to hearts, listening to lungs popping the abdomens, seeing internally what that person looks like, seeing their gait, all these different things. I think that's the key to creating a complete package. I'll say that you need a patient to be able to move around and can't have them stationary because part of that examination is that movement"

(male, 33 years old, family medicine physician)

"If I could get vitals off a VR platform, that would help. You know, blood pressure, pulse, temperature, oxygen saturation."

(male, 37 years old, family medicine physician)

Economic and Regulatory considerations

Economic and regulatory considerations reflect the need for the platform to be affordable and rewarding and meet the relevant verification standards for data security and privacy. Moreover, the ability to bill for telehealth services often depends on whether a platform has been certified by appropriate health authorities. This certification can assure users of the platform's reliability and sometimes determines the financial viability of using the platform for delivering professional medical services. Some health insurance providers, including government programs, only reimburse services delivered through certified platforms. Without certification, physicians might be unable to claim these reimbursements. One respondent explained this situation:

"Ontario Health has a virtual visit verification standard, and they certify virtual visit technology as meeting their standards. And if we're not using one of their certified solutions, we don't get to bill for the work. So, this would need to meet those standards and preferably be approved and certified by Ontario Health."

(male, 62 years old, family medicine physician)

Interestingly, while these platforms may not need approval, e.g., Health Canada and fda, to operate, these approvals can encourage users to trust the system as a reliable healthcare delivery platform. One respondent highlighted the point.

"I think these platforms are not widely adopted because they don't need Health Canada and fda approval, which is good or bad. It's good because you can launch technologies faster. You can get to market faster. It's bad because I have no reason to trust you if it doesn't. That fda approval and/or Health Canada approval is a symbol of trust and a symbol of that, you know, if something goes wrong and the patient sues me or has a complaint, I can say it's fda approved."

(male, 37 years old, family medicine physician)

Accessibility and Inclusivity

Accessibility and Inclusivity require addressing the potential barriers preventing individuals from accessing or benefiting from telehealth. This entails ensuring it is accessible to patients with disabilities — physical or mental — through adaptive technologies, providing multilingual support (i.e., real-time translation) to address language barriers, and including alternative healthcare providers such as nurse practitioners or physician assistants who may be more in favour of using the technologies due to the versatile care models in which they frequently operate.

"We see a lot of patients whose first language is not English; you need a translator. How would that work? We need to think about various patient needs. For instance, individuals with intellectual disabilities may not understand how to operate the system. Also, consider nonverbal patients or those who use wheelchairs — how effective would the interaction be? Often, you might end up communicating with a caregiver, but it is crucial to see the patient as well."

(female, 42 years old, pediatrician)

Additionally, one respondent raised a point about ensuring the inclusion of other modes of healthcare delivery to avoid sole reliance on VR.

"I think your biggest challenge is ensuring clinicians don't go solely to VR because that's wrong, too. It has to be multimodal."

(male, 33 years old, family medicine physician)

Accuracy of Diagnosis

Accuracy of Diagnosis concerns the reliability of the diagnostic results obtained via telehealth examination. The precision of diagnostic outcomes can directly influence the quality of care and patient trust in virtual healthcare settings. Telehealth can pose unique challenges in diagnosing accurately compared to traditional in-person visits due to potential limitations in physical examinations, the dependence on digital tools, and patient self-reported symptoms.

3.3 Possible Scenario of the Proposed VR Telehealth in a Multi-Specialty setting

Study I (3.1) and Study II (3.2) explored the perceptions of both healthcare receivers and service providers on three modes of care delivery, *in-person, traditional telehealth, and VR telehealth* both quantitatively and qualitatively. The resulting themes show shared and nuanced needs or expectations for VR telehealth between physicians and patients. Some of the shared expectations in terms of VR capabilities include privacy and security — both the patients and the physicians expect secure transmission of medical information in VR telehealth, reliable internet connection, records & review (patients), or integration with electronic medical records (physicians), clarity & detail (patients) or comprehensive visual assessment (physicians). Some of these expectations were unique to the group. For instance, patients were interested in support for provider transparency — suggesting they would be more comfortable if they could verify the expertise of the service provider before the consultation; on the other hand, physicians emphasized the need for proper billing infrastructure, regulatory approval of the VR telehealth, ease of integration with their current workflow, and tailored design for specific specialty or use. These nuances show that VR systems would need to be designed to address diverse needs, and designers need to consider user requirements from the perspective of both the service providers and the care receivers.

Figure 3.17, presents a UML use case diagram to illustrate the possible interactions between patients, healthcare providers, and the VR system, adapted from the study by Pourabbas et al. [138].

This scenario presents a typical flow for care delivery in the proposed VR telehealth based on some of the features demanded by the patients and the physician participants in this study. The system is expected to facilitate convenient healthcare delivery to address

specific challenges, such as patient mobility during virtual visits and comprehensive diagnostics in a virtual environment. It shows a possible interaction flow between the system components, including actors (care providers and patients) and the devices.

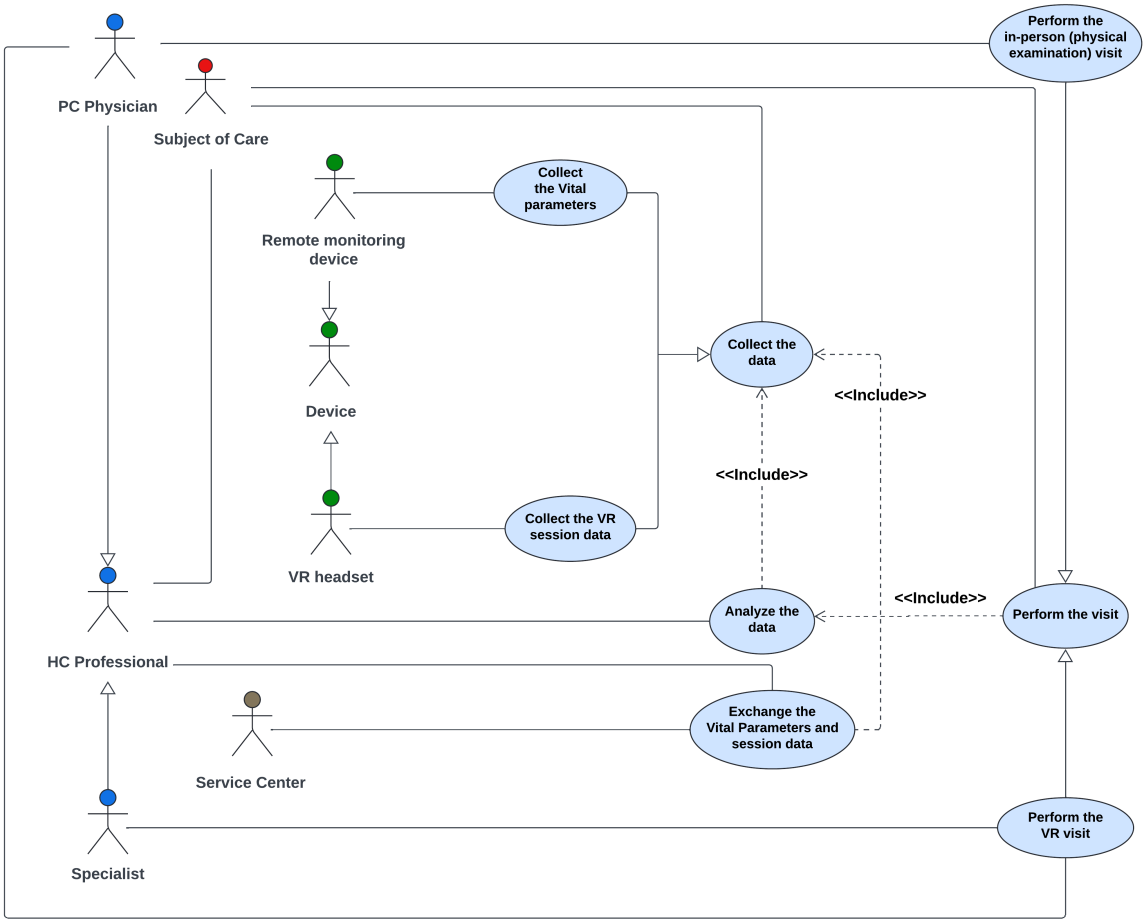


Figure 3.17: UML use case for the VR Telehealth showing the interaction between system components, adapted from [138]. *PC Physician = Primary Care physician, HC Professional = Healthcare Professional*

3.3.1 Use Case Example

Consider the scenario involving a patient, John, a 65-year-old with chronic arthritis. John's treatment plan requires frequent interaction with rheumatologists, physiotherapists, and primary care physicians. John can visit, say, companyABC's portal, an approved VR telehealth company. He can look up available care providers and view their profiles for any reviews before booking an appointment.

John will use a VR headset to attend his appointments and can communicate with his healthcare providers during a session. John's movement in real-time can be captured and retargeted to his photorealistic avatar in the virtual environment. By studying the avatar's movement, his healthcare provider can better assess his gait and mobility challenges. The system can enable providers to continuously track visible signs of swelling or inflammation in joints through sensors integrated with the telehealth system. John can also use connected devices to measure other vital signs and transmit them to his healthcare provider. John's healthcare team can utilize the VR system to conduct regular meetings to discuss his progress and adjust treatment plans. Thus, all specialists can be aligned regarding care strategies. As for the visits, the primary care physician can perform an in-person visit in case John needs a physical examination and a remote VR visit for follow-up on the home visit. The specialist can meet with John and/or the primary care physician in VR. Session information can be exchanged directly or through a service center. The service center may collect, analyze, or manage the telehealth session data and upload the post-processed data to the EMR so any care providers can later assess it. John and his care providers may interact without going through the intermediary service center.

Payment is automated using HIPAA-compliant payment forms integrated with the platform. After the session, each care provider will document the visit using the appropriate billing codes specific to the services offered. Claims are automatically sent to the insurance company listed in John's profile. Payments are processed and disbursed to the providers once the claims are approved. Depending on John's insurance plan, any co-pays, deductibles, or out-of-pocket expenses will be automatically charged to his account. John can receive adequate care without leaving his house.

The example use case also illustrates how the proposed system can address some of the patients' and physicians' concerns and requests in this study. Here's how some specific concerns are addressed:

- *Support for Comprehensive Diagnosis* or *Accuracy of Diagnoses* The use case example shows how remote monitoring devices may aid diagnosis by collecting and transmitting vital parameters. For example, blood pressure monitors may be used

to transmit blood pressure readings to healthcare providers in real time, and digital stethoscopes may allow providers to listen to heart and lung sounds remotely. Likewise, glucometers, pulse oximeters, and wearable ECG monitors may also be used to obtain relevant patient data remotely. Care providers can then utilize these vital data paired with the information collected during VR session to provide more accurate diagnosis.

- *Records and Review* or *Integration with EMRs* One of the significant features requested by the survey participants was the ability to record or access the session recordings. Similarly, the physicians requested the ability to take notes during sessions without exiting the virtual environment and to access and review patient history from the platform. The patient and physician can record sessions using their VR headsets. For session notes, the service center can facilitate post-processing of the session data by transcribing the audio recording, extracting relevant information such as symptoms and treatment plans from the unstructured data, summarizing these data to highlight essential points such as patient concerns, physician recommendations, and follow-up actions, and integrating them into the electronic health records (EHR) to be accessed by the care physician from within the patient's medical records. The platform may also handle these post-processing steps automatically by utilizing natural language processing (NLP) and artificial intelligence (AI) feature integrations, thus eliminating the need for a separate service center.

- *Clarity and Detail* Patients' request that the environment should be as close to as accurate as possible for the sessions to feel less awkward could be addressed by the use of highly realistic 3D environments, photorealistic 3D avatars for a highly detailed representation of the care provider and themselves, full-body tracking to ensure realistic movements of the avatars in the virtual environment and 3D sound spatialization.

- *Provider Transparency* Patients may be able to confirm the expertise of their care provider before an appointment by reviewing feedback provided by previous patients and the summary of the care provider's training or experience, all available on the platform.

- *Billing or Reimbursement* As mentioned in the use case discussion (section 3.3.1), payment is automated through HIPAA-compliant integrations on the platform, reducing delays in reimbursement that are often caused by lengthy administrative procedures in traditional claim filing.

Chapter 4

Discussions and Conclusions

4.1 Discussion

In study I of this two-part work, perspectives were gathered from patients regarding the proposed VR telehealth in light of the existing telehealth and face-to-face visits. The analyses have suggested the possibility that some of the shared perspectives are correlated with specific participant characteristics. Patients' comfort levels in sharing medical information in VR telehealth were found to vary significantly among technology affinity levels and levels of experience with VR devices. Also, patients' confidence in the diagnosis received via telehealth, their comfort level in obtaining a diagnosis in telehealth, or in sharing medical information in telehealth were found to vary substantially among groups based on telehealth experience, income level, employment status, education level, age, and dependent relatives' status. These findings corroborate results from past research [27, 31, 139], suggesting that demographic factors play a significant role in shaping telehealth perceptions.

Several studies corroborate the findings regarding the likely associations of the demographic factors with perceptions. For example, chang et al. [27] have reported that individuals with prior telehealth experience generally report higher comfort levels, as familiarity with the technology reduces anxiety and increases the likelihood of positive experiences. Moreover, lower-income individuals often face barriers such as limited access to reliable broadband connectivity, making telehealth less convenient. These observations suggest a need for more interventions; for instance, to solve the broadband issues, initiatives like the government-backed Connecting Families Initiative [115] to provide high-speed internet for low-income families need to be encouraged.

While the causal analysis suggests that technology affinity might positively influence patients' comfort in sharing medical information in VR, the average effect is not statistically significant. Therefore, a definitive conclusion regarding technology affinity impact on comfort levels in VR cannot be made. However, the statistically significant differences in comfort levels among various *levels of VR experience* and *technology affinity* are corroborated by previous findings. These findings indicate that patients who are enthusiastic about technology find telehealth platforms easier to navigate and, thus, are likely to perceive these platforms positively [91]. To encourage interest in technology, digital literacy should promoted widely, and people should be incentivized to enroll if possible. Government-backed digital literacy initiatives, such as the Digital Literacy Exchange Program [74] which have been effective and can serve as models. Other countries can adopt similar models to enhance digital literacy.

In Study II, thematic analysis reveals that physician participant groups share similar needs for VR telehealth as the patient groups. The physicians and patients expect VR telehealth to be private and secure, provide support for comprehensive visual assessment, and have reliable broadband connectivity. Results also suggest that some of the concerns may differ by physician specialty. Notably, only one of the physicians (a pediatrician) expressed distinct worries about keeping a child's attention in video visit. Family medicine physicians with prior telehealth experience were mostly concerned about the financial aspects of telehealth, including the complex reimbursement procedures, the difficulties in claiming reimbursements for telehealth services, the unfavourable volume-based billing policies, and the current payment disparity between in-person and telehealth services.

Ensuring that telehealth services are reimbursed at a rate similar to in-person visits can encourage physicians to adopt telehealth. Without payment parity, physicians may be less inclined to offer telehealth services [171]. Moreover, the process of claiming reimbursements for telehealth services should be simplified. Generally, physicians require VR telehealth to seamlessly integrate with their current workflow and the EMR. When telehealth is integrated with EMR systems, physicians can easily access and update patient records in telehealth, reducing their administrative burdens [44].

4.2 Limitations and Future Work

All participating physicians in this study were based in Canada. Therefore, their opinions may predominantly reflect Canadian healthcare contexts and may be less representative of experiences and challenges in other regions. As a result, the interview findings may not

generalize to healthcare systems with different regulations, practices, and patient demographics.

The limited size of physician participants *(n = 6)*, coupled with a lack of sufficient diversity in medical specialties, may have limited the depth of the perspectives. Another limitation of the qualitative study is the challenge of achieving complete data saturation. Attaining saturation with a limited number of interviews can be difficult, and the emergence of new insights during the sixth interview suggests that additional interviews might have provided further valuable information. Future research should consider recruiting more participants to ensure a thorough exploration of the themes, mainly when variations in participant categories may introduce new perspectives.

Analysis of the survey data focused on socio-economic variables likely to directly affect access to VR devices and prior experiences that might shape how participants perceive VR telehealth. As a result, factors such as participants' gender or race were not considered in the analysis. This exclusion is another limitation of this work, which future studies can address. Moreover, the illustration of the proposed VR telehealth provided to participants (Figure 3.2 may not have sufficiently aided specific demographics to conceptualize the types of interactions anticipated within the system fully, and as such, could have coloured their perceptions. Future research can advance this work by illustrating a typical user experience using an interactive prototype or a video demonstration.

Moreover, inorder to gather patient perspectives, the study relied solely on surveys. Surveys lack the capacity for dynamic interaction and follow-up questions that interviews facilitate.

Future studies can improve on this study by ensuring sufficient diversity in the sampling of the healthcare providers and, if possible, utilizing both interviews and surveys to gather data on the perceptions of VR telehealth by both care providers and patients.

4.3 Conclusion

This study explored the perceptions of traditional telehealth and a potential form of VR telehealth by patients and physicians. Several challenges in current telehealth were identified, and anticipated features in the proposed VR telehealth emerged from the surveys and interviews. Telehealth designers should address patient-centric concerns such as provider transparency by making the provider credentials and licenses accessible on the platform. The VR telehealth platform should be designed to allow patients to leave reviews about

their past telehealth sessions. This feature could help other patients to appropriately select their care providers and be more confident in the diagnosis received from a telehealth provider.

Moreover, the VR telehealth implementation should allow patient data from VR sessions to synchronize with EMRs automatically. Perhaps including a service center to process the unstructured session data and update the EMR will help minimize manual data entry.

Designers of VR telehealth systems must address all other identified adoption barriers, including payment discrepancies between in-person and remote service, users' reluctance to utilize telehealth (because of the learning curve associated with using new technology or setting up remote sessions), internet connectivity issues, and limited examination. The proper billing infrastructure needs to be implemented to address the payment issue. Moreover, all payment liabilities must be figured out before implementation, e.g., whether the government, health insurance company or the patient will be responsible for the cost of telehealth service.

Developers should ensure that the telehealth platform meets the country's approval criteria and is approved by the relevant regulatory bodies. This is necessary for physicians to be able to claim reimbursements. It can also enhance users' trust in the system as a reliable means of receiving or providing care. To foster the safe adoption of VR telehealth, the public should be aware of and trained on its use, benefits, and limitations.

Telehealth is not necessarily suitable when a visit requires a physical examination, nor is it a replacement for one; instead, it might be best utilized when a hybrid model is followed, whereby the initial diagnosis is made in person, and the follow-ups are conducted virtually when possible. Moreover, VR telehealth should simplify rather than complicate physicians' existing workflows. VR telehealth platforms should integrate seamlessly with remote monitoring devices and allow for the inclusion of support persons like family members in VR telehealth sessions.

Artificial Intelligence Disclosure (AID)

AID Statement [179]:

- **Artificial Intelligence Tool(s)**: Microsoft Copilot, ChatGPT-4, and Grammarly AI Writing Assistant, Accessed between June and October 2024.
- **Writing —- Review & Editing**: These AI tools were used in refining the grammar of some parts of this work.

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APPENDICES

Appendix A

Causal Analysis: Regression Discontinuity Design (RDD)

A.1 Regression Discontinuity Design (RDD)

In section 3.1.4 from the main text, the relationships between sociodemographic factors and the survey participants' views on various care delivery modalities using ANOVA, t-tests, correlation analysis, and SEM were examined. However, these analyses alone do not tell whether the observations are merely correlations or causal. The boxplots and scatter plots in Figures A.1 and A.2 suggest a phenomenon where comfort levels in sharing medical information in VR abruptly change between medium and high technology affinity levels. This sharp comfort level change suggests a potential causal relationship that warrants further investigation. The phenomenon might be explained through the technique of regression discontinuity, which is discussed in this section.

Regression discontinuity is a statistical method that uses threshold-based decisions to generate causal estimates for various interventions [177]. It is a quasi-experimental technique for studying causal effects when a randomized control trial is not feasible. This section demonstrates the causal relationship between participants' affinity to technology and their comfort levels in sharing their medical information in VR is demonstrated through RDD.

A.1.1 The preprocessing steps, variables, and the assumptions

The boxplot in Figure A.1 indicates a shift in the median comfort rating for individuals with an affinity score of 4 or higher. Therefore, an affinity score of 4 has been established as the preliminary cut-off point. This threshold serves as a randomizing tool, allowing those just above the cut-off to experience a higher comfort level (specifically, greater than "somewhat comfortable"), while those just below do not.

Subsequently, the proportion of participants at each unique affinity score who reported being *very comfortable* (i.e., a comfort level greater than 4) when sharing medical information in virtual reality (VR) was calculated. These analyses resulted in the variables needed for the regression discontinuity design (RDD), which will be defined along with other essential terms below.

1. The *outcome variable:* The outcome variable is the proportion of participants for each unique affinity score that rated their comfort level above 4. It represents the main variable of interest in the study, which is evaluated against different values of *Affinity Scores* and is affected by the treatment.

2. The *running variable:* The running variable represents the unique technology affinity scores, whose effect on the outcome variable is under study.

3. The *threshold or cutoff:* The threshold or cutoff point is the affinity score of 4. The participants below the cut-off are considered the *untreated* group, whereas participants above the cut-off are considered the *treated* group.

4. The *treatment assignment:* A binary indicator (1 for treated, 0 for untreated) based on whether a participant's affinity score is above or below the cutoff. Based on this sharp regression discontinuity design, the probability of being treated "jumps from 0 to 1 at the cutoff" [93, 110, 18, 125, 8].

The assumptions are as follows:

1. *Continuity of the Regression function:* The individuals positioned "just to the right and left of the cut-off" are presumed to be interchangeable, similar to a randomized trial [96].

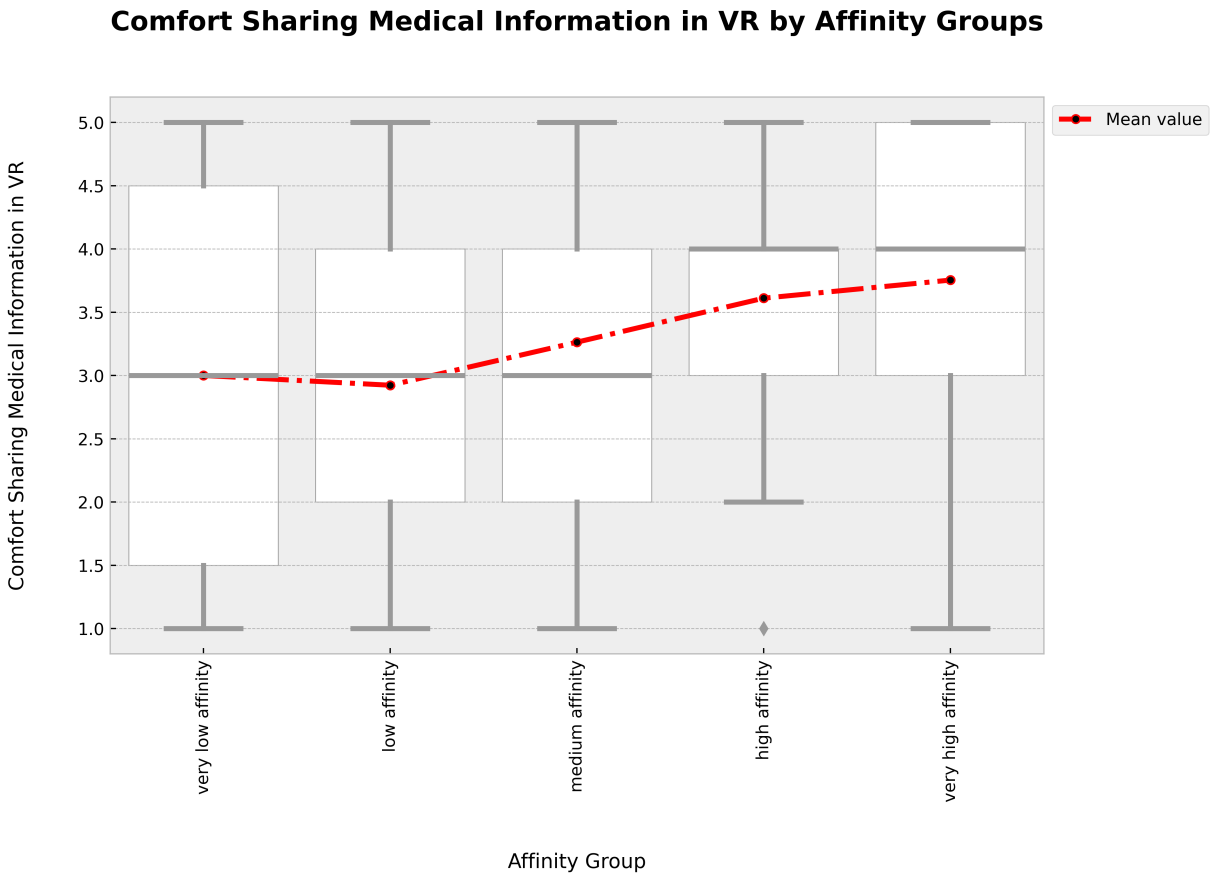


Figure A.1: Box plots of the Comfort ratings grouped by Technology Affinity



Figure A.2: Scatter plot of Participants' proportion and Affinity scores showing regression lines for the two groups on either side of the cut-off

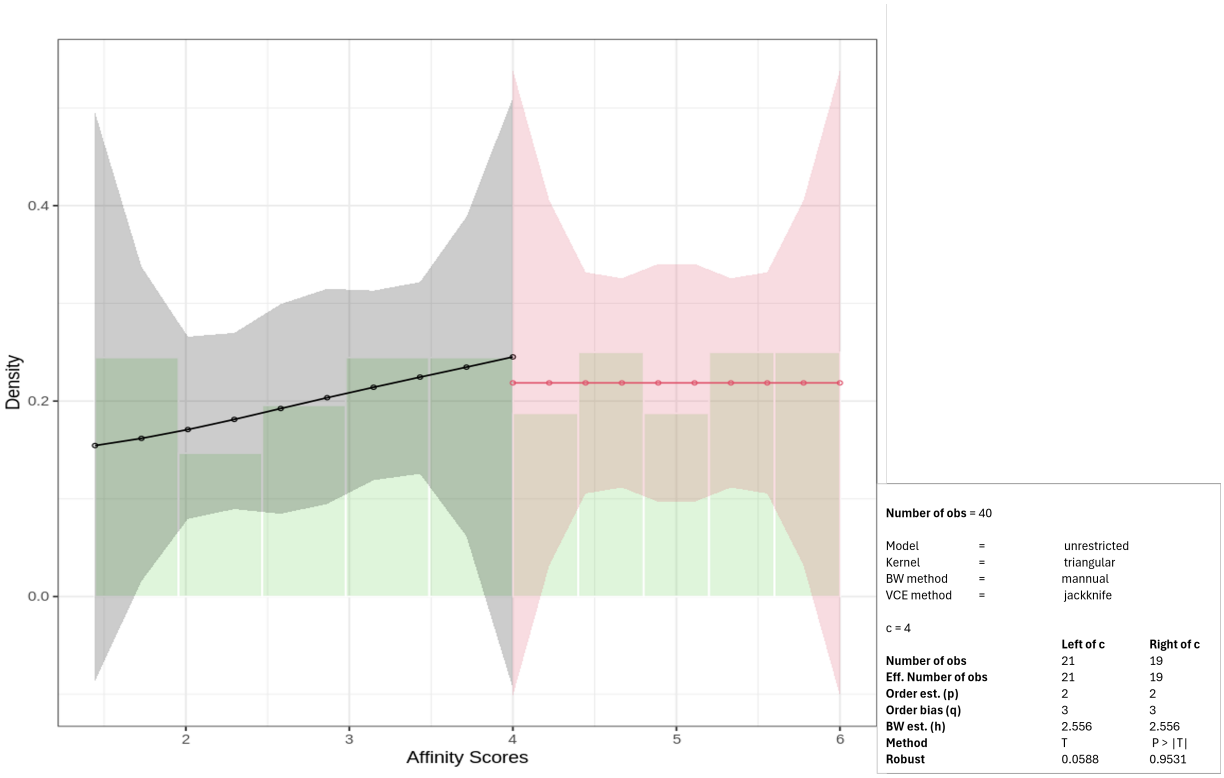


Figure A.3: McCrary test for bunching or manipulation of Affinity Scores

2. *Absence of Sorting:* For the RDD to produce unbiased estimates, it was assumed that participants did not falsify their affinity scores to move above or below the cutoff threshold (i.e., an affinity score of 4). To validate this assumption, the McCrary density test was used to assess potential manipulation of the affinity scores. The p-value derived from the overlap in the confidence intervals of the two points on either side of the cutoff (illustrated in Figure A.3) indicates that there is no statistically significant discontinuity in the density of affinity scores. This finding suggests that there is no evidence of manipulation in the affinity scores.

3. *No Spillover Effect:* The treatment received by participants on one side of the cutoff does not affect the outcomes of those on the other.

4. *Sufficient Observations Around the Cutoff:* There is a sufficient number of observations close to the cutoff. This ensures that the treatment estimation at the cutoff is not based on outliers.

A.1.2 Beta Regression model

Beta regression was used in the analysis to model the relationship between the affinity scores (running variable) and the proportion of participants who were very comfortable sharing their medical information in VR (outcome variable). This method was chosen due to the nature of the outcome variable, which is a proportion bounded between 0 and 1.

Additionally, due to the limited size of the dataset, a Bayesian approach to RDD was adopted. Bayesian framework enabled the integration of context-specific knowledge about the expected sizes of the effects of technology affinity into the model by formulating informative priors on the causal parameters. It also explicitly accounts for uncertainty in parameter estimates, which is particularly useful. The specification of the Beta regression model is as follows:

- The response variable y (i.e., the fraction of participants) is bounded between 0 and 1.
- Predictor transformation:

$$\text{logit}(\mu) = \beta_{\text{intercept}} + \beta_x x + \beta_d d + \beta_{dx} x d \tag{A.1}$$

Here, $\beta_{\text{intercept}}$, β_x, β_d, and β_{dx} are coefficients representing the intercept, the effect of the continuous predictor x (i.e., technology affinity), the effect of the treatment d (i.e., having above medium affinity for technology), and the interaction between x and d, respectively.

Model Parameters:

- The mean μ of the Beta distribution is transformed from the logit scale back to the probability scale using the sigmoid function: $\mu = \text{sigmoid}(\text{logit}(\mu))$.
- α and β parameters of the Beta distribution are modeled using the μ and a dispersion parameter ϕ, which controls the concentration or variance: $\alpha = \mu \times \phi$, $\beta = (1-\mu) \times \phi$.
- ϕ is typically set using a prior that allows the likelihood function to flexibly model the observed variability in the response variable y.

The treatment effect is defined as:

$$b_{\text{gap}} = \text{sigmoid}(\beta_{\text{intercept}} + \beta_2) - \text{sigmoid}(\beta_{\text{intercept}}) \tag{A.2}$$

Likelihood:

- The observed data is assumed to be generated from the Beta distribution with parameters α and β.

The initial model specification in PyMC [3] is shown in the acyclic graph in Figure A.4.

Prior beliefs and the Likelihood

1. Intercept ($\beta_{\text{intercept}}$): A normal prior is assumed for the intercept, with a mean of -1.9. This setting represents an initial belief about the baseline level of the probability of being very comfortable sharing medical information when affinity and treatment effects are absent.

2. Slope for Technology Affinity (b_x): The effect of technology affinity on the outcome is modeled with a normal prior centered at 0 with a standard deviation of 0.552. Uncertainty about the direction is implied.

3. Treatment effect on the intercept ($b_d \sim \mathcal{N}(\mu = 0.026, \sigma = 0.448)$): The mean of 0.026 implies a small expected positive shift in the baseline log odds due to the treatment. This signifies a cautious optimism about the effectiveness of crossing the affinity score threshold.

4. Interaction effect ($b_{dx} \sim \mathcal{N}(\mu = 0, \sigma = 0.4356)$): The prior allows for the possibility that the effect of technology affinity on comfort levels might vary depending on whether the participant is above or below the treatment threshold.

5. Dispersion parameter ($\phi \sim \text{Exponential}(\lambda = \frac{1}{20})$): The prior reflects a belief in the moderate variability of the outcome variable around its mean. The rate parameter ($\lambda = \frac{1}{20}$) is chosen to balance the precision of the Beta distribution, which supports a flexible model to describe the data variability.

6. Likelihood: The likelihood is used along with the prior distribution to update beliefs about the parameters in light of the observed data. The likelihood was modeled with a Beta distribution, where the shape parameters α and β are functions of the modeled probabilities and a dispersion parameter. Specifically, the likelihood is defined as:

$$y_i \sim \text{Beta}(\alpha = \mu_i \times \phi, \beta = (1 - \mu_i) \times \phi) \tag{A.3}$$

   Here, μ_i represents the expected value of the outcome for the i-th observation, transformed from the logistic scale, and ϕ is the dispersion parameter.

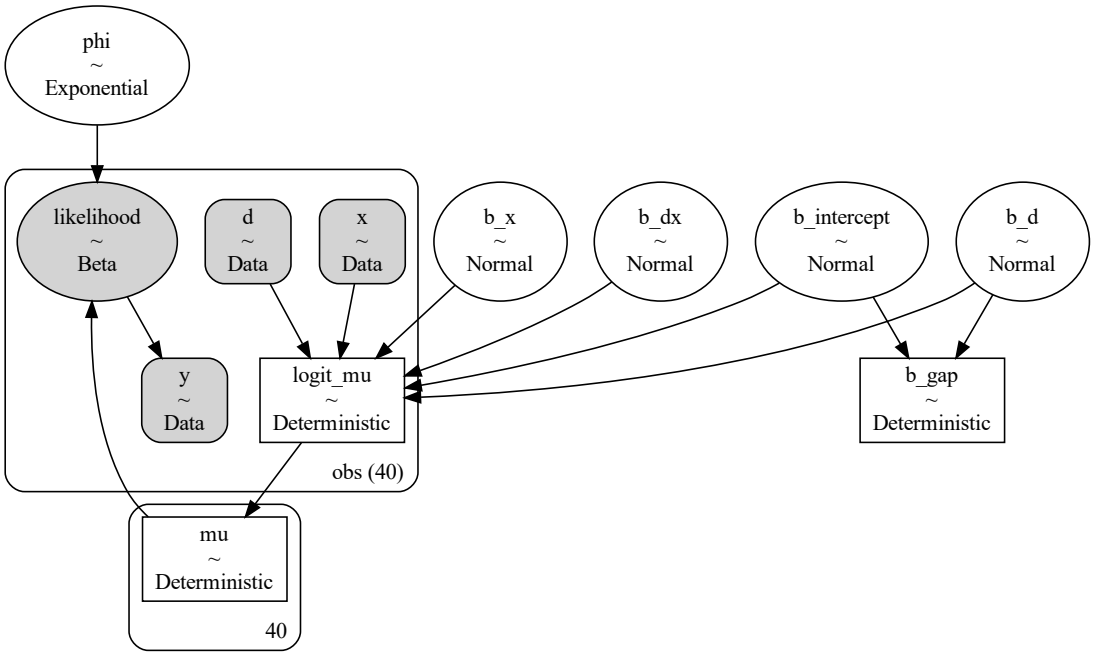


Figure A.4: Specification of the Beta Regression Model in a Directed Acyclic Graph (DAG)

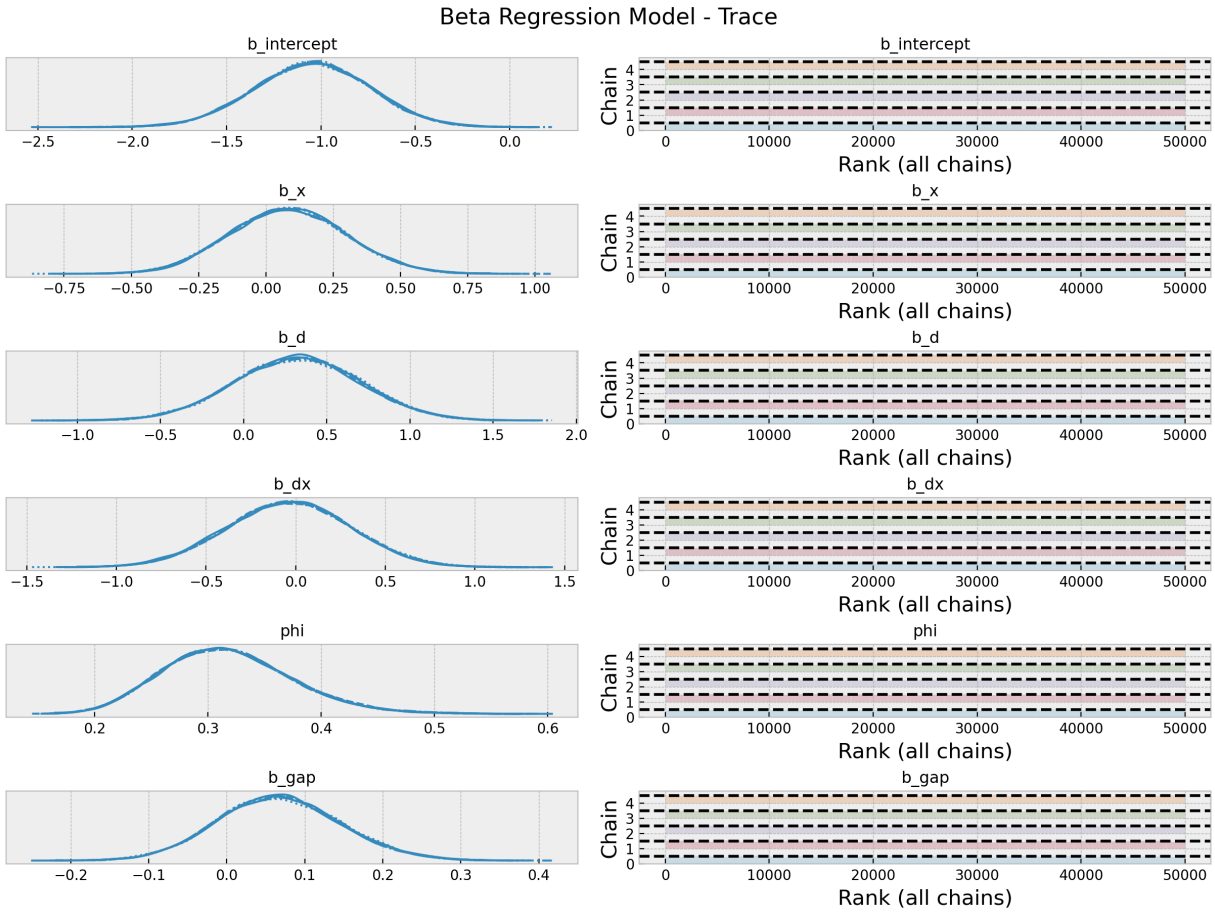


Figure A.5: Beta regression: trace plots of parameter samples

A.1.3 Sampling the parameters and fitting the model

Using prior beliefs on the parameters, 10,000 samples of each parameter were drawn from their respective prior predictive distributions. Prior predictive observations were also sampled based on these parameters. These observations represent the distribution of possible data outcomes predicted by the model before any actual data are observed, based solely on the prior distribution of the parameters. Plots for the 95% highest density interval (HDI) of the prior predictive observations are shown in Figure B.11. The plot shows that the prior predictive observations of the response variable are constrained to positive values bounded between 0 and 1, which is a desirable property of the dataset. Moreover, most of the actual data fall within the 95% HDI of the prior observations. The plot of the prior predictive observation of the treatment effect b_{gap} in Figure B.17 is centered around zero, indicating that the prior belief regarding the treatment effect does not inherently favor a positive or a negative outcome. It is also not very restrictive, meaning the possible values that the treatment effect can take based on the prior beliefs alone are not heavily constrained.

Next, a Markov chain Monte Carlo (MCMC) algorithm was used to draw the samples from the posterior distribution. Before drawing the samples, the sampler parameters (that is, numpyro [135]) were fine-tuned for 2,000 iterations each for the five independent chains. These tuning iterations optimize the sampler parameters but are not used in the final analysis. Subsequently, 10,000 samples were drawn from the posterior distribution for each chain. These samples were used to approximate the posterior distribution of the model parameters. Multiple independent chains (or sequences) enable the check for convergence. Specifically, convergence is assessed by comparing the variance within each chain to the variance between chains to determine whether the chains have reached a common distribution. The sampled values of the parameters over the iteration of the MCMC algorithm are shown in the trace plot A.5. Then, new data points were generated by sampling from the likelihood function using the parameter samples. The posterior predictive plots of the observations in the 95% HDI and the posterior mean are shown in Figure B.12.

The results show an average treatment effect with a mean estimate of 0.067 and a standard deviation (SD) of 0.079. The 94% Highest Density Interval (HDI) ranges from -0.018 to 0.22, implying a wide statistical uncertainty around the estimate. The result, however, suggests a positive effect of technology affinity on the likelihood of participants being very comfortable sharing medical information in a virtual reality. However, the interval contains positive and negative values, which implies that the mean of the treated group could be higher or lower than that of the control group. Thus, the effect is not statistically significant.

Kernel weighting was applied to the data to improve the precision of the estimate of

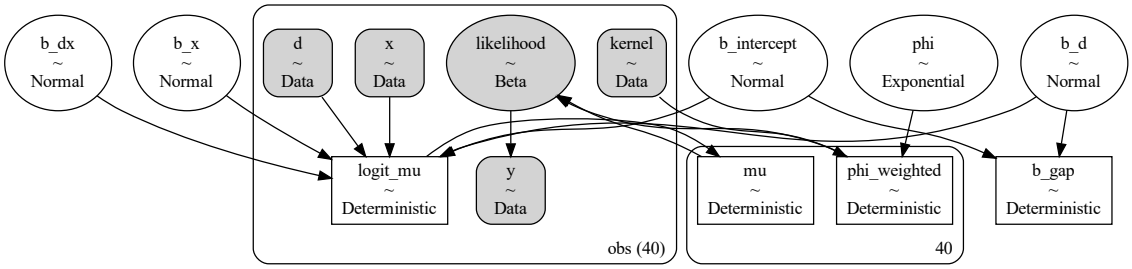


Figure A.6: Specification of the Weighted Beta Regression model

the treatment effect.

A.1.4 Kernel Weighted Beta Regression Model

Since the Regression Discontinuity estimate of the treatment effect depends on the values at the beginning and end of the post- and pre-treatment curves, respectively, the estimate of these limits must be accurate. Through kernel weighting, higher weights are given to points closer to the threshold to minimize the focus on the other points and improve the fit at the threshold.

A triangular kernel weighting was chosen because it is simple, easy to implement, and offers a transparent interpretation. The bandwidth was set to $h = 1$, so that affinity scores more than 1 unit away from the cutoff are assigned zero weights. For other points, the weights decay linearly and symmetrically from the cutoff. Specifically, the triangular weights are defined as follows:

$$k(r, c, h) = \begin{cases} 1 - \frac{|r-c|}{h} & \text{if } |r - c| \leq h \\ 0 & \text{otherwise} \end{cases} \tag{A.4}$$

Where h is bandwidth and c is the cut-off point. The kernel function for the case of $h=1$ and $c = 4$ is visualized in Figure B.13.

To handle data weighting for the model, the scale parameter (ϕ) of the likelihood was adjusted based on the observation weights. This approach involved scaling the variance

of the observed variable, allowing observations with higher weights to have a greater influence on the model's likelihood function and, hence, on the posterior distribution [119]. Essentially, the variability or noise around each observation is adjusted inversely with its weight: more weight means less noise, making the observation more influential in determining the model parameters. The weighted beta regression model specification is shown in Figure A.6. The specification remained largely consistent with the unweighted version; however, adjustments were made to reflect information gained from the posterior predictive checks of the initial model. Specifically, the priors for the model parameters were "fine-tuned": the intercept ($\beta_{\text{intercept}}$) was set to a mean of -1.995 with a standard deviation of 0.306, the priors for β_x, β_d, and β_{dx} were adjusted to means of 1.144, 0.197, and 1.07 with standard deviations of 1.315, 0.329, and 0.0345 respectively. To incorporate the effect of kernel-based weighting into the model, ϕ was dynamically adjusted to form ϕ_{weighted}, calculated as ϕ divided by the sum of kernel weights plus a minimal numerical constant (`np.finfo(float).eps`) to prevent division by zero. The prior predictive plots, posterior predictive plots, and the trace for the weighted beta distribution are shown in Figures B.14, B.15, and A.7, respectively. The posterior predictive plot (Figure B.15) shows that the variance of the treatment effect is significantly reduced due to the regularization effect of kernel weighting. Further, discontinuity plots in Figure A.8 show an improved precision in the treatment effect estimate since the posterior distribution of the β_{gap} is more concentrated around the mean. An assessment of the goodness of fit in the posterior predictive checks (Figure B.16) shows the weighted beta regression model better fits the observed data than the beta regression model. However, the discontinuity plot (Figure A.8) suggests that despite the improvements in the estimates, the average treatment is still not significant, given the existence of zero in the 95

A.1.5 Significance of the result

Given the lack of statistical significance in the average treatment effect (ATE) of 0.048, the implications of this study for VR telehealth technology development are more tentative than initially anticipated. Although a positive ATE suggested that users with higher affinity scores for technology might experience greater comfort in VR settings, zero in the highest density interval suggests that these results could be due to chance. This uncertainty indicates the need for further research to confirm these findings before significant policy or design changes are considered. Should future studies establish a significant effect, it would validate the approach of designing VR telehealth technologies to improve user comfort, particularly for users with varying levels of familiarity with technology. The approach might include designing interfaces that prioritize ease of use, improved privacy and security

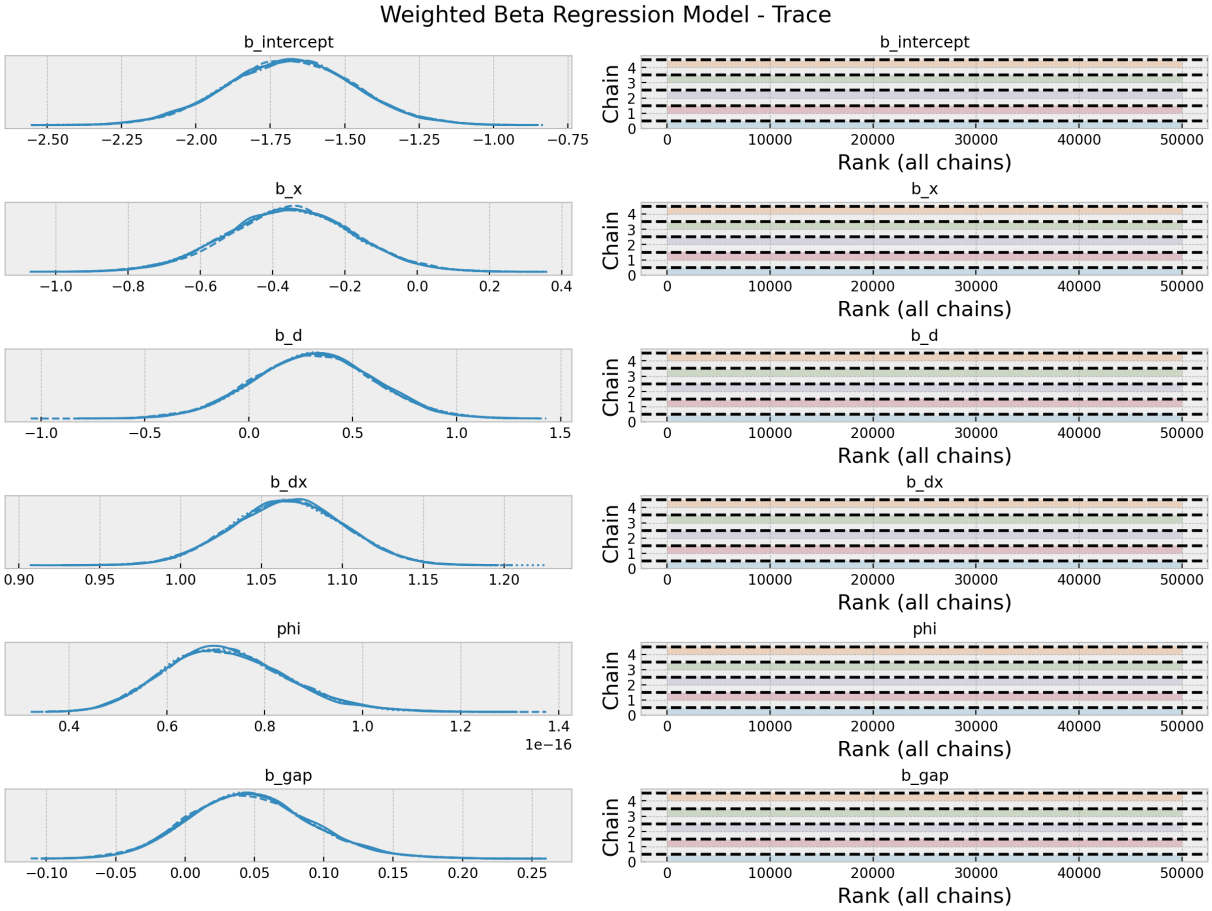


Figure A.7: Weighted Beta regression: trace plots of parameter samples

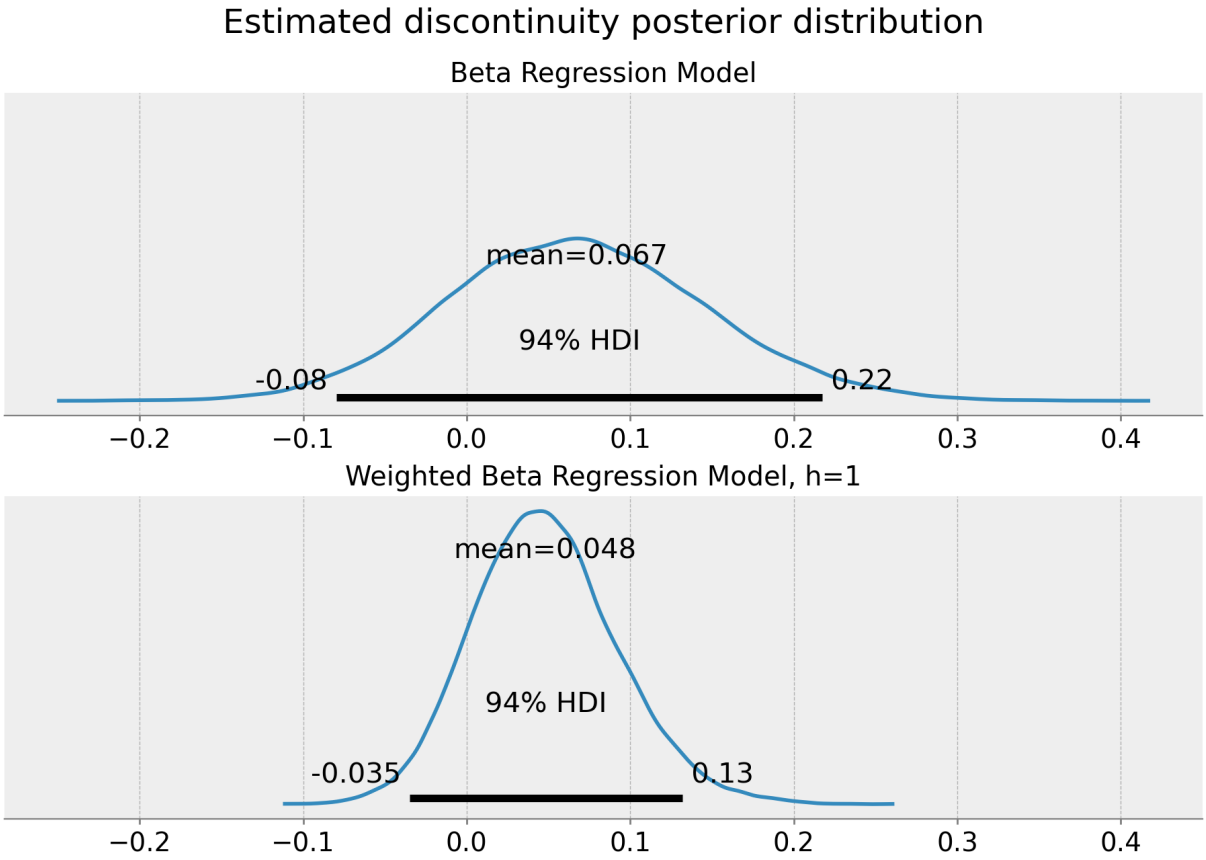


Figure A.8: Beta Regression and Weighted Beta Regression: Discontinuity plots showing the improvement in the average treatment effect estimate due to weighting.

measures, and educational initiatives to increase technological literacy among users with lower affinity scores.

Appendix B

Figures

B.1 Other figures from the Survey and Interview results

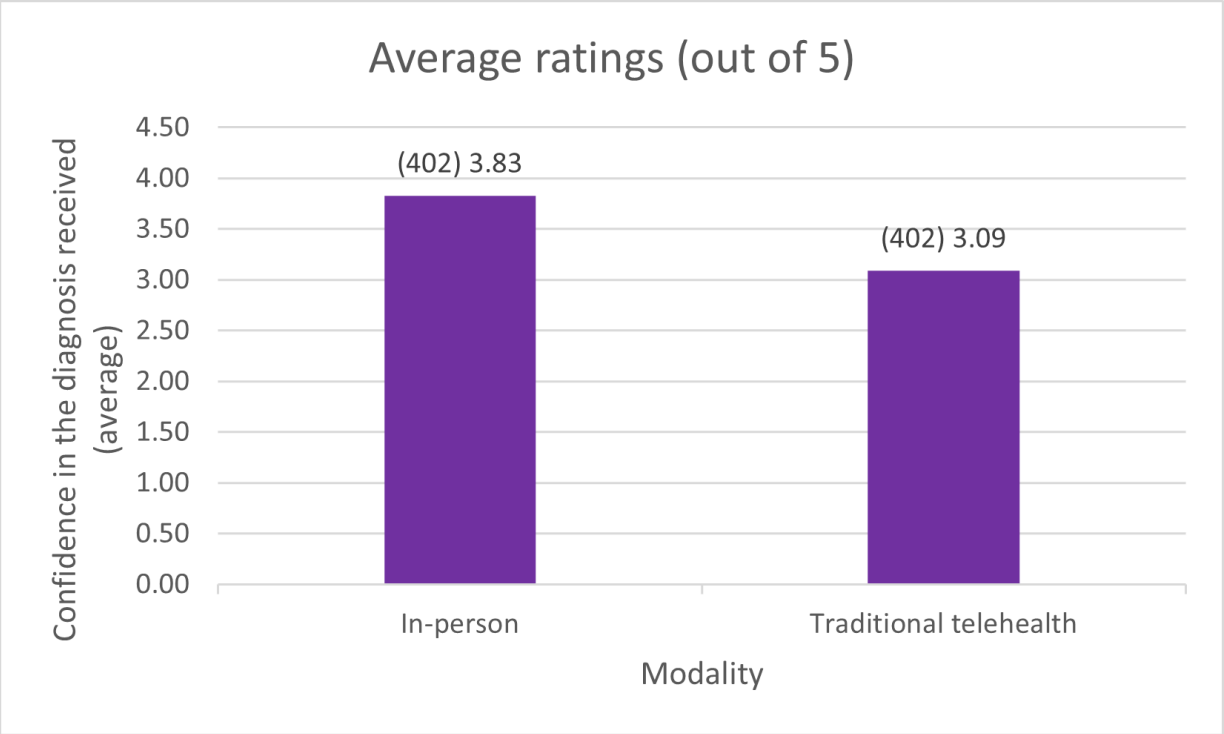


Figure B.1: Confidence Levels in Diagnosis: In-person vs Traditional Telehealth

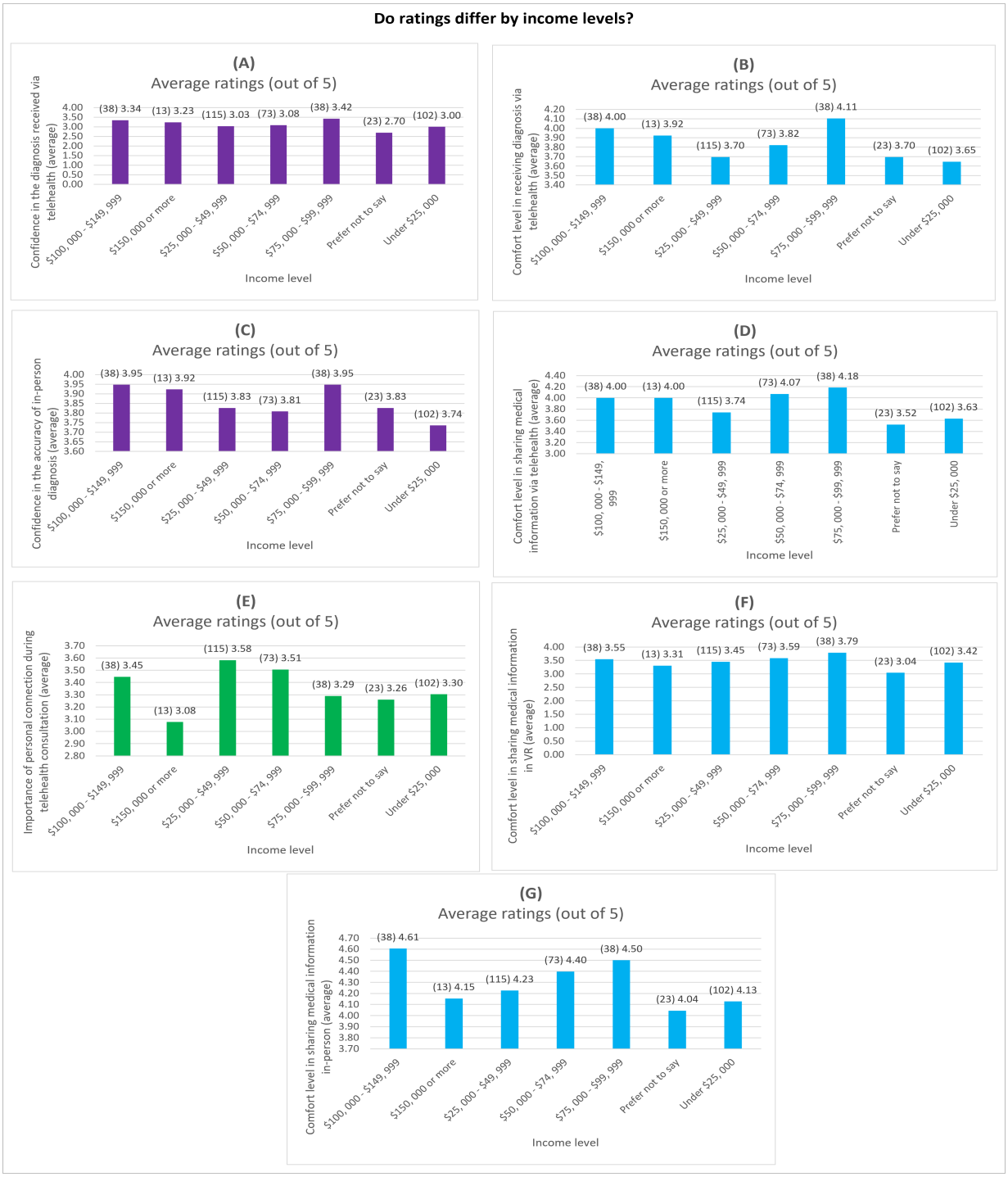


Figure B.2: Ratings by Income Levels

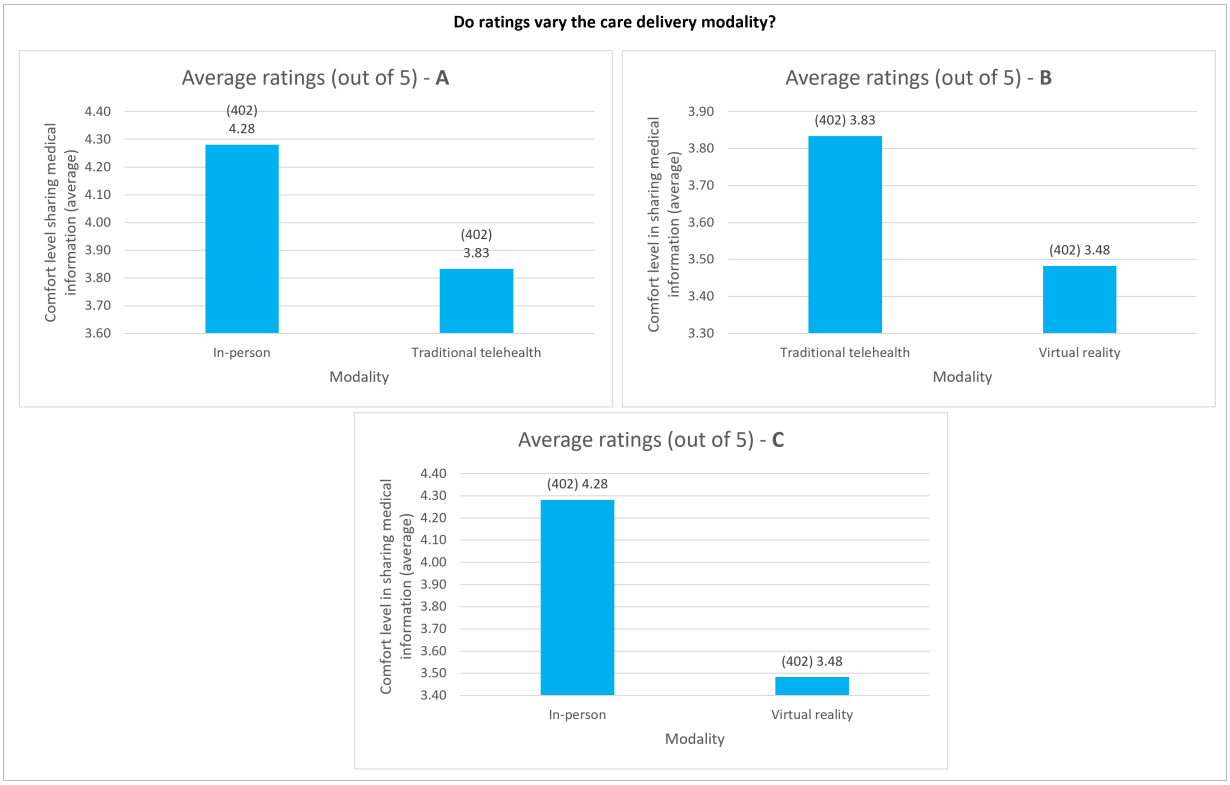


Figure B.3: Comfort ratings: In-person vs. Traditional Telehealth vs. VR Telehealth

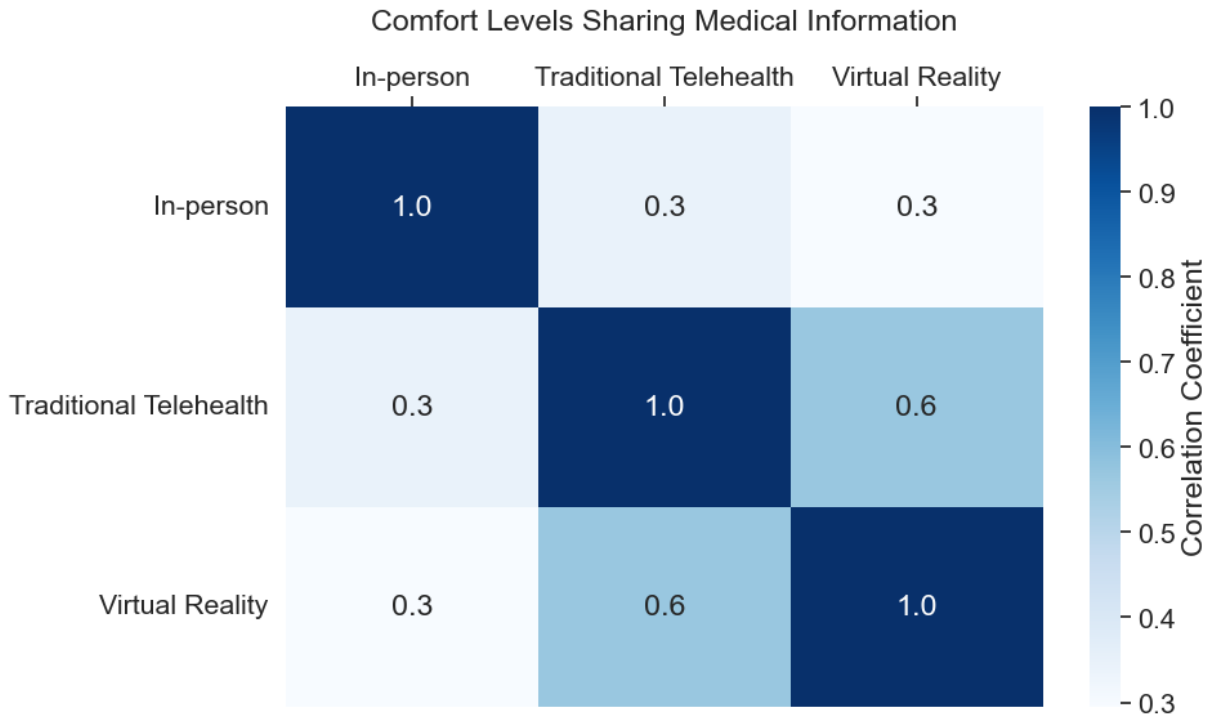


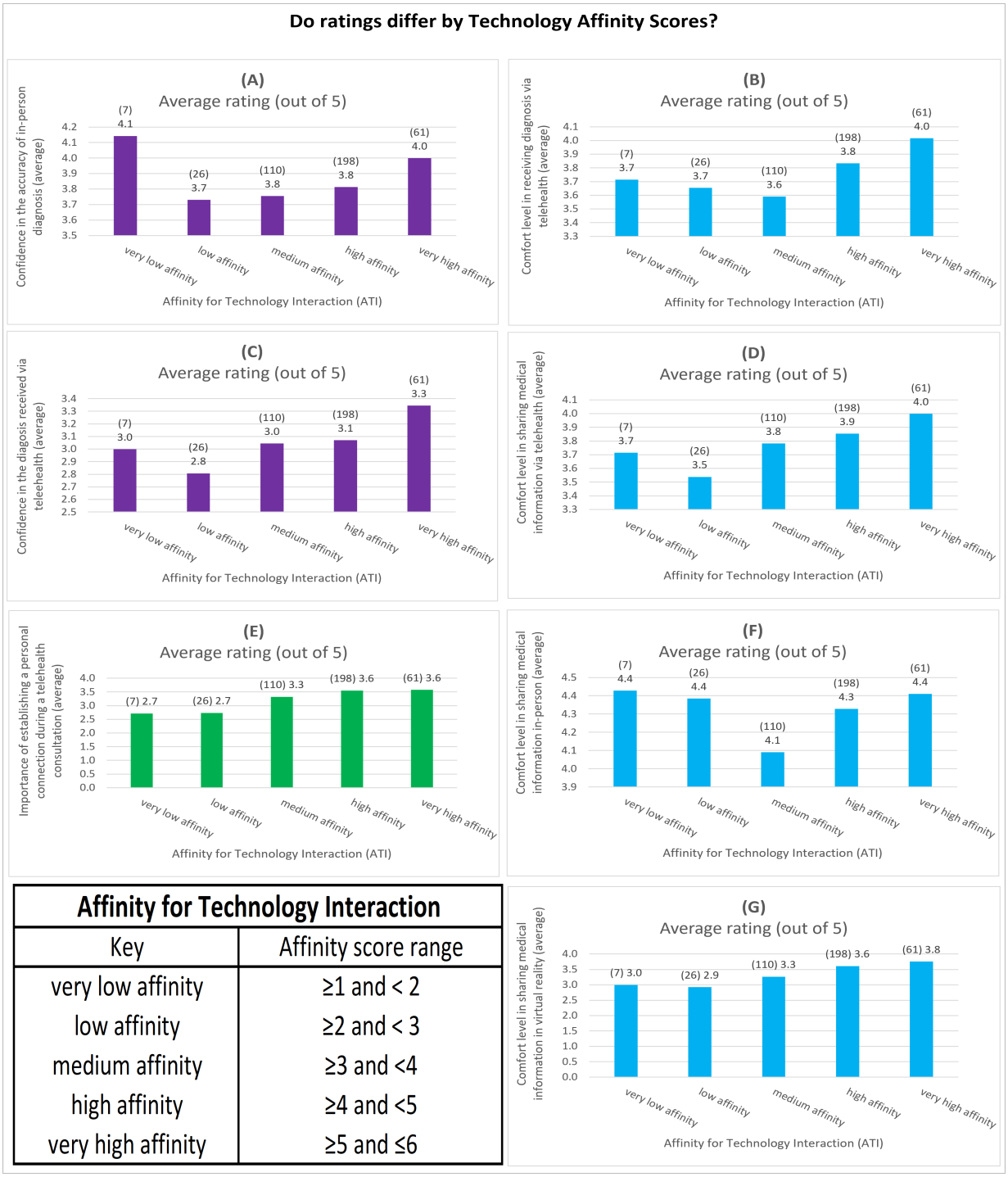
Figure B.4: Correlations: In-person vs. Traditional Telehealth vs. VR Telehealth comfort ratings

Variable	N	Mean	Item-Total Correlation	McDonald's Omega if removed
ATI_1	402.00	4.36	0.62	0.77
ATI_2	402.00	4.62	0.74	0.76
ATI_3	402.00	3.47	0.06	0.86
ATI_4	402.00	4.42	0.70	0.76
ATI_5	402.00	4.57	0.75	0.76
ATI_6	402.00	3.54	0.57	0.85
ATI_7	402.00	4.12	0.67	0.79
ATI_8	402.00	3.31	0.50	0.85
ATI_9	402.00	4.69	0.69	0.78

Overall McDonald's Omega: 0.81
Average inter-item correlation 0.41
ATI_1 - ATI_9 represent the items 1 through 9, respectively, of the ATI scale.

Overall average score (M) 4.12
Sample Standard deviation (σ) 1.32

Figure B.5: Affinity for Technology Interaction



Affinity for Technology Interaction	
Key	Affinity score range
very low affinity	≥1 and < 2
low affinity	≥2 and < 3
medium affinity	≥3 and <4
high affinity	≥4 and <5
very high affinity	≥5 and ≤6

Figure B.6: Ratings by Technology Affinity

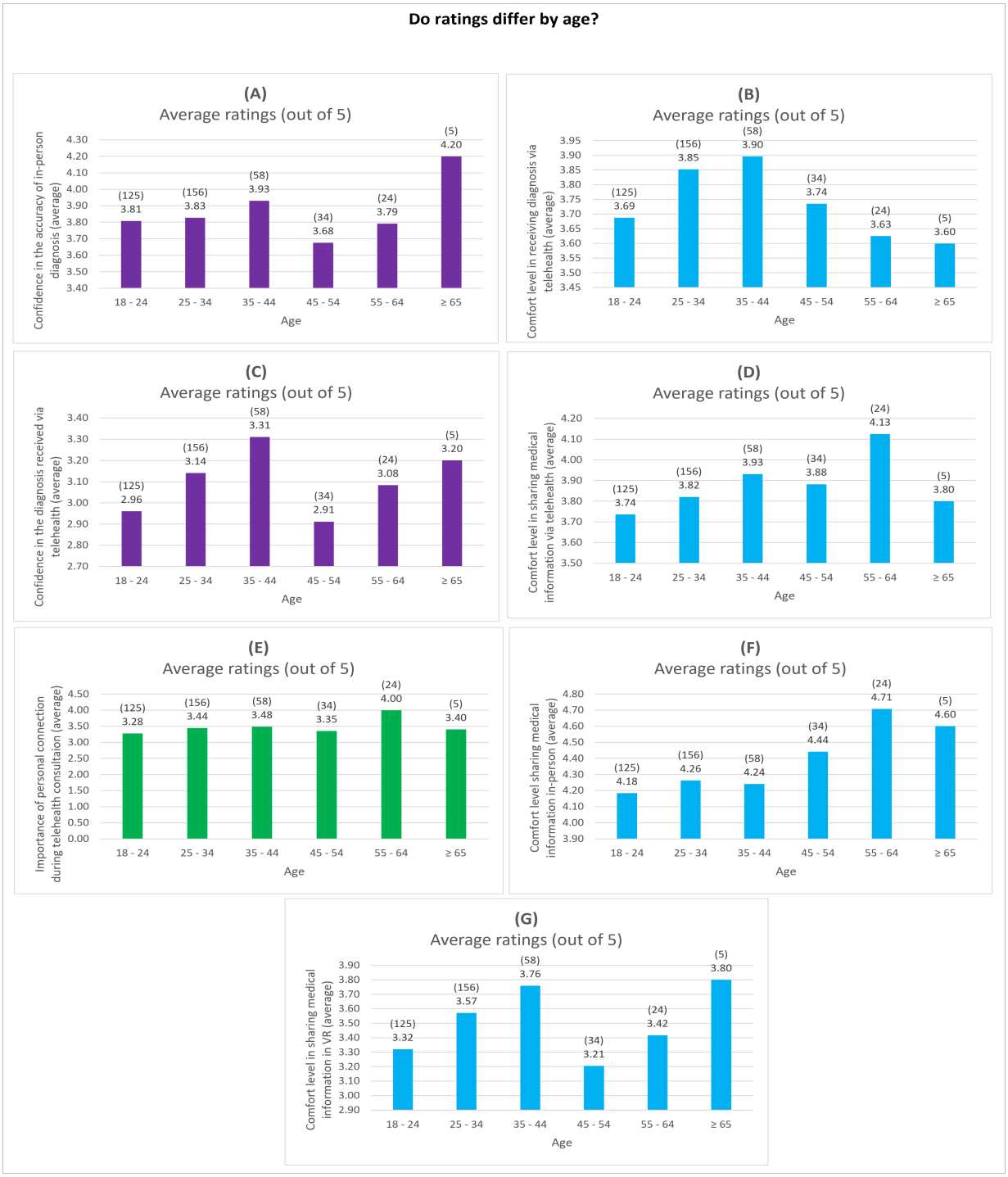


Figure B.7: Ratings by Age

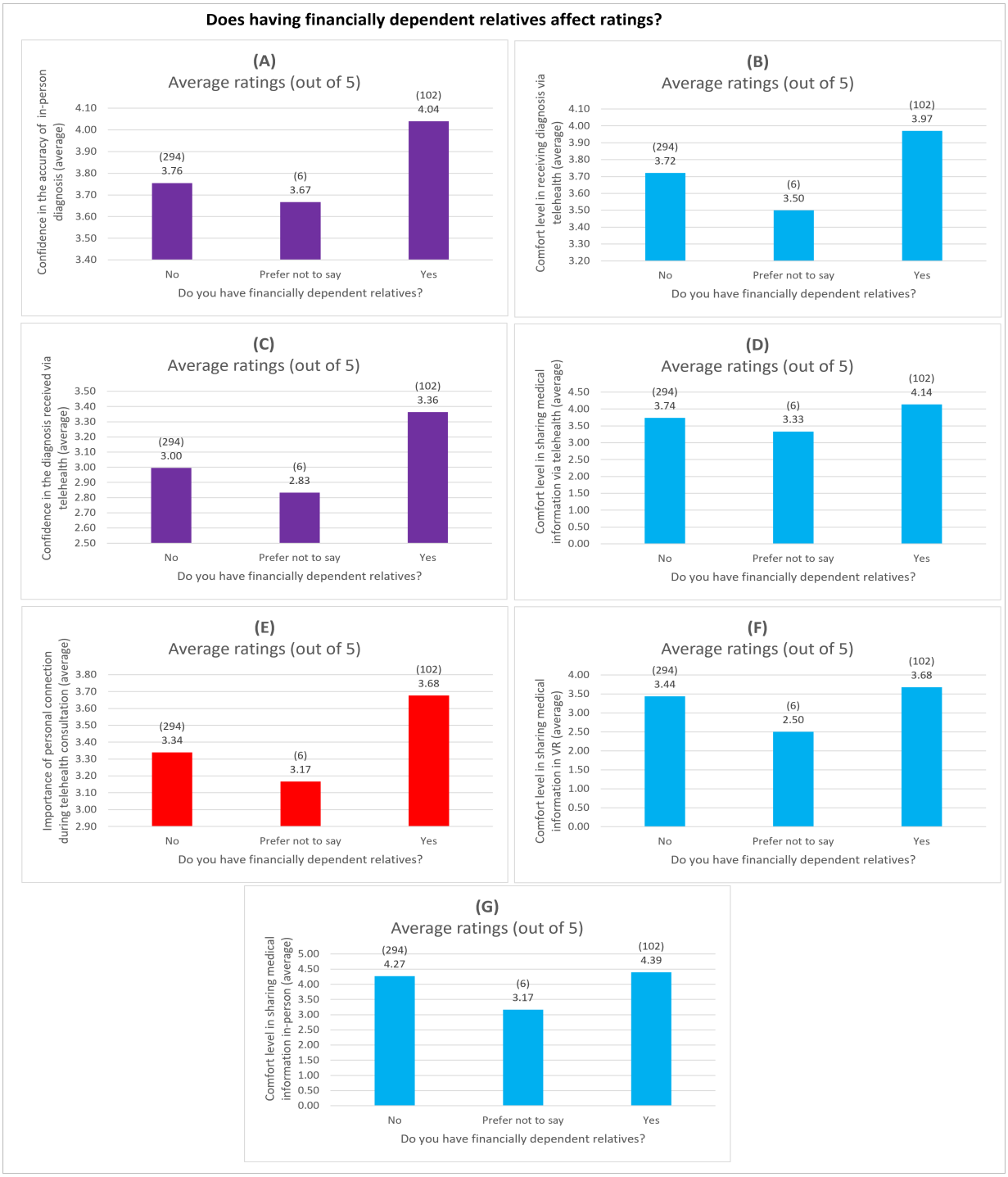


Figure B.8: Ratings by Dependent relatives status



Figure B.9: Ratings by Education levels

		Education_level								
		Total	Associate degree	Bachelor's degree	College	High School	Master's degree	Other Graduate or Professional degree	PhD	Prefer not to say
Telehealth Experience	Total Count (Answering)	402.0	23.0	165.0	44.0	89.0	58.0	12.0	7.0	4.0
	Have Telehealth Experience	249.0	16.0	94.0	27.0	50.0	47.0	8.0	6.0	1.0
		61.9%	69.6%	57.0%	61.4%	56.2%	81.0%	66.7%	85.7%	25.0%
	No Telehealth Experience	153.0	7.0	71.0	17.0	39.0	11.0	4.0	1.0	3.0
		38.1%	30.4%	43.0%	38.6%	43.8%	19.0%	33.3%	14.3%	75.0%

Figure B.10: Participants grouped by Education Levels and Telehealth experience

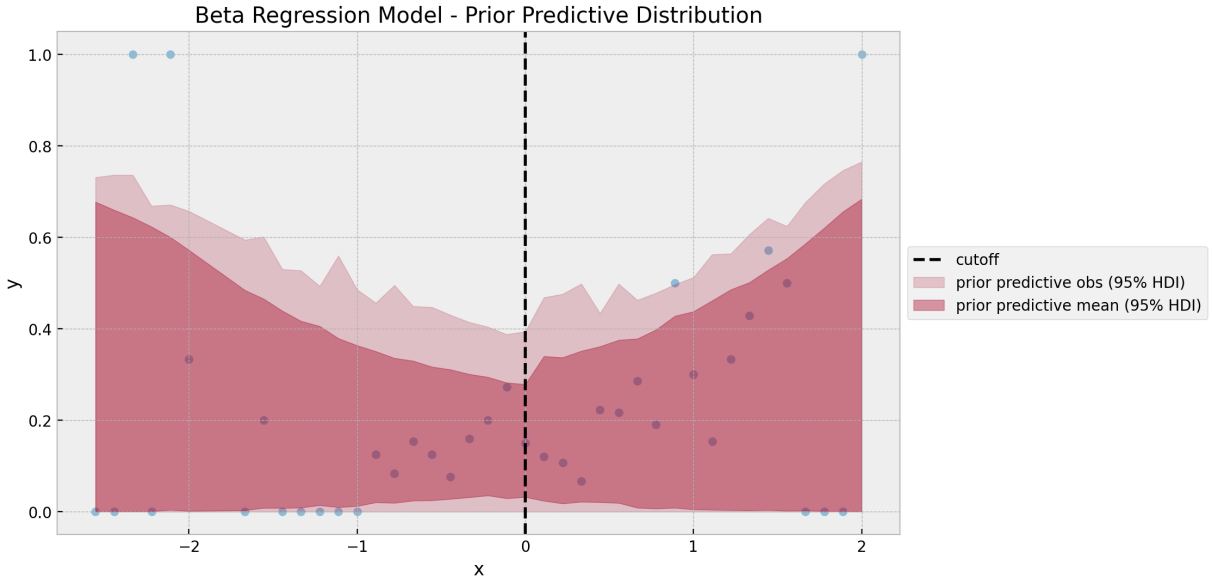


Figure B.11: Beta distribution: prior predictive plots



Figure B.12: Beta distribution: posterior predictive plots

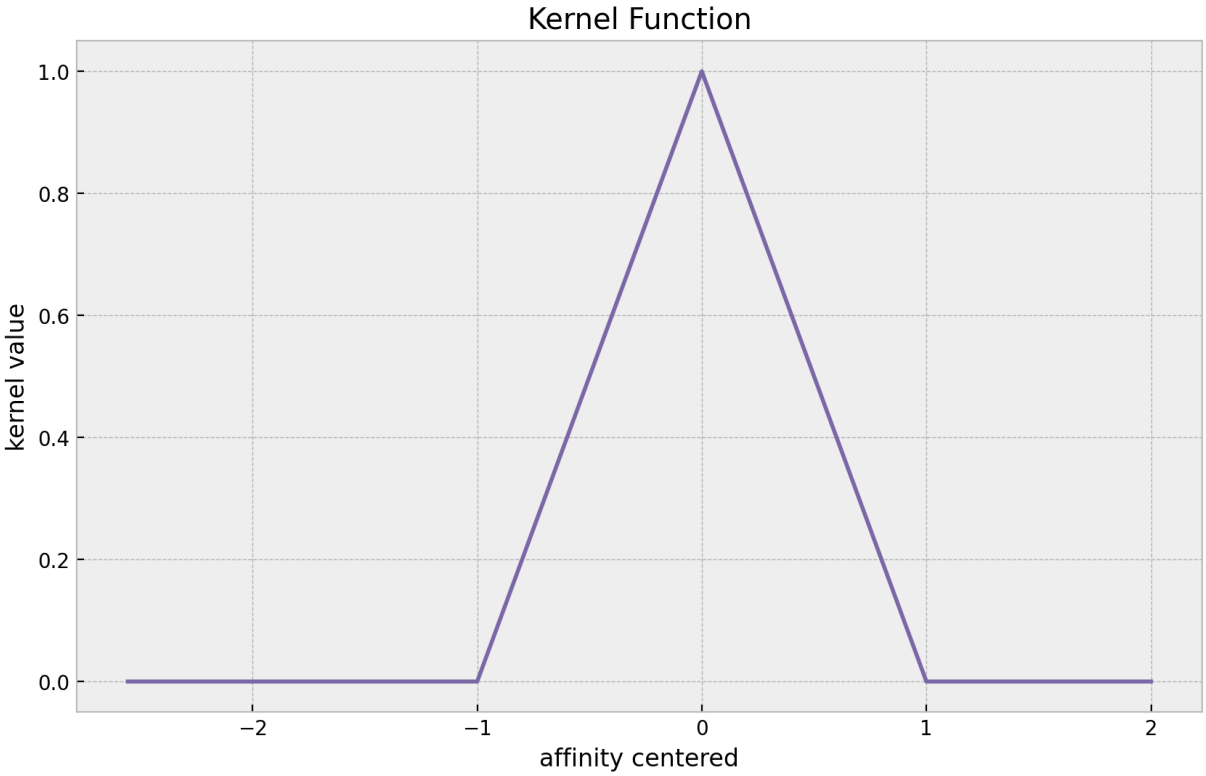


Figure B.13: Plot of kernel function (bandwidth h=1)

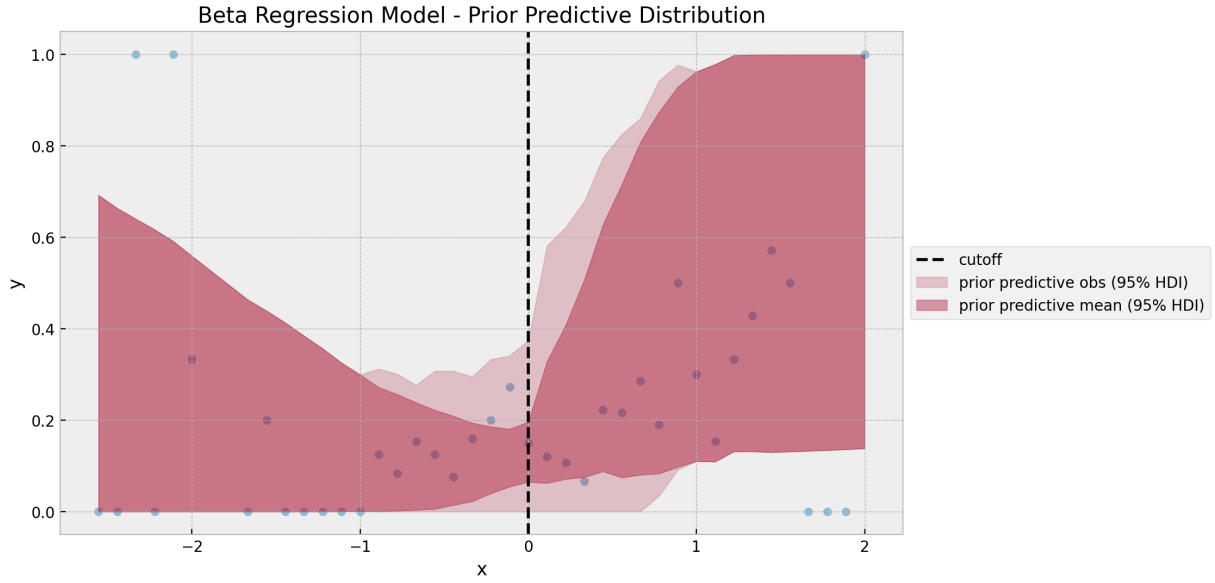


Figure B.14: Weighted Beta Regression: prior predictive plots

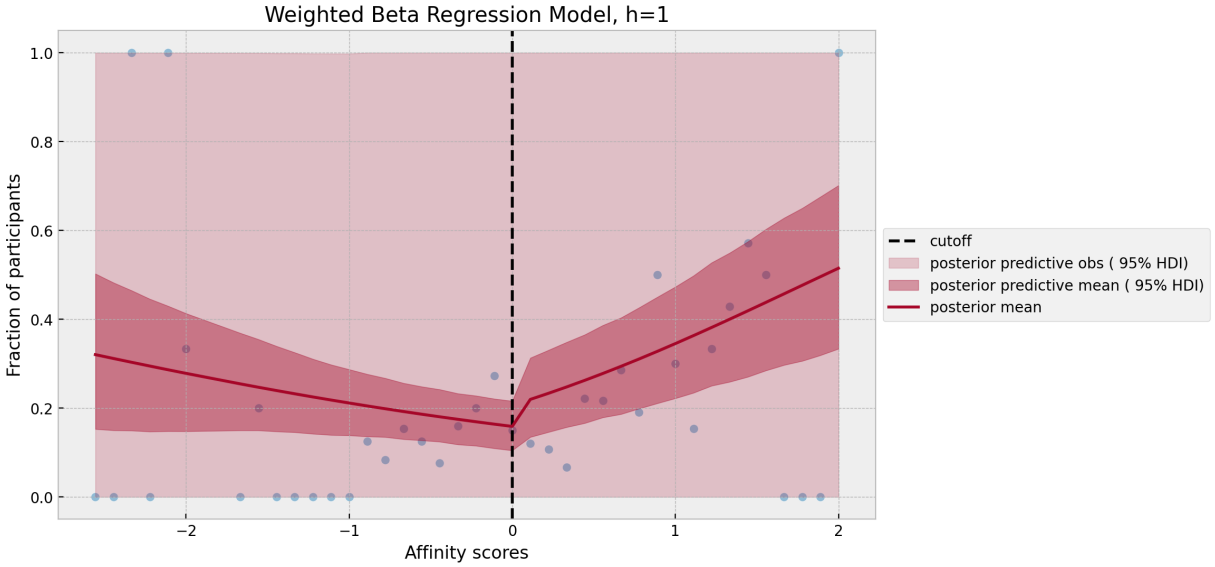


Figure B.15: Weighted Beta Regression: posterior predictive plots

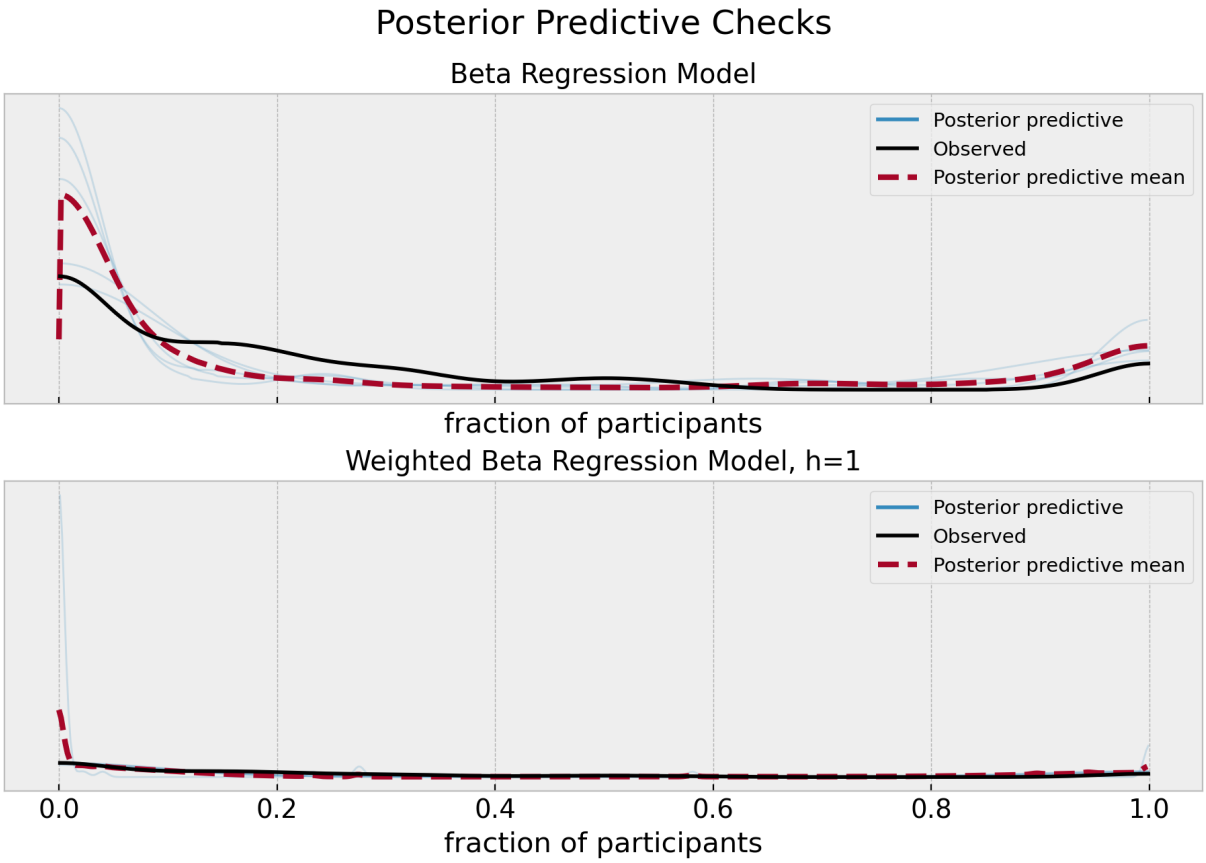


Figure B.16: Weighted Beta Regression vs Beta Regression: posterior predictive checks

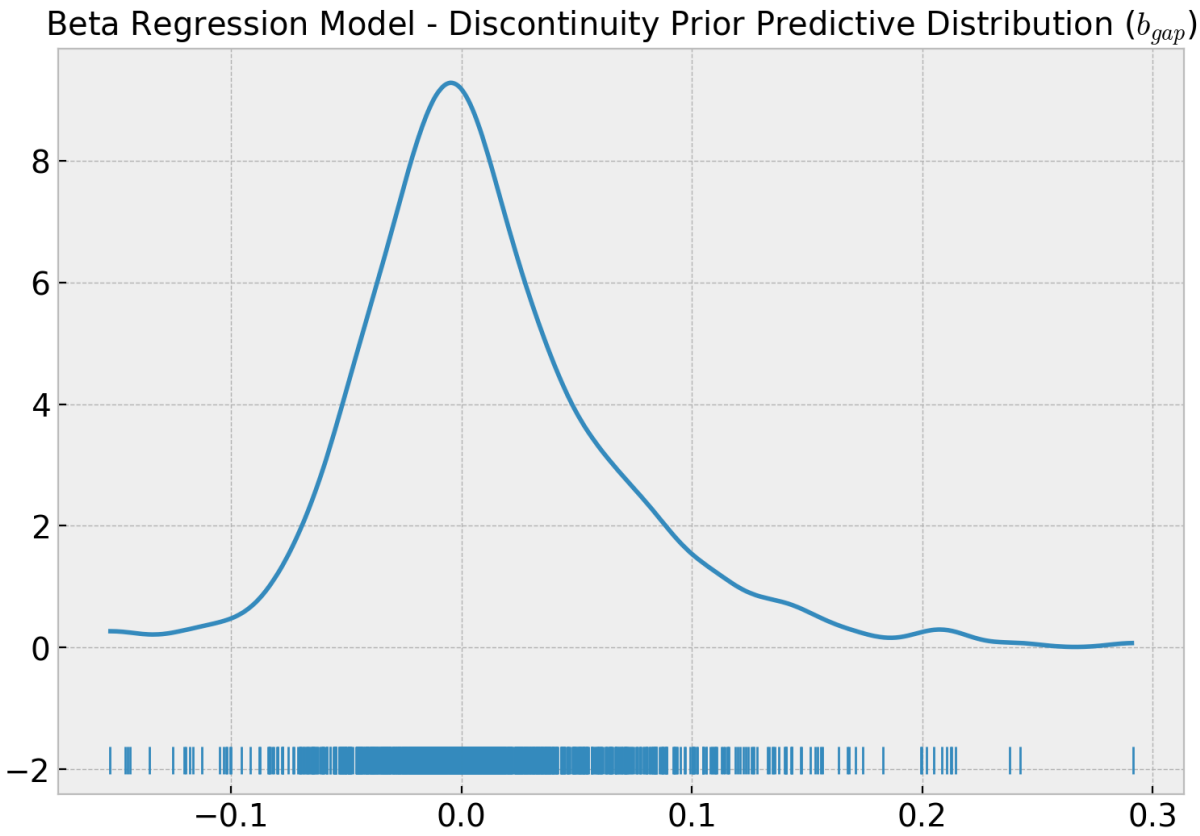


Figure B.17: Prior Predictive Distribution of the Treatment Effect (b_{gap})

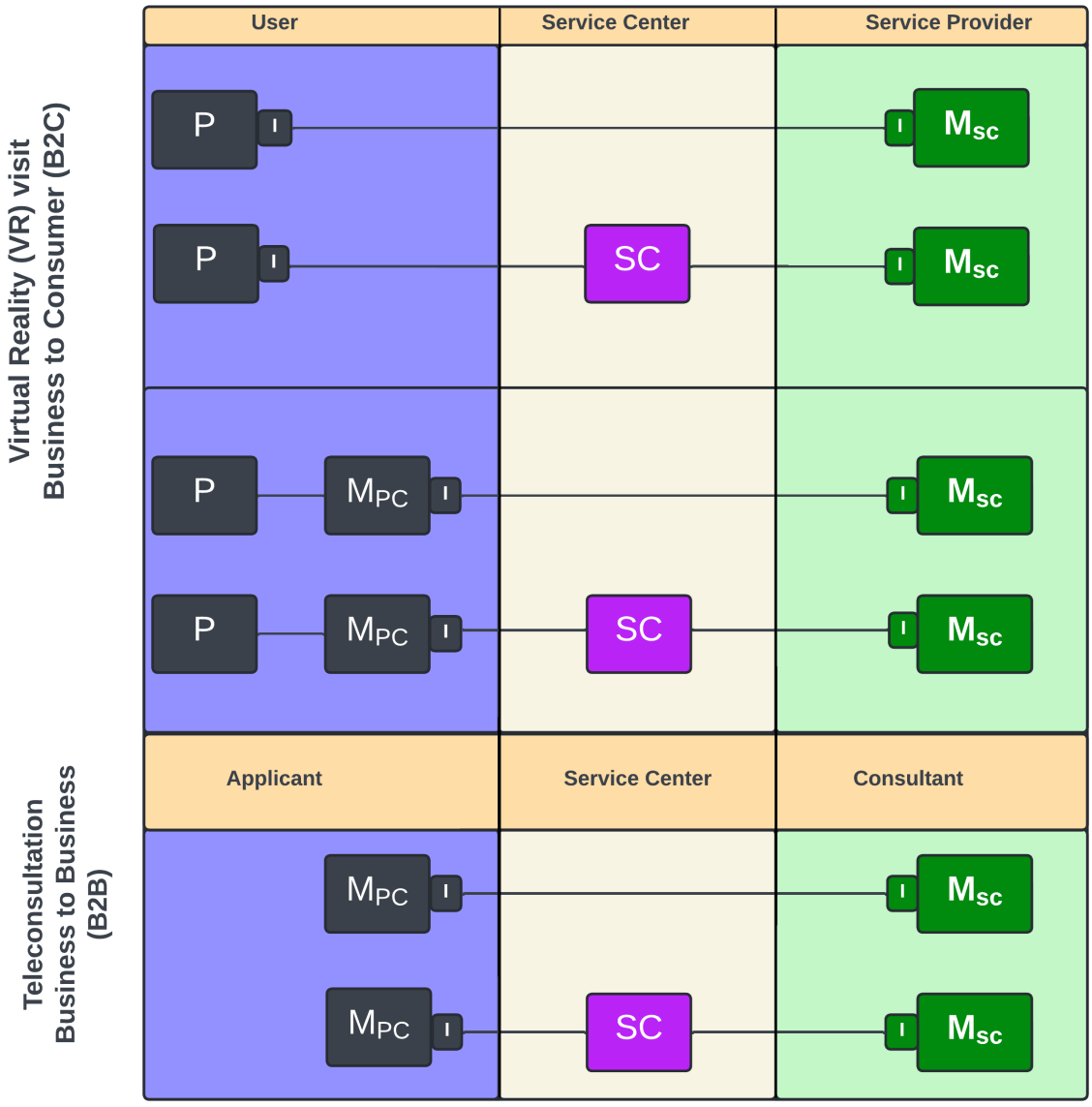


Figure B.18: Teleorganizational model showing the possible interaction flows: patient-to-provider and provider-to-provider. *Msc = specialist medical doctor, Mpc = primary care medical doctor, P = patient, SC = service center.*

Appendix C

Physician Interview Documents

C.1 Recruitment Email

Seeking Physicians to Participate in an Interview about the Use of Virtual Reality for Remote Patient Diagnosis

This invitation is being sent on behalf of all the researchers involved in this study.

Hello,

My name is ***Mustapha Momoh,*** and I am a master's student working under the supervision of ***Dr. Ville Mäkelä*** at the Stratford School of Interaction Design and Business, and **Dr. Catherine Burns** in the Department of Systems Design Engineering at the University of Waterloo.

We are reaching out to you because as part of my Master's degree, **we seek to interview physicians with diverse backgrounds on the use of virtual reality (VR) for remote patient diagnosis**. We are interested in hearing your perspectives regardless of whether or not you have experience with VR.

The interview will be held online and is expected to take around 30 minutes, during which we will explore what you think about VR and its possible use in remote patient diagnosis, its opportunities and pitfalls, the type of training or education you believe is required for physicians to proficiently use this technology, and the patient cases that might benefit from virtual reality technology.

Your insights will be invaluable in helping us understand the potential and challenges of virtual reality in remote diagnosis. As a token of our appreciation for your time, **you will receive a $30 Tango gift card** via email upon completion of the interview.

If you wish to participate, please visit booking-link to book a time slot. If you require additional information to help you decide, please do not hesitate to contact us at mmomoh@uwaterloo.ca , ville.makela@uwaterloo.ca , or c4burns@uwaterloo.ca.

This study has been reviewed and cleared by the University of Waterloo Research Ethics Board (REB # 45343). Participation is entirely voluntary. You may decline to answer any questions that you do not wish to answer, and you may withdraw your participation at any time during the interview.

Sincerely,

Mustapha Unubi Momoh

MASc Student Researcher

University of Waterloo, Canada

C.2 Study Information and Consent Form

Information and Consent Form

Date: 16/11/2023

Project Title: Remote Patient Diagnosis in Virtual Reality

Student Investigator:

Mustapha Unubi Momoh
University of Waterloo, Canada
mmomoh@uwaterloo.ca

Faculty Supervisors:

Dr. Ville Mäkelä
University of Waterloo, Canada
ville.makela@uwaterloo.ca

Dr. Catherine Burns
University of Waterloo, Canada
c4burns@uwaterloo.ca

Study Overview

We are researchers conducting a study focused on the use of telehealth and virtual reality in healthcare. You are invited to participate in this research study aimed at understanding people's attitudes, concerns, and needs regarding the use of telehealth services, including virtual reality platforms, for medical consultations. The insights gained from this study will inform the design of future virtual healthcare systems, with the goal of improving patient experiences and outcomes. This research is being conducted at the University of Waterloo, Canada.

Your Role in the Study

If you choose to participate in this study, you will be invited to an interview that should take approximately 30 minutes. This interview will focus on your experiences and perceptions as a physician regarding telehealth services, including the potential use of virtual reality for medical consultations. While the interview will be recorded for transcription purposes, your identity will remain confidential, and any identifiable information will be anonymized in the final report.

Eligibility and Participation Guidelines

To be eligible to participate in this study, you must be a practicing physician and have experience using telehealth services. If you meet these criteria and choose to participate, you will be invited to an interview that should take approximately 30 minutes. This interview will delve into your experiences and perceptions regarding telehealth services, including the potential use of virtual reality for medical consultations.

Your participation in this study is entirely voluntary. You have the right to decline to answer any questions that you do not feel comfortable answering, and you can withdraw your participation at any time during the interview. There will be no penalties for withdrawal.

Please note that while the interview will be recorded for transcription purposes, your identity will remain confidential, and any identifiable information will be anonymized in the final report. Therefore, once the interview is concluded and transcribed, we will not be able to identify or remove your specific data.

As a token of our appreciation for your time and contribution, you will receive a $25 Tango gift card via email upon completion of the interview.

Study Impact

Through this study, our goal is to gain insights into people's attitudes, concerns, and needs regarding the use of telehealth services, including the potential application of virtual reality in healthcare. The findings will help us identify existing gaps in current telehealth platforms. This knowledge will be instrumental in informing the design of future virtual healthcare systems, ensuring they are better equipped to meet users' expectations and address their concerns.

Potential Risks of Participation

We do not foresee any known or expected risks associated with your participation in this study

Data Confidentiality and Security Measures

Your identity will remain confidential throughout this study. The interview will be recorded for transcription purposes, but once the transcription is complete, the recording will be immediately destroyed. All indirect identifying information, such as demographic data, will be stored separately from the file containing your responses to other questions. Upon data collection, we will assign a random ID to each participant. Participants will be referred to only by this ID in both files and in the presentation of our findings. Access to these records will be restricted to our research team, as listed on the first page. The records will be stored on a cryptographically encrypted hard drive of a password-protected computer. We will retain our study records for 7 years, after which all records will be destroyed in accordance with the University of Waterloo policy. All data will be summarized in our final publication, and no individual can be identified from these summarized results. Your identity will be completely confidential.

The study will be conducted via a virtual interview using Zoom. We utilize secure protocols to ensure confidentiality during the transcription process. However, it's important to understand that while we take all necessary precautions, no internet transmission can be guaranteed as entirely secure or error-free. While the risk is minimal with secure protocols, complete anonymity and confidentiality cannot be assured during any internet transmission. Rest assured, our storage systems are password-protected and encrypted, and the management of the data is under the strict control of our research team.

Study Sponsorship and Ethics Approval

This study is sponsored by the Mitacs Accelerate Program in partnership with Otekha Health Corporation.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #45343). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca.

Consent to Participate

With full knowledge of all the foregoing, I agree, of my own free will, to participate in this study and understand that the interview will be recorded for research purposes.

- By checking this box ☐, you agree to participate in this study, provide your best answers to the questions asked, and consent to the recording of the interview.
- I do not wish to participate (please close the page now).

C.3 Interview Questions

Survey and Interview Questions for Physicians

Remote Patient Diagnosis in Virtual Reality

Study Information and Consent Form [1]

[Information to participants goes here, see attached *Information* and Consent *Form*]

Contact information

Student Investigator:

Mustapha Unubi Momoh
University of Waterloo, Canada
mmomoh@uwaterloo.ca

Faculty Supervisors:

Dr. Ville Mäkelä
University of Waterloo, Canada
ville.makela@uwaterloo.ca

Dr. Catherine Burns
University of Waterloo, Canada
c4burns@uwaterloo.ca

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Consent to Participate

- With full knowledge of all the foregoing, I agree, of my own free will, to participate in this study and understand that the interview will be recorded for research purposes.
- By checking this box ☐, you agree to participate in this study, provide your best answers to the questions asked, and consent to the recording of the interview.
- "I do not wish to participate (please close the page now)."

---

[1]The study information letter is designed based on the University of Waterloo, Sample information letters for survey and interview combined studies. Available at: https://uwaterloo.ca/research/office-research-ethics/research-human-participants/application-process/samples-and-other-supporting-materials/information-consent-samples/sample-information-letters
Accessed on May 19, 2022.

[Give a quick overview of what this interview is about and how we will use the data. Also mention that we'd like to record the interview and it will not be accessible to anyone outside of our research team.]

Before we begin with the interview questions, I'd like to seek your verbal consent to participate in this interview and for us to record it. Do you agree?

[Wait for verbal consent]

Thank you. Let's proceed.

PART 1: Demographic Questions

The questions in this section are designed to enable us to understand your background and experiences.

Q1. What is your age?

Enter your age

Q2. What is your gender?

- Male
- Female
- Non-binary
- Prefer not to say
- Other (please specify)

Q3. What is your highest level of education?

- Medical degree (MD) or equivalent
- Doctor of Osteopathic Medicine (DO)
- Other Postgraduate Degree (PhD, MPH, etc.)
- Other (please specify)

Q4. How many years of experience do you have in the medical field?

- Less than 5 years
- 5-10 years
- 11-20 years
- More than 20 years

Q5. What is your medical specialty/specialties?

- Internal Medicine
- Family Medicine
- Pediatrics

- Surgery
- Obstetrics and Gynecology
- Psychiatry
- Radiology
- Anesthesiology
- Emergency Medicine
- Dermatology
- Neurology
- Cardiology
- Oncology
- Orthopedics
- Other

If 'Other', please specify ☐

Q6. In what type of setting do you practice primarily?

- Hospital
- Solo practice
- Group practice
- Private practice
- Academic medical centre
- Community health centre
- Other (please specify)

Before we begin with the interview questions, I'd like to seek your verbal consent to participate in this interview and for us to record it. Do you agree?

PART 2: Traditional Telehealth Platforms

Telemedicine refers to the use of digital technologies to provide medical care remotely. It allows a person to seek the advice of a doctor on non-emergency situations that do not require an in-office visit. This can include a variety of services, such as online consultations, remote patient monitoring, and digital transmission of medical images or data. Online consultations can take place through text, video conferencing, phone calls, or even virtual reality platforms, allowing patients to communicate with healthcare providers without the need for an in-person visit. [1,2,3]

[1] Danny Bonvissuto (2022. What is telemedicine? How Does Telehealth Work? WebMD. https://www.webmd.com/covid/how-does-telemedicine-work

[2] Tee-Melegrito, R. A. (2022). Telemedicine: Definition, uses, benefits, and more. Medical News Today. Retrieved from https://www.medicalnewstoday.com/articles/telemedicine

[3] VSee. (n.d.). Telemedicine: The complete guide 2021. https://vsee.com/telemedicine

Q1. Do you use telehealth services in your practice? If yes, How often do you use them? In what ways do you use them?

If they have not provided telehealth services at all:

Q2. What are your primary reasons for not providing telehealth services? Any challenges or obstacles that you have identified or faced?

If they have provided telehealth services in the past:

Q7. What types of telehealth services have you provided?

Below are examples of telehealth services:

- Video Consultation
- Telephone consultations.
- Online messaging such as email
- Remote patient monitoring
- Mobile health apps
- Virtual reality consultations
- Other [Please specify_____]

Q8. Which telehealth platforms have you used in your practice?

The following are examples of some of the existing platforms:

- Maple
- Teladoc
- Babylon
- Doctor on Demand
- Amwell
- VSee
- If you have used something other than the above, please state:_____

Q3. What benefits are you experiencing with telehealth services, particularly over conventional in-person services? Why do you provide telehealth services?

Q4. What issues have you experienced with telehealth services? What do you think are the biggest obstacles in improving telehealth services?

Q5. What are the limits of telehealth services in your work? Are there particular things that current telehealth platforms cannot do, but you wish they did?

Q6. How comfortable do you feel providing a diagnosis through a telehealth platform? Would you say that you are very comfortable, somewhat comfortable, neutral, somewhat uncomfortable, or very uncomfortable?

a. Follow up: why do you feel this way?

Q7. How confident are you in the accuracy of a diagnosis provided through a telehealth platform? Would you say that you are extremely confident, very confident, moderately confident, slightly confident, or not at all confident?

a. Follow up: why do you feel confident or less confident in the accuracy of a diagnosis provided through a telehealth platform.

Q8. To what extent do you feel you are able to establish a personal connection with your patients during a telehealth consultation?

a. Are there any clear obstacles for establishing such a connection in telehealth?
b. How important are personal connections to you with your patients?

Q9. In general, how satisfied are you with the telehealth services you have provided? Would you say that you are very satisfied, somewhat satisfied, neutral, somewhat dissatisfied, or very dissatisfied?

a. Follow up:

PART 2: Virtual Reality Telehealth Platforms

Virtual reality (VR) technologies have advanced rapidly in recent years. Especially by using a VR headset (also known as a head-mounted display), it is now possible to create healthcare experiences that are more immersive and interactive than traditional telehealth platforms. Imagine a healthcare experience that transcends the boundaries of traditional video consultations, immersing you and your patient in a virtual environment that simulates a real-world clinical setting. These experiences can range from virtual consultations and remote monitoring to health education and therapy sessions.

In this section, we are interested in your thoughts regarding the use of VR to provide healthcare services.

Q1. Before we go into the details, would you be open to the idea of using VR in your office for healthcare delivery? Why or why not?

Q2. Have you so far been involved in any efforts to use VR technology in healthcare, or are you aware of any such efforts? Can you tell us about them, and what you think of these efforts?

Now, imagine this: You are in a virtual consultation room with your patient. You can move around their 3D projection, choosing the angle or side from which you view them. You can pick up on non-verbal cues and interact with the environment in a way that is not possible in a traditional video consultation.

Patients could access this virtual environment using personal equipment at home or through community centers and libraries that provide the necessary hardware.

Now, let us dive into your thoughts and experiences on this possible approach to healthcare delivery.

Q3. What are your initial thoughts on using VR in this manner for healthcare services? What advantages and challenges do you foresee?

Q4. What do you think about the use of avatars or 3D projections of patients and physicians in a VR telehealth platform. What would it require to be beneficial in your work?

Q5. To make such a VR telehealth platform viable and beneficial for your work, and to support your workflow, what kinds of functionalities do you foresee that such a VR platform should have? For example, in what ways would you need to be able to interact with the patient and the virtual environment?

Q6. In the area of healthcare, what kinds of patient meetings do you think such a VR platform would be especially suitable for? What types of meetings do you think it would not be suitable for?

Q7. Can you share any specific concerns that you might have about incorporating a virtual reality telehealth platform into your practice?

Q8. When thinking about accessibility, what features do you think a VR telehealth platform should have to accommodate patients with different abilities and needs. For example, patients with visual impairment, range of motion problems, language issues, etc?

Q9. Have you ever experienced motion sickness or discomfort while using VR technology? How do you think this could impact your use or your patients' use of a VR telehealth platform?

Q10. What are your thoughts on data privacy and security? Do you foresee any benefits or challenges for VR telehealth in this regard?

Q11. After discussing the various aspects of VR in healthcare, has your perspective on using VR in your office changed? Would you now consider implementing it in your practice?

Q12. Before we conclude, is there anything else you'd like to share with us about VR, healthcare, or anything else?

This concludes the interview. We sincerely thank you for your time and valuable feedback. As a token of appreciation, we will be sending you a $25 gift card once the study has been completed.

C.4 Interview Appreciation Form

Interview Appreciation

Project Title: Remote Patient Diagnosis in Virtual Reality

Student Investigator:

Mustapha Unubi Momoh
University of Waterloo, Canada
mmomoh@uwaterloo.ca

Faculty Supervisors:

Dr. Ville Mäkelä
University of Waterloo, Canada
ville.makela@uwaterloo.ca

Dr. Catherine Burns
University of Waterloo, Canada
c4burns@uwaterloo.ca

Thank you for participating in the interview on **Remote Patient Diagnosis in Virtual Reality.**

In this study, you engaged in a detailed discussion, sharing your valuable insights and experiences as a healthcare provider in the realm of telehealth, with a particular focus on the integration of virtual reality. The objective of this interview was to gain a deeper understanding of the medical professionals' perspectives, apprehensions, and requirements in the context of virtual healthcare. Your expertise will significantly aid us in pinpointing the shortcomings in existing telehealth platforms and will guide the future design of more efficient and user-centric virtual healthcare systems.

If you expressed interest in receiving a copy of the results, rest assured that we will forward them to the email address you provided once they are compiled. For any further queries or feedback, please feel free to reach out to any member of our research team.

Your confidentiality is of utmost importance to us. While the interview was recorded for transcription purposes, please be informed that once the transcription is complete, the video recording will be deleted immediately. Your identity and any indirect identifying information will be kept strictly confidential, stored securely, and only accessible to our research team. All findings will be presented in an aggregated manner, ensuring that individual identities remain anonymous.

Appendix D

Patient Survey Documents

D.1 Recruitment Poster

Stratford School of Interaction Design and Business, University of Waterloo

PARTICIPANTS NEEDED FOR RESEARCH PROJECT ON REMOTE PATIENT DIAGNOSES IN VIRTUAL REALITY

We are seeking adult volunteers, aged 18 years or older, who have experience or interest in the use of telehealth platforms and services, to participate in a study focused on remote patient diagnosis using virtual reality technologies. Telehealth platforms and services refer to digital tools and systems used to access and manage health care services remotely. This includes virtual appointments with healthcare providers, telephonic consultations, digital transmission of medical imaging, and use of health apps for monitoring and managing health conditions. If you have used such platforms and services, we invite you to contribute to this research. You do not need to have prior experience with virtual reality to respond to this survey.

As a participant in this study, you will be asked to complete an online survey that will take approximately 15 minutes of your time. Your responses will be instrumental in shedding light on the potential advantages and challenges of using virtual reality for remote patient diagnosis. We aim to understand the specific patient cases that could benefit from this technology, and the necessary training or education required for its proficient use. Additionally, your insights will help us explore the user experience, accessibility, and privacy concerns related to VR telehealth platforms. This will guide the development of more user-friendly and secure VR telehealth solutions in the future.

Your participation is voluntary, and as a token of our appreciation, you will receive **$5 CAD** in your Prolific account.

For more information about this study, please contact:

Mustapha Unubi Momoh | *Research Assistant* | *Systems Design Engineering* | *University of Waterloo*

mmomoh@uwaterloo.ca

Dr. Ville Mäkelä | *Assistant Professor | Stratford School of Interaction Design and Business | University of Waterloo*

ville.makela@uwaterloo.ca

Thank you!

This study has been reviewed by and has received ethics clearance through a University of Waterloo Research Ethics Board. (REB # 45343)

D.2 Information and Consent Form

Information and Consent Form

Date: [To be Added]

Project Title: Remote Patient Diagnosis in Virtual Reality

Student Investigator:

Mustapha Unubi Momoh
University of Waterloo, Canada
mmomoh@uwaterloo.ca

Faculty Supervisors:

Dr. Ville Mäkelä
University of Waterloo, Canada
ville.makela@uwaterloo.ca

Dr. Catherine Burns
University of Waterloo, Canada
c4burns@uwaterloo.ca

Study Overview

We are researchers conducting a study focused on the use of telehealth and virtual reality in healthcare. You are invited to participate in this research study aimed at understanding people's attitudes, concerns, and needs regarding the use of telehealth services, including virtual reality platforms, for medical consultations. The insights gained from this study will inform the design of future virtual healthcare systems, with the goal of improving patient experiences and outcomes. This research is being conducted at the University of Waterloo, Canada.

Your Role in the Study

If you choose to participate in this study, you will be asked to complete an online survey that should take approximately 15 minutes. This survey will be completed anonymously. The questions will focus on your experiences and perceptions of telehealth services, including the use of virtual reality for medical consultations.

Upon reviewing this information and consent form:

- You will be asked to answer preliminary questions to determine your eligibility for this survey.
- If you qualify, you will be asked to provide demographic information, such as age, gender, education level, race/ethnicity, annual household income, marital status, and whether or not you have dependent children. This information will help us understand the demographics of our study sample.
- You will be asked about your experiences and concerns regarding the use of telehealth services, including any experiences with virtual reality platforms.

- You will be presented with descriptions of different virtual healthcare scenarios and asked about your perceptions and preferences.
- After the survey, if you are interested in seeing a summary of the results, you can contact any member of the research team listed on the first page of this form.

Eligibility and Participation Guidelines

To be eligible for this study, you must:

- Be 18 years of age or older.
- Have previous experience with telehealth services, or have an interest in using such services in the future.

Your participation in this study is entirely voluntary. You have the right to decline to answer any questions that you do not feel comfortable answering, and you can withdraw your participation at any time by choosing not to submit your responses. There will be no penalties for withdrawal. Please note that this survey is anonymous, and we do not collect your name or any direct identifying information. Therefore, once you have submitted your responses, we will not be able to identify or remove your data.

As a token of our appreciation for your time and contribution, you will receive $5 in prolific account upon completion of the survey.

Please note that the amount received is taxable. It is your responsibility to report this amount for income tax purposes.

Study Impact

Through this study, our goal is to gain insights into people's attitudes, concerns, and needs regarding the use of telehealth services, including the potential application of virtual reality in healthcare. The findings will help us identify existing gaps in current telehealth platforms. This knowledge will be instrumental in informing the design of future virtual healthcare systems, ensuring they are better equipped to meet users' expectations and address their concerns.

Potential Risks of Participation

We do not foresee any known or expected risks associated with your participation in this study

Data Confidentiality and Security Measures

Your identity will remain confidential throughout this study. This survey is designed to be anonymous, and we do not request your name or any direct identifying information. All indirect identifying information, such as demographic data, will be stored separately from the file containing your responses to other questions. Upon data collection, we will assign a random ID to each participant. Participants will be referred to only by this ID in both files and in the presentation of our findings. Access to these records will be restricted to our research team, as listed on the first page. The records will be stored on a cryptographically encrypted hard drive of a password-protected computer. We will retain our study records for 7 years, after which all records will be destroyed in accordance with University of Waterloo policy. All data will be summarized in our final publication, and no individual can be identified from these summarized results. Your identity will be completely confidential.

The study will be conducted via an online survey facilitated by Qualtrics. Qualtrics has established technical, administrative, and physical safeguards to protect the information provided through the

Services from loss, misuse, and unauthorized access, disclosure, alteration, or destruction. However, please note that no internet transmission is ever entirely secure or error-free. Qualtrics temporarily collects your computer IP address to prevent duplicate responses in the dataset but does not collect information that could personally identify you.

All data will be temporarily stored on the Qualtrics server (approximately one month) and will then be downloaded to the investigator's computer at the University of Waterloo. Upon downloading the data, we will erase the data saved on the server. While we will use secure protocols (SSL/SSH) to ensure confidentiality during the download of data from the Qualtrics server to the investigator's computer, anonymity and confidentiality cannot be guaranteed during internet transmission of data if insecure protocols are used. Anonymity and confidentiality also cannot be guaranteed during the time the data is stored on the Qualtrics server before being downloaded to the investigator's computer. Although the Qualtrics server is password-protected, the management of the server is beyond the investigator's control.

Your responses in this study may be used in future scientific publications as anonymized quotations. In these cases, no further information about you will be provided.

Study Sponsorship and Ethics Approval

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #45343). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca.

For all other questions about the study, please contact any member of the research team listed on the first page of this form.

Consent to Participate

With full knowledge of all the foregoing, I agree, of my own free will, to participate in this study and understand that the interview will be recorded for research purposes.

By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

- By checking this box ☐, you agree to participate in this study, provide your best answers to the questions asked, and consent to the recording of the interview.
- By checking this box ☐, you agree that anonymous quotations from this study may be used in publications.
- "I do not wish to participate (please close the page now)."

We appreciate your consideration to participate in this study. Thank you.

D.3 Survey Questionnaire

Prolific ID

What is your Prolific ID?
Please note that this response should ***auto-fill with the correct ID***

${e://Field/PROLIFIC_PID}

Information and Consent Form



Information and Consent Form

Project Title: Remote Patient Diagnosis in Virtual Reality

Student Investigator:
Mustapha Unubi Momoh
University of Waterloo, Canada
mmomoh@uwaterloo.ca

Faculty Supervisors:
Dr. Ville Mäkelä
University of Waterloo, Canada
ville.makela@uwaterloo.ca

Dr. Catherine Burns

University of Waterloo, Canada
c4burns@uwaterloo.ca

Study Overview

We are researchers conducting a study focused on the use of telehealth and virtual reality in healthcare. You are invited to participate in this research study aimed at understanding people's attitudes, concerns, and needs regarding the use of telehealth services, including virtual reality platforms, for medical consultations. The insights gained from this study will inform the design of future virtual healthcare systems, with the goal of improving patient experiences and outcomes. This research is being conducted at the University of Waterloo, Canada.

Your Role in the Study

If you choose to participate in this study, you will be asked to complete an online survey that should take approximately 15-18 minutes. This survey will be completed anonymously. The questions will focus on your experiences and perceptions of telehealth services, including the use of virtual reality for medical consultations.

Upon reviewing this information and consent form:

- You will be asked to answer preliminary questions to determine your eligibility for this survey.
- If you qualify, you will be asked to provide demographic information, such as age, gender, education level, race/ethnicity, annual household income, marital status, and whether or not you have dependent children. This information will help us understand the demographics of our study sample.

- You will be asked about your experiences and concerns regarding the use of telehealth services, including any experiences with virtual reality platforms.
- You will be presented with descriptions of different virtual healthcare scenarios and asked about your perceptions and preferences.
- After the survey, if you are interested in seeing a summary of the results, you can contact any member of the research team listed on the first page of this form.

Eligibility and Participation Guidelines

To be eligible for this study, you must:

- Be 18 years of age or older.

- Have previous experience with telehealth services, or have an interest in using such services in the future.

Your participation in this study is entirely voluntary. You have the right to decline to answer any questions that you do not feel comfortable answering, and you can withdraw your participation at any time by choosing not to submit your responses. There will be no penalties for withdrawal. Please note that this survey is anonymous, and we do not collect your name or any direct identifying information. Therefore, once you have submitted your responses, we will not be able to identify or remove your data.

As a token of our appreciation for your time and contribution, you will receive **$6 CAD** in your Prolific account upon completion of the survey.

Please note that the amount received is taxable. It is your responsibility to report this amount for income tax purposes.

Study Impact

Through this study, our goal is to gain insights into people's attitudes, concerns, and needs regarding the use of telehealth services, including the potential application of virtual reality in healthcare. The findings will help us identify existing gaps in current telehealth platforms. This knowledge will be instrumental in informing the design of future virtual healthcare systems, ensuring they are better equipped to meet users' expectations and address their concerns.

Potential Risks of Participation

We do not foresee any known or expected risks associated with your participation in this study

Data Confidentiality and Security Measures

Your identity will remain confidential throughout this study. This survey is designed to be anonymous, and we do not request your name or any direct identifying information. All indirect identifying information, such as demographic data, will be stored separately from the file containing your responses to other questions. Upon data collection, we will assign a random ID to each participant. Participants will be referred to only by this ID in both files and in the presentation of our findings. Access to these records will be restricted to our research team, as listed on the first page. The records will be stored on a cryptographically encrypted hard drive of a password-protected computer. We will retain our study records for 7 years, after which all records will be destroyed in

accordance with University of Waterloo policy. All data will be summarized in our final publication, and no individual can be identified from these summarized results. Your identity will be completely confidential.

The study will be conducted via an online survey facilitated by Qualtrics. Qualtrics has established technical, administrative, and physical safeguards to protect the information provided through the Services from loss, misuse, and unauthorized access, disclosure, alteration, or destruction. However, please note that no internet transmission is ever entirely secure or error-free. Qualtrics temporarily collects your computer IP address to prevent duplicate responses in the dataset but does not collect information that could personally identify you.

All data will be temporarily stored on the Qualtrics server (approximately one month) and will then be downloaded to the investigator's computer at the University of Waterloo. Upon downloading the data, we will erase the data saved on the server. While we will use secure protocols (SSL/SSH) to ensure confidentiality during the download of data from the Qualtrics server to the investigator's computer, anonymity and confidentiality cannot be guaranteed during internet transmission of data if insecure protocols are used. Anonymity and confidentiality also cannot be guaranteed during the time the data is stored on the Qualtrics server before being downloaded to the investigator's computer. Although the Qualtrics server is password-protected, the management of the server is beyond the investigator's control.

Your responses in this study may be used in future scientific publications as anonymized quotations. In these cases, no further information about you will be provided.

Study Sponsorship and Ethics Approval

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #45343). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca.

For all other questions about the study, please contact any member of the research team listed on the first page of this form.

CONSENT FORM

Study Title: Remote Patient Diagnosis in Virtual Reality

With full knowledge of all the foregoing, I agree, of my own free will, to the following terms:

- I agree to participate in this study and provide my best answers to the questions asked
- I have read and understood the details of the study
- I am aware that I can withdraw at any time by not submitting my responses, but once submitted, my data cannot be retracted due to the survey's anonymity
- I agree that anonymous quotations from this study may be used in scientific publications

By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

We appreciate your consideration to participate in this study. Thank you.

○ I agree to participate in this study

○ I do not agree to participate in this study

Screening Questionnaire

Section 1. Screening Questionnaire

Before proceeding with the main survey, please answer the following questions to determine your eligibility to participate:

How old are you?

Telehealth experience or interest

Telehealth refers to the use of digital technologies to deliver medical care and health-related services remotely. It allows patients to seek a doctor's advice about non-emergency situations that do not require an in-office visit. This can include a variety of services, such as online consultations, remote patient monitoring, and digital transmission of medical images or data. Telehealth comes in various forms and can take place through text, video conferencing, phone calls, or even virtual reality platforms, allowing patients to communicate with healthcare providers without the need for an in-person visit.



Fig 1: Online text messaging by author



Fig 2: Phone consultation [+]



Fig 3: Remote diagnosis in Augmented Reality (VR + Real Environment) [**]



Fig 4: Remote Video consultation with doctor [++]



Fig 5: Remote transmission of medical data [*]



Fig 6: Remote patient monitoring [***]

Have you ever used a telehealth platform or service, or are you interested in using a telehealth platform or service in the future?

- ○ Yes, I have used a telehealth platform or service.
- ○ No, but I am interested in using a telehealth platform or service in the future.
- ○ No, and I am not interested in using a telehealth platform or service in the future.

[**]Hermant, N. (2023) Regional Victoria aged care trial uses VR to allow remote doctor exams and visits. [Dr Jennie Hutton is helping trial the use of augmented reality to conduct remote medical examinations.] ABC News. Available at: https://abc.net.au/news/regional-victoria-aged-care-trial-vr-remote-doctor-exams-visits/102356004 (Accessed: 31 August 2023)

[***]Truell, K. (2023) Benefits of Remote Patient Monitoring. Mozzaz. Available at: https://www.mozzaz.com/blog/benefits-of-remote-patient-monitoring-in-healthcare (Accessed: 31 August 2023).

[++]tao55 (2023) Elderly woman sit at home having online consultation. Available at: https://depositphotos.com/photo/elderly-woman-sit-home-having-online-consultation-doctor-382540744.html (Accessed: 31 August 2023)

[+]stocasso (2023) Young female doctor working at office desk and answering phone calls. Available at: https://depositphotos.com/photo/doctor-on-the-phone-165415654.html (Accessed: 31 August 2023)

[*]stivog (2023) Female hand with continuous glucose monitor showing glucose. Available at: https://depositphotos.com/photo/female-hand-continuous-glucose-monitor-showing-glucose-level-534471070.html (Accessed: 31 August 2023)

Section 2: Demographic Questions

Section 2. Demographic Questions

In this section, we are interested in collecting basic demographic information to better understand the diverse backgrounds of our participants. This will help us ensure that our findings are representative and meaningful. You'll be asked questions about aspects such as age, gender, occupation, and education.

In which country do you currently reside?

What is the highest level of education you have completed?

- ○ High school
- ○ College
- ○ Associate degree
- ○ Bachelor's degree
- ○ Master's degree
- ○ PhD
- ○ Other Graduate or Professional degree
- ○ Prefer not to say

Which of the following best describes your current employment status?

- ○ Employed full time
- ○ Employed part time
- ○ Self-employed
- ○ Unemployed and looking for work
- ○ Unemployed not looking for work
- ○ Retired
- ○ Student
- ○ Unable to work

- ○ Other
- ○ Prefer not to say

Section 2. Demographic Questions

Please specify your current employment status

In which field do you work?

What is your annual household income (in USD)?

- ○ Under $25, 000
- ○ $25, 000 to $49, 999
- ○ $50, 000 to $74, 9999
- ○ $75, 000 to $99, 999
- ○ $100, 000 to $149, 999
- ○ $150, 000 or more
- ○ Prefer not to say

What kind of internet access do you have at home? (Select all that apply)

- ☐ High-speed broadband
- ☐ DSL
- ☐ Fibre optic
- ☐ Mobile data
- ☐ Satellite
- ☐ Dial-up
- ☐ None

☐ Prefer not to say

Do you have children or relatives who are financially dependent on you?

○ Yes
○ No
○ Prefer not say

Do you own or have you owned a virtual reality device (e.g., a head-mounted display)?

○ Yes
○ No

What is your level of experience with virtual reality devices (e.g., using a head-mounted display)? Choose the option that best describes your experience.

○ I have no experience with VR devices and I have not observed VR devices being used
○ I have no experience with VR devices but I have seen others use VR
○ I have used a VR device once
○ I have used VR devices a few times
○ I have used VR devices many times
○ I have used VR devices on a monthly basis
○ I have used VR devices on a weekly basis
○ I have used VR devices on a daily basis

AFFINITY FOR TECHNOLOGY INTERACTION (ATI) SCALE based on Franke et al (2019)

In the following questionnaire, we will ask you about your interaction with technical systems in general. The term "technical systems" refers to apps and other software applications, as well as entire digital devices (e.g., mobile phone, computer, TV, car navigation).

Please indicate the degree to which you agree/disagree with the following statements.

	Select an option for each statement on the left					
	completely disagree	largely disagree	slightly disagree	slightly agree	largely agree	complet agree
I like to occupy myself in greater detail with technical systems.	○	○	○	○	○	○
I like testing the functions of new technical systems.	○	○	○	○	○	○
I predominantly deal with technical systems because I have to.	○	○	○	○	○	○
When I have a new technical system in front of me, I try it out intensively.	○	○	○	○	○	○
I enjoy spending time becoming acquainted with a new technical system.	○	○	○	○	○	○
It is enough for me that a technical system works; I don't care how or why.	○	○	○	○	○	○
I try to understand how a technical system exactly works.	○	○	○	○	○	○
It is enough for me to know the basic functions of a technical system.	○	○	○	○	○	○
I try to make full use of the capabilities of a technical system.	○	○	○	○	○	○

Section 3.

Section 3. Experience with In-Person Healthcare Services

In this section we are interested in your experiences with meeting physician(s) **in the same physical location**.

How often have you used in-person healthcare services in the past two (2) years on average (i.e., met with a physician)? Select the option that most closely describes your situation.

- ○ Weekly
- ○ Monthly
- ○ Once every two months
- ○ A few times a year
- ○ Once year
- ○ Less than once a year
- ○ Never

How comfortable are you with receiving a diagnosis in an in-person meeting with your doctor?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

How confident are you in the accuracy of a diagnosis received in an in-person meeting with your doctor?

Not at all confident	Slightly confident	Moderately confident	Very confident	Extremely confident
○	○	○	○	○

How comfortable are you with sharing your medical information in an in-person meeting with your doctor?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

How would you rate your overall satisfaction with the in-person healthcare services you have used?

Very dissatisfied	Somewhat dissatisfied	Neutral	Somewhat satisfied	Very satisfied
○	○	○	○	○

How would you rate your overall satisfaction with in-person healthcare in your country of residence?

Very dissatisfied	Somewhat dissatisfied	Neutral	Somewhat satisfied	Very satisfied
○	○	○	○	○

What challenges, issues, or concerns do you primarily face with accessing or using **in-person healthcare services**? If you have not experienced any, you can state it here.

Section 4. Experience with Telehealth or Telemedicine

Section 4. Experience with Telehealth or Telemedicine

Telehealth refers to the use of digital technologies to deliver medical care and health-related services remotely. In the next set of questions, we are primarily interested in your experiences with receiving clinical services remotely. It allows patients to seek a doctor's advice about non-emergency situations that do not require an in-office visit. This can include a variety of services, such as online consultations, remote patient monitoring, and digital transmission of medical images or data.

Telehealth comes in various forms and can take place through text, video conferencing, phone calls, or even virtual reality platforms, allowing patients to communicate with healthcare providers without the need for an in-person visit.

Have you ever used texting, video conferencing, phone calls or virtual reality platforms to access healthcare professionals and/or resources?

- ○ Yes
- ○ No

Since you answered YES to Experience with Telehealth:

Section 4. Experience with Telehealth or Telemedicine

Which telehealth platforms have you used? (Select all that apply)

- ☐ Maple
- ☐ Teladoc
- ☐ Doctor on Demand
- ☐ Amwell
- ☐ VSee
- ☐ Babylon
- ☐ Other
- ☐ I have not used a telehealth platform

Section 4. Experience with Telehealth or Telemedicine

Please enter the name(s) of the other telehealth platform(s) you have used

How often have you used telehealth services in the past two years on average? Select the option that most closely describes your situation

- ○ Weekly
- ○ Monthly

- ○ Once every two months
- ○ A few times a year
- ○ Once year
- ○ Less than once a year
- ○ Never

What types of telehealth services have you used? (Select all that apply)

- ☐ Video consultations
- ☐ Phone consultations
- ☐ Online messaging consultations
- ☐ Remote patient monitoring
- ☐ Mobile health apps
- ☐ Virtual reality consultations
- ☐ Other
- ☐ I have not used telehealth services.

Section 4. Experience with Telehealth or Telemedicine

Please enter the name(s) of the other telehealth service(s) you have used.

How comfortable are you with receiving a diagnosis through a telehealth platform?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

How confident are you in the accuracy of a diagnosis received through a telehealth platform?

Not at all confident	Slightly confident	Moderately confident	Very confident	Extremely confident
○	○	○	○	○

How comfortable are you with sharing your medical information over a telehealth platform?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

How important is it for you to establish a personal connection with your physician during a telehealth consultation?

Not at all important	Slightly important	Moderately important	Very important	Extremely important
○	○	○	○	○

To what extent have you been able to establish a personal connection with your physician during telehealth consultations?

Not at all	Slightly	Moderately	Very much	Extremely
○	○	○	○	○

How would you rate the importance of the privacy of your healthcare information?

Not important at all	Slightly important	Moderately important	Very important	Extremely important
○	○	○	○	○

I believe my privacy is adequately protected when using telehealth platforms.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

What challenges, issues, or concerns do you primarily face with accessing or using **telehealth services**? If you have not experienced any, you can state it here.

Since you answered NO to experience with telehealth

Section 4. Experience with Telehealth or Telemedicine

Since you have not used telehealth services before, please describe your primary reasons for not using them.

If you were to use a telehealth platform in the future, how comfortable would you be with receiving a diagnosis through a telehealth platform ?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

If you were to use a telehealth platform in the future, how confident would you be in the accuracy of a diagnosis received through a telehealth platform?

Not at all confident	Slightly confident	Moderately confident	Very confident	Extremely confident
○	○	○	○	○

If you were to use a telehealth platform in the future, how comfortable would you be with

sharing your medical information over a telehealth platform?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

If you were to use a telehealth platform in the future, how important would it be for you to establish a personal connection with your physician during a telehealth consultation?

Not at all important	Slightly important	Moderately important	Very important	Extremely important
○	○	○	○	○

What challenges, issues, or concerns do you anticipate with accessing or using **telehealth services**? If you are unable to name any, you can state it here.

Section 5: Virtual Reality Telehealth Platforms

Section 5. Virtual Reality Telehealth Platforms

Virtual reality (VR) technologies have advanced rapidly. Especially by using a VR headset (also known as a head-mounted display), it is now possible to create healthcare experiences that are more immersive and interactive than traditional telehealth platforms. Imagine a remote healthcare experience that transcends the boundaries of traditional video consultations, immersing you and your physician in a virtual environment that simulates a real-world clinical setting. These experiences can range from virtual consultations and remote monitoring to health education and therapy sessions.

In this section, we are interested in your **thoughts regarding the use of VR to provide healthcare services**.

For the next set of questions, we are asking you to imagine the following scenario as an example of what VR healthcare could look like:

You are wearing a VR headset (also called a head-mounted display) and using it to enter a virtual environment where you can meet with your doctor. Imagine being either at home, wearing your own VR headset, or using a VR telehealth installation at a public location (like a community center or library, that has a dedicated room for VR telehealth that people can use privately). You're in a virtual consultation room with your doctor. Instead of a flat screen, you see a 3D projection of your doctor, who can move around just like in a real room. You can choose the angle or side from which you view them, just as if you were in the same physical space. Even more, imagine that you can interact with the virtual environment. For instance, you could pick up a virtual prescription or even 'feel' objects in virtual space thanks to haptic technology.

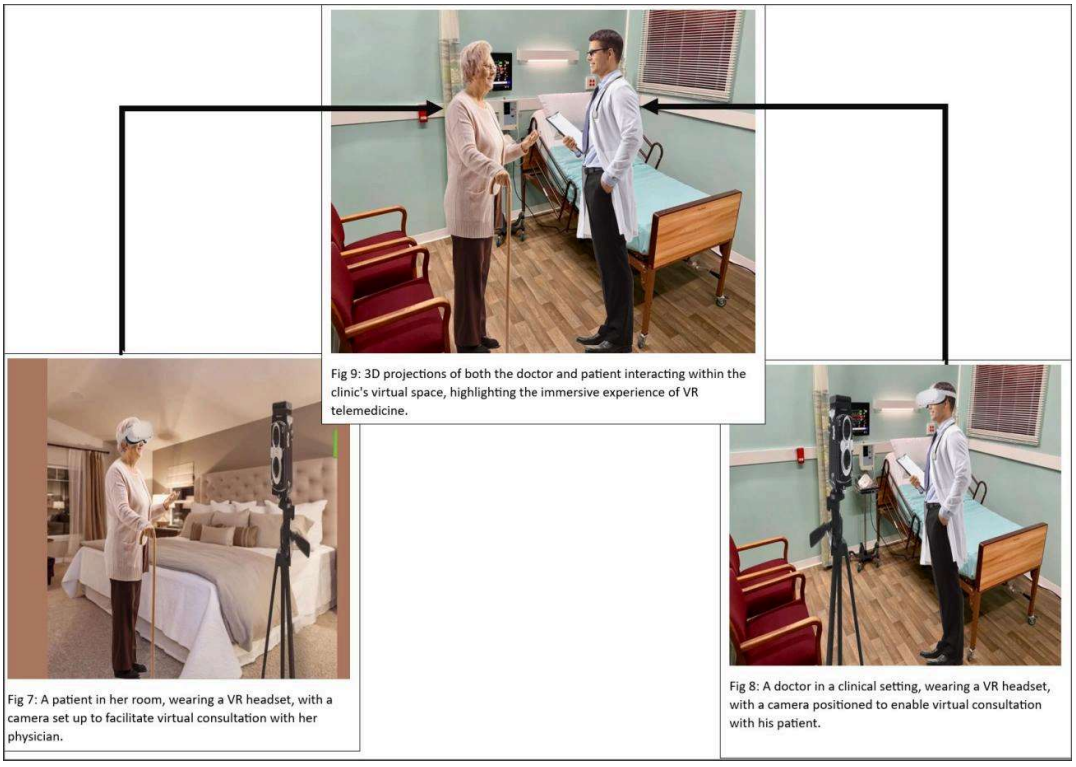


Fig 9: 3D projections of both the doctor and patient interacting within the clinic's virtual space, highlighting the immersive experience of VR telemedicine.

Fig 7: A patient in her room, wearing a VR headset, with a camera set up to facilitate virtual consultation with her physician.

Fig 8: A doctor in a clinical setting, wearing a VR headset, with a camera positioned to enable virtual consultation with his patient.

Accounting for the scenario above, we would like to know more about your perspectives on VR telehealth platforms.

Please click this to acknowledge that you have read the scenario above before moving on to the final set of questions.

○ I have read the above scenario, and I will keep it in mind when answering the next set of questions.

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How comfortable do you estimate you would be with using virtual reality for a medical consultation, if you used your own VR headset and could participate **in your own home**?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

How comfortable do you estimate you would be with using virtual reality for a medical consultation, if you used a virtual reality (VR) system in a **shared space like a local community center or library**?

NOTE: in this scenario, you would have a dedicated time slot to use the VR system in private.

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

Please respond to the following statements on a 1-5 scale, where 1 means 'strongly disagree' , 3 means “neither agree nor disagree', and 5 means 'strongly agree'.

	The options are on a 1-5 scale, where 1 means 'Strongly dis; means “neither agree nor disagree’, and 5 means 'Strongly			
	1	2	3	4
A virtual reality (VR) telehealth platform would improve my access to healthcare	○	○	○	○
A virtual reality (VR) telehealth platform could provide the same quality of care as in-person consultations	○	○	○	○
A virtual reality (VR) telehealth platform could provide the same quality of care as existing telehealth services (e.g., telephone, videoconferencing, text)	○	○	○	○

How comfortable would you be with sharing your medical information over a virtual reality (VR) telehealth platform?

Very uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Very comfortable
○	○	○	○	○

How important would it be for you to have a realistic representation of your physician in a virtual reality telehealth platform?

Not at all important	Slightly important	Moderately important	Very important	Extremely important
○	○	○	○	○

Imagine that you are meeting with your healthcare provider in a virtual reality (VR) setting. What features or capabilities would you expect to have in this VR environment to ensure that your consultation is satisfactory, productive, and supportive of your healthcare needs? If you are unable to name any, you can state it here.

What challenges, difficulties, or concerns do you anticipate you might face when accessing or using a **virtual reality telehealth platform**? If you do not anticipate any, you can state it here.

OPTIONAL: If you have any additional comments about the use of virtual reality (VR) for telehealth, healthcare in general, or this survey, please state them here.

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D.4 Survey Appreciation

Survey Appreciation

Project Title: Remote Patient Diagnosis in Virtual Reality

Student Investigator:

Mustapha Unubi Momoh
University of Waterloo, Canada
mmomoh@uwaterloo.ca

Faculty Supervisors:

Dr. Ville Mäkelä
University of Waterloo, Canada
ville.makela@uwaterloo.ca

Dr. Catherine Burns
University of Waterloo, Canada
c4burns@uwaterloo.ca

Thank you for participating in our survey on **Remote Patient Diagnosis in Virtual Reality.**

In this study, you completed an online survey focusing on your experiences and perceptions of telehealth services, including the use of virtual reality in healthcare. The purpose of the survey is to understand people's attitudes, concerns, and needs in the context of virtual healthcare. This knowledge will help us identify the gaps in current telehealth platforms and will inform us of the future design of virtual healthcare systems that are able to address users' expectations and concerns.

If you indicated in the survey that you would like a copy of the results, we will send out the results by email to the address you provided. You can contact any member of the research team listed above.

Your identity is considered completely confidential. This survey is anonymous in that we did not collect your name or any direct identifying information. All indirect identifying information (e.g., demographic data) will be kept in a separate file from the file that contains responses for other questions. Upon data collection, we randomly generated an ID for each participant. Participants will only be referenced using the ID (as the key) across the two files and in the write-up of our findings. Only those in our research team (as listed above) will have access to these records. The records will be stored on a cryptographically encrypted hard drive of a password-protected computer. We will keep our study records for a minimum of 7 years. After that, all records will be destroyed according to policy. All the

data will be summarized in our final publication, and no individual can be identified from these summarized results. Your identity will be completely confidential.

All data will be saved on the server temporarily (approximately one month) and will be downloaded to the investigator's computer. Upon downloading of data, we will erase the data saved on the server. Anonymity and confidentiality cannot be guaranteed during Internet transmission of data if insecure protocols are used. The download of data from the server to the investigator's computer will be carried out using secure protocols (SSL/SSH) to ensure confidentiality. Anonymity and confidentiality cannot be guaranteed for the time (approximately one month) during which data will be stored on the server before being downloaded to the investigator's computer. Although the server is password protected, management of the server is outside of the investigator's control.

This study is funded by the Mitacs Accelerate Proposal program, in partnership with Otekha Health Corporation.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #45343). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440.

We really appreciate your participation. Thank you for your time.