An Empathetic Approach to Human-Centric Requirements Engineering Using Virtual Reality

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***Abstract*—People who use software applications are different, including with significant cognitive differences such as neurodiversity. Capturing requirements for software that addresses these cognitive differences is hard for software engineers, especially when they do not have the same cognitive challenges. We wanted to explore the use of virtual reality (VR) in assisting software engineers to better understand the perspectives of the end user for the purpose of human-centric requirements elicitation, with a focus on users with attention-deficit/hyperactivity disorder (ADHD). We developed an immersive VR prototype using a virtual gym environment and fitness app as a concrete motivating example scenario. We carried out an evaluation of requirements identification for ADHD fitness app users by instructing participants to complete activities whilst under visual and auditory distractions similar to various documented symptoms of ADHD. Results indicated an increase in understanding the perspectives of someone with ADHD and an awareness of potential challenges with software not intentionally designed for ADHD users. Improved requirements for our target fitness app resulted that better take into account these diverse user needs.**

***Index Terms*—Virtual Reality, Human-Centric Requirements Engineering, Attention Deficit Hyperactivity Disorder**

I. Introduction

Software engineers are often very different from their end users, due to their differing human aspects of age, gender, culture, language proficiency, socio-economic status, technology proficiency, personality, cognitive style, emotions, physical and mental challenges, and many others [1], [2]. As a result, there are many issues related to the challenges and frustrations of software that fail to meet the needs of diverse end users, due to a lack of understanding and incorporation during software engineering of different end-user human aspects [1], primarily during Requirements Engineering (RE).

One particular user group that we were interested in better supporting is neuro-diverse users. Neuro-diversity describes people with developmental or neurological conditions. Neuro-diverse people experience the world around them in many different ways [3], with conditions that range from autism, dyslexia, dyscalculia and ADHD. In this research, we focus upon neuro-diverse users with ADHD. Attention-deficit/hyperactivity disorder (ADHD) is a behavioural disorder that affects many adults [4]. People with ADHD show a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning and development [5]. A study by Morris et al. [6] of a large software company (840 engineers) found a lack of representation of ADHD among software engineers. 92.98% of engineers they surveyed were neurotypical, while the remaining 7.02% were neuro-diverse. Such under-representation of neuro-diversity among software engineers suggests that it contributes to this gap in Human-Centric Requirements Engineering (HCRE).

Motivated by a 'virtual gym' environment constructed using immersive VR for capturing requirements for a new fitness app [7], we were interested in applying a similar approach to help software engineers improve requirements capture for ADHD users of the target app. We extended this virtual gym VR simulation to include a variety of documented impacts of ADHD, namely a range of sensory, auditory and visual distractions. In our VR environment these can be switched on and off or severity changed, as different people with ADHD experience different impacts and with different levels of severity. We then carried out a user study of our VR environment with software engineers and asked them to perform a range of requirements capture tasks for the target fitness app. Results show an increased understanding of potential ADHD impacts on the target fitness app users, an increased appreciation of the need to address these in the app, and improved requirements capture for the app to address ADHD end-user needs, compared to using the original VR environment.

The key contributions of this work include:

- we identified from the medical and HCI literature various impacts ADHD has on using mobile apps in different contexts for end users;
- we extended an immersive VR simulator targeted to supporting requirements capture to include the impact of end users with various ADHD symptoms;
- we carried out a user study of our VR simulation with software engineers to see how their understanding and appreciation of end users with ADHD has on app usage in a noisy, distracting environment.

II. Related Work

Davis defines empathy as the "reactions of one individual to the observed experiences of another" [11]. Empathy has been widely studied and investigated using VR. It has been used to help people empathise with certain groups of people such as refugees, homeless people, and people with impairments. Previous studies have shown VR's ability to create environments that reflect reality and give the illusion of being another person increases a user's sense of empathy [8], [9].

To achieve better empathy in RE, virtual reality approaches may provide support for requirements engineers in the elicitation phase, which more conventional methods lack – immersion and natural affordance for perception. The sense of presence and immersion in VR, often used interchangeably, describes the psychological sense of "being there" in a virtual environment. In accordance with immersion and sense of presence in relation to requirements elicitation, a study by Bhimani et al. [10] shows the effectiveness and usefulness of VR in the elicitation of requirements due the feeling of being fully immersed. Study participants showed positive responses to the use of VR in collecting requirements [10].

However, requirements elicitation becomes more complicated when it involves special needs users as they are impaired due to disabilities as the requirements or knowledge from these stakeholders are harder to convey or express. Another study by Bhimani et al. [11] investigated the use of a VR environment to enhance requirements elicitation by developing a generic environment for each disability to provide a sense of "presence" which can help in requirements elicitation.

Both the Dyer et. al. and Adefila et al [12], [13] studies demonstrate that VR immersion training is an effective teaching method to help medical and health professionals students develop empathy. The meta-analysis conducted on the most current research in the field of immersive virtual reality by Vilalba et. al. [14] further propounds this sentiment as it posits that perspective taking is more effective than providing data to feel empathy, and that virtual reality can increase engagement and empathy concern and perspective taking. However, they claim that there is much more evaluation needed and to date there is insufficient evidence to show that perspective-taking virtual reality (PTVR) is an effective method for developing empathy [14]. In light of this, much research on VR as a training resource is still required [13], especially relating to neurodiversity. Accordingly, our study aims to expand on this research by simulating the symptoms of ADHD aimed at improving software engineers' empathy and understanding.

III. Research Methodology

A. Research Questions (RQs)

We formulated the following key research questions (RQs):

RQ1. How does VR assist software engineers in better understanding different viewpoints, challenges and behaviours of diverse end users and stakeholders through an empathic approach? Our aim was to explore how VR can be used in HCRE using an empathetic approach.

RQ2. How does VR help in designing better solutions for end users with ADHD? Our aim was to see how the VR prototype helps software engineers in designing better solutions for end users with ADHD.

B. Interactive gym environment and app

We used a previously-developed highly realistic interactive virtual gym environment as the basis for our participants to do experiments [7]. An example of this in use is shown in Figure 1. In this study, we chose the gym as our virtual environment as many diverse people, including people with ADHD, go to the gym as their daily routine. Many of these people use applications on their phone for entertainment or for instructional or fitness tracking purposes while at the gym.

In our virtual gym environment, we have a tablet (Figure 1: 11) that contains a poorly designed fitness application and we aimed to show, from a first-person perspective, the challenges that people with ADHD had using the application in the gym. The fitness app contained five different lengthy worded instructions, an average of 40 words per instruction, on how to do each exercise, designed so that the participant had to pay full attention following the instructions to complete each exercise, whilst experiencing different levels of distractions happening around them (from no distractions, to only visual distractions, to only auditory distractions, and finally both visual and auditory distractions) which people with ADHD would find challenging [15].

C. System implementation

This virtual gym environment was created with Unity. We added our own modifications to simulate the experience of people living ADHD. Our modifications to this virtual gym environment included 3D avatars and posters, labelled as 8, 9 and 10 in Figure 1, and sound effect and animation for objects labelled by red and green arrows respectively.

We used the HTC Vive Pro 2 head mounted display to enable the participant to experience this virtual gym environment. This VR headset can track the head movements of the wearer and display corresponding views making the wearer really feel like they are in the room. The participants can use the controllers to grab objects inside the gym, move around and interact with the virtual mobile phone.

D. Symptom simulation

According to the Diagnostic and Statistical Manual of Mental Disorders [5], ADHD is classified into two categories: inattentiveness and hyperactivity and impulsivity. Inattentiveness can manifest differently in people but some of the symptoms included are: failing to give close attention to details or making careless mistakes, difficulty sustaining attention in tasks or play activities, does not seem to listen when spoken to directly, does not follow through on instructions, having difficulty organising tasks and activities, and being easily distracted by extraneous stimuli, and this is not because of defiance or lack of comprehension [5].

In this work, we chose to focus on simulating two inattentiveness symptoms: having difficulty sustaining attention in tasks (e.g., difficulty remaining focused during lectures, conversations, or lengthy reading), and being easily distracted (for older adolescents and adults, may include unrelated

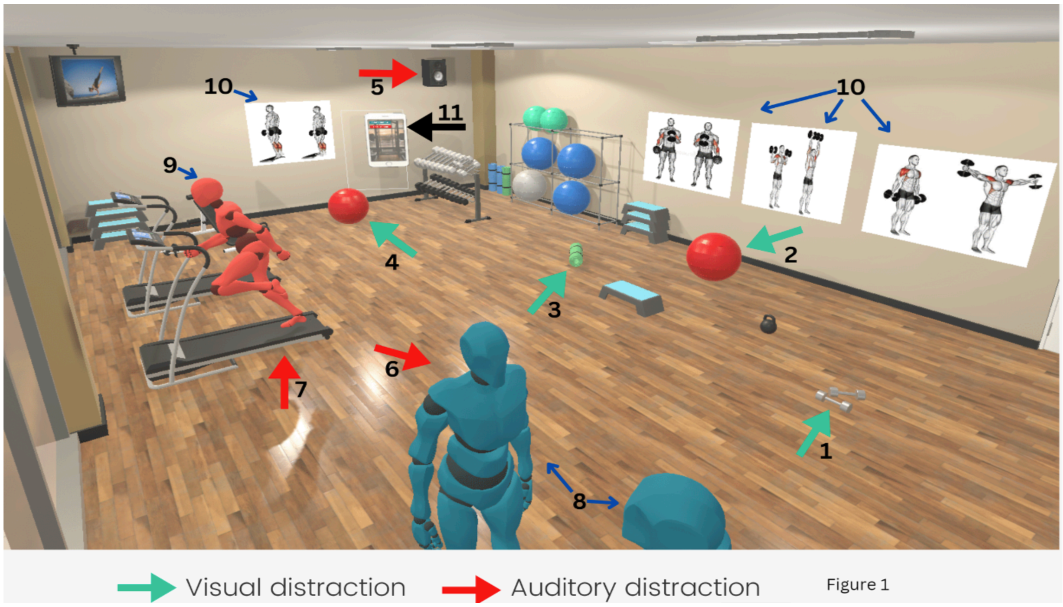

Fig. 1. Annotated screenshot of our Virtual Gym Environment.

thoughts). Such ADHD symptoms commonly manifest using apps, particularly in noisy and distracting situations [16], [17].

We simulated these symptoms by including several visual and auditory distractions in the virtual gym environment to distract the participant or draw the attention of the participant away from the task they were currently doing. Visual distractions include objects in the background moving or resizing, for example, a fitness ball in the corner of the room repeatedly getting bigger then smaller (Figure 1: 2,4). In addition, a dumbbell and an exercise mat would be rolling back and forth on the floor (Figure 1: 1,3). We simulated unrelated thoughts by playing a random video that covered a small portion in the field of view of the participant. The video would follow the participant's field of view wherever the participant looked when the visual distraction was activated. Auditory distractions included background noise such as equipment noise, chattering noise, and music gradually getting louder (Figure 1: 5,6,7).

E. Experiment Procedure

We conducted a study using our modified virtual gym environment with human participants to answer our research questions. Software Engineering, Information Technology and Computer Science students along with anyone working within those respective fields were invited to participate. All participants were required to respond to pre- and post-VR simulation questionnaires. Both questionnaires contained questions about basic demographic information and their understanding of ADHD in a general sense and within the context of technology. We received approval from our Human Subject Ethics Committee prior to conducting our user study (Monash University Human Subject Ethics Approval # 35586).

Our pre-VR simulation contained questions from Davis' Interpersonal Reactivity Index [18] as a measure of participants' sense of empathy and subscales of perspective taking, fantasy, empathic concern, and personal distress. Participants were also encouraged to describe their feelings and thought processes during the simulation. After the pre-simulation questionnaire, we provided information on using the VR controls and set up the VR headset for the participant. The participants were then asked to complete the following [19]:

- Navigate to the virtual tablet and selecting "Begin Exercise".
- Perform the first exercise with no distractions, completing 10 repetitions of the Calf Raise.
- Turn on the visual distraction only before performing the second exercise, completing 10 repetitions of the Cross-Body Hammer Curl.
- Turn on the audio distraction only before performing the third exercise, 10 repetitions of the Shoulder Press.
- Turn on both the visual and auditory distractions before performing the fourth exercise, completing 10 repetitions of the Dumbbell Scaption.
- Perform the fifth exercise with no distractions, performing ten repetitions of the Dumbbell Squat.

IV. Results

A. Participants

We recruited 13 participants for our study (12 males and 1 female). The participants' age ranged from 18 to 52 years (median of 22). All participants were recruited through peer-recommendation by students at our university, and most were current or previous students in IT, Computer Science or

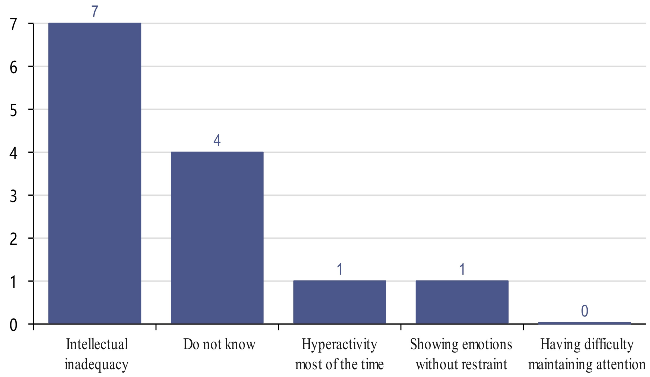

Fig. 2. "Which of the following is "not" a symptom of ADHD?" Pre-experiment questionnaire results on participant ADHD knowledge.

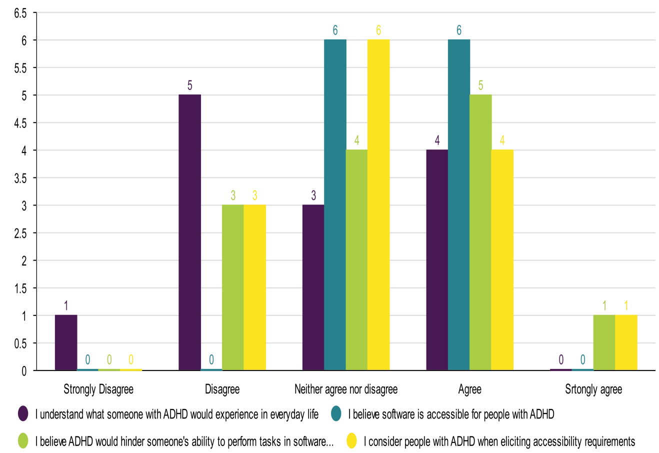

Fig. 3. Pre-experiment questionnaire results on participant understanding of ADHD (5 point Likert from "Strongly Agree" to "Strongly Disagree").

Software Engineering. In addition, a few participants were also joint enrolled in Arts, Business and Economics, or Science Degrees. Two out of 13 participants were working in the technology industry, both with a Bachelor's Degree of qualification in the field of Computer Science. Six out of 11 participants had previous intern or work experience, with half continuing to work in their current role. They ranged from frontend and backend engineers, quality assurance engineers and DevOps. 5 out of 13 participants knew someone clinically diagnosed with ADHD. No participants had been diagnosed with ADHD.

B. Pre-Experiment Questionnaire

Our pre-experiment questionnaire was made up of three sections: Demographic Details, IRI index, and ADHD knowledge. The first section began with 4 questions about the demographics of the participant. Participants had an additional 7 questions about their university course and any internship experience, while industry participants had an additional 6 questions. We applied the Interpersonal Reactivity Index (IRI) to measure dispositional empathy for every participant, which includes 28 questions on a 5-point Likert scale ranging from A to E as "Does not describe me well" to "Describes me very well", respectively. Following the IRI were questions that covered participant's knowledge and understanding of ADHD. Below we discuss the results shown in Figure 2 and Figure 3 on participant ADHD knowledge and understanding from our pre-experiment questionnaire.

C. Post-Experiment Questionnaire

For the second questionnaire, we designed eight questions for all participants after the VR simulation had been completed to compare their results from the pre-experiment questionnaire and identify whether the VR platform made a difference in their understanding of ADHD. The questions in the post-experiment questionnaire were a combination of qualitative and quantitative questions. The questions covered 1. Participant's knowledge of ADHD, 2. Likert scale rating level of agreement with statements based on the participants' ADHD understanding, 3. How participants would design the simulation workout application to be more suitable for people with ADHD, 4. How the VR prototype changed participants' understanding of ADHD, and 5. General comments on the study. Figures 4 and 5 show participant ADHD knowledge.

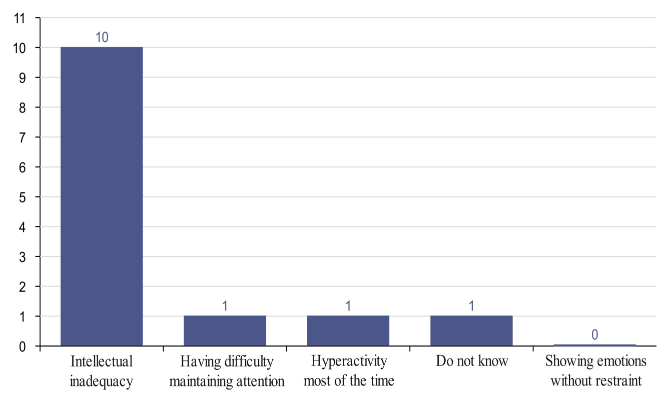

Fig. 4. "Which of the following is "not" a symptom of ADHD?" Post-experiment questionnaire result on participant ADHD knowledge

D. Positive Findings

Q3.1: *"I understand what someone with ADHD would experience in everyday life."*: 92.31% of participants Agreed, and 7.69% Strongly Agreed. From the pre-questionnaire in Figure 3, the number of Agreed participants significantly increased. 'Strongly Disagree', 'Neither Agree nor Disagree' and 'Disagree' both changed from the pre-questionnaire having 7.69%, 38.46% and 23.08% respectively, to all having a scoring of 0%. In the post questionnaire 100% of participants either 'Agreed' or 'Strongly Agreed' to this statement, whilst in the pre-questionnaire 30.77% 'Agreed'. This increase of positive agreement suggests the VR Experiment helped participants understand the experiences of ADHD people.

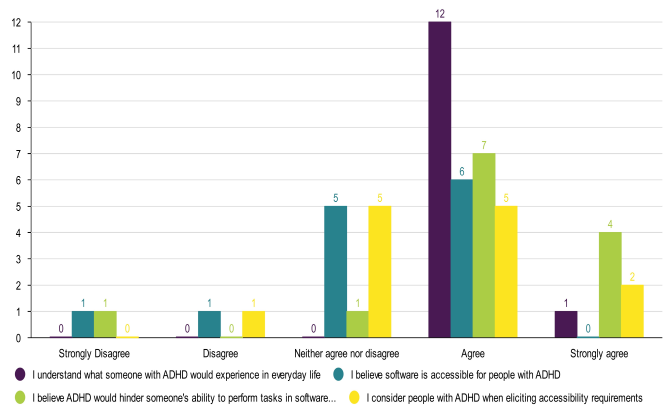

Fig. 5. Post-experiment questionnaire results on participant understanding of ADHD (5 point Likert from "Strongly Agree" to "Strongly Disagree").

Q3.2: *"I believe software is accessible for people with ADHD."*: The Post-Questionnaire (Figure 5) Results showed 46.15% of participants selected 'Agree', 38.46% selected 'Neither Agree nor Disagree'. 7.69% of participants selected 'Disagree' and 7.69% of participants selected 'Strongly Disagree'. There was a slight change in these results, where 15.38% scored either 'Strongly Disagree' or 'Disagree', whilst there was 0% of participants scoring 'Strongly Agree', and a decrease of 7.69% from 'Neither Agree nor Disagree' to a post-questionnaire score of 38.46%. 46.15% of participants in both the pre and post-questionnaire 'Agreed' to the statement. This suggests that the VR Experiment made participants realise software is not as accessible for people with ADHD as previously thought prior to the experiment. However, it is not as conclusive as the difference from pre-questionnaire results to post-questionnaire results is not substantial.

Q3.3: *"I believe ADHD would hinder someone's ability to perform tasks in software compared to someone without ADHD"*: Participants had varied responses in the pre-questionnaire (Figure 3) with 'Agree' as the highest (38.46%), 'Neither Agree nor Disagree' (30.77%), followed by 'Disagree' (23.08%) and lastly strongly agree (7.69%). Whilst 7.69% of participants 'Strongly Disagreed' in the post-questionnaire (Figure 5) to the statement, there was a significant increase in 'Agree' (53.85%) and 'Strongly Agree' (30.77%) and a decrease in 'Neither Agree nor Disagree' (7.69%), demonstrating that the VR Experiment made participants realise that ADHD does hinders one's ability to perform tasks in software applications.

E. Negative Findings

Q3.4: *"I consider people with ADHD when eliciting accessibility requirements."* Participants had varying results in the pre-questionnaire: 23.08% Disagree. The majority being 46.15% Neither Agree nor Disagreed and lastly 30.77% Agreed with the statement. In the post questionnaire, there was a decrease in the amount that disagreed, 7.69%. There were 38.46% in both Neither Agree nor Disagree and Agreed, and lastly there was 15.39% who Strongly Agreed. There was an increase in the mean participant score, from 3.08 in the pre-questionnaire to a 3.62 in the post-questionnaire. However, this statement can be interpreted in two ways and thus is ambiguous: A decrease in participant mean score can imply participants previously thought they did think about ADHD user requirements, but the experiment showed them they in fact did not. An increase in participant mean score can be interpreted as participants will now make more informed choices and think about ADHD requirements in the future. Thus, whilst the results show the mean increasing, the nature of the statement means this data is inconclusive and in the future clarification is needed.

Q4 *How would you design the in-simulation workout application to be more suitable for people with ADHD?* 38.46% of participants' feedback was regarding a potential improvement of the Tablet Exercise Application with ADHD people in mind. One respondent said *"The tablet application could have more visuals to closely guide the user."* and another participant said: *"I would potentially include things like timers or visual aids of the workouts... The app could incorporate music functionality too, which would again reduce users from being distracted by external audio sources."* These suggestions, as well as others, provided suggested improvements that would help ADHD users navigate and use the Exercise Tablet Application.

30.77% of the feedback was regarding improvements of the VR Experiment Prototype, not the Tablet Exercise Application, despite further clarification of the question. *"Bigger ipad"* and *"Music should be quieter / less distracting"* were examples of such suggestions. These participants did not directly answer the question, and provided inconclusive results.

15.38% of feedback were ambiguous improvements for the Tablet Exercise Application and did not seem to focus upon improvements for ADHD, an example being to *"Increase colour contrast in the UI."* Whilst there was feedback on the Exercise Tablet Application, the feedback did not seem to cater directly to ADHD end users.

7.69% of the feedback was not an improvement; rather, a comment on the distractions: *"Some pages were very text heavy which made it difficult to read. The distractions compounded this issue. e.g question 5 and the dumbbell one were much more difficult to understand."* Thus, these participants did not directly answer the question.

Lastly, 7.69% of participants said that the *"Tablet is fine."* Hence, these participants thought the tablet application was usable for ADHD users, and needed no further improvements. Thus, while some feedback given was positive (38.46%), other participants (53.85%) did not seem to properly understand the given question and gave feedback that was either ambiguous, feedback for the VR Experiment Prototype itself, or were simply comments and not improvements. The remaining 7.69% of participants thought there was no improvement needed. With the given positive feedback, it suggests the VR Experiment helped people understand how ADHD people interact with software, and that our participants are able to come up with some potential solutions to tackle ADHD problems.

Whilst there was clarification by the researchers about the question, a direct rewording of the question is needed so participants give proper feedback for the tablet application: e.g. *"How would you design the Tablet Exercise Application to be more suitable for people with ADHD?"*, better emphasising redesign of the tablet to lessen participants' confusion and give focus to it. Potentially adding a footnote: e.g. *"NOTE: this is NOT in relation to improvements of the VR Gym Experiment Prototype"* might also further clarify understandings.

Q5 *How has the VR prototype changed your understanding of people with ADHD?* This open-ended question can be split into two types of responses: 1. Participants commented it helped in their understanding of distractions, which ADHD people can't control. This suggests the VR Experiment helped them understand what are the potential symptoms of ADHD. We received comments like *"People with ADHD will get distracted easily and that's not something they can control"*, *"I didn't know things pop out of the room when you work out"*, and *"That they face a lot more variety and intensity of distractions than I realised"*.

2. Participants noted it helped them understand what it's like to have various ADHD symptoms. This indicates participants were immersed and in the perspective of ADHD people, through this empathetic approach of VR. It demonstrates how ADHD symptoms might manifest in their everyday lives and act as a hindrance. For example: *"It has helped me understand how people with ADHD view distractions, and their focus is impacted much more than people without ADHD. This would have a negative effect on the working habits of people with ADHD as they are much more easily distracted."* and *"It gives me an idea of how to be in their shoes"*. These illustrate how some of our participants were affected by the VR Experiment, and their understanding of people with ADHD.

This suggested an overall positive response to the VR Experiment. The responses all reflected upon the positive aspects of the VR Experiment giving them a better, and clearer understanding of ADHD people, and what they may experience in everyday life. The positive results suggest that the VR Experiment gave them newfound knowledge of the experiences of ADHD people through the empathetic approach of VR, through their perspective and also in understanding how ADHD symptoms might affect software usage.

F. Fitness Level

The fitness level of participants had some effect on the experiment procedure. Those who did frequent the gym commented in a similar manner e.g. *"I think you should take into account how often the person does workouts as the workouts shown in the game were all quite known to me. It wasn't hard to do"*. These participants excelled in the exercises and were less likely to be distracted, as the familiar motion and environment made them more comfortable performing the exercises. Those less familiar with the gym, or who did less frequent exercise, often took their time in performing the exercises or had incorrect forms. Thus, these differences can contribute to one's level of distraction, where one's comfort led to them being less focused on the ADHD symptoms and more focused on getting the exercise done. In addition, this familiarity can also affect the time spent within the VR simulation, as often participants with prior knowledge of the exercises had less time spent as they understood the task more quicker. Thus, they exited the immersion faster and potentially were not as immersed as someone who spent longer trying to get a better understanding of the exercises, thus also being exposed to the ADHD symptoms for longer.

G. Visual Distraction

It was observed that the video in the middle of the screen only distracted users to a certain extent. Participants simply looked to the side to read the instructions on the tablet or to look at the visual aid posters. They ignored this distraction together by looking past it. Another aspect of the visual distraction - the abnormal movement of objects - was highly distracting for some of the participants. Some of the comments made by participants during the movement of objects included: *"Haha why is the gym ball expanding?"*, *"Pretty creepy… the exercise ball"* and *"I just noticed that thing moving… the green mat"*. However, overall it was observed most participants still completed the exercise to completion without much trouble.

Thus, having a more relevant video, instead of a "3, 2, 1 countdown", can help aid in focusing more attention to this visual distraction, such as a person working out, or speakers blaring the music. Other improvements to this distraction from a participant included *"...instead have the objects move towards the person as their presence can feel much larger than it really is....* These improvements would help the Visual Distraction stand out, but also aid in the immersion. However, much more expertise is required around ADHD distractions to ensure the accuracy of the visual distraction is true to what people with ADHD experience.

H. Audio Distraction

Most, if not all participants, found the Audio Distraction to be distracting, albeit to varying degrees. It was observed that most participants completed the exercise with the Audio Distractions on with little added difficulty. Some commented on its ability to distract them: *"I find it so hard to read because of the music"*, and it was observed that one participant took a deep breath as though overwhelmed by both distractions. Thus current findings are inconclusive as to whether Audio Distractions fully distracted participants, or was a minor annoyance and distraction.

It was noted by one participant that they found the music to actually help in their exercises, keeping in rhythm with the beat, however when further questioned they were found to like listening to loud music, thus they were an outlier. This suggests participants may have different noise thresholds. What is considered too loud and distracting for one, may be sufficient enough to drown out other distractions for another.

I. Interpersonal Reactivity Index (IRI)

The Interpersonal Reactivity Index is a "multidimensional approach to individual differences in empathy" [18]. The IRI is used as a measurement of four separate aspects of empathy: social functioning, self-esteem, emotionality, and sensitivity to others, categorised into the subscales of Perspective Taking, Fantasy, Empathetic Concern and Personal Distress. With a total of 28 questions using 5-point (0-4) Likert scale ranging from “Does not describe me well” to “Describes me very well”, split equally into 7 questions per subscale. Thus a participant can individually score up to 28 points in a subscale, with the participants’ scores shown in the following Figure 6.

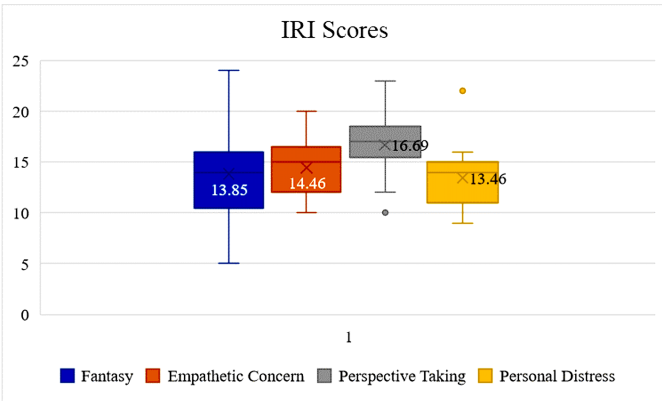

Fig. 6. Overall IRI scores of participants measuring levels of empathy.

In this experiment, the results for Fantasy are insignificant compared to the remaining subscales. Perspective Taking, Empathic Concern and Personal Distress are important in the analysis of this experiment. The Empathetic Scores range from 10 - 20 (Average = 14.46) and the Perspective Taking 10 - 23 (Average = 16.69), and a Personal Distress from 9 - 22 (Average = 13.46), as shown in Figure 6. Figure 6 shows a slightly above average mean score of 16.69 in the subscale of Perspective Taking, which describes the tendency to spontaneously adopt the psychological point of view of others [18]. Empathetic Concern describes ”other-oriented” feelings of sympathy and concern for unfortunate others. In our sample there was an average mean score of 14.46, and lastly, Personal Distress had an average mean score of 13.46, describing the ”self-oriented” feelings of personal anxiety and unease in tense interpersonal settings [18]”.

There were some outlier participants: 3 scored above the measured average for all subscales and 1 scored below the measured average for all subscales. However, overall the mean scores of the three main subscales of Perspective Taking, Empathic Concern and Personal Distress were approximately a middle score of 14, not being too far off as shown in Figure 6. Overall IRI scores were at the expected levels.

V. Discussion

A. Measuring Empathy after the Simulation

In this study, we intended to explore how VR can assist software engineers in better understanding different viewpoints, challenges and behaviours of diverse end users and stakeholders through an empathetic approach. Accordingly, the responses of the pre- and post-experiment questionnaire indicate that a greater proportion of participants recognise what someone with ADHD would experience in everyday life, and agree with the fact that ADHD would hinder someone’s ability to perform tasks in software, at the conclusion of the user study. It can thus be inferred that after experiencing various symptoms of ADHD in the VR simulation, participants got some experience of what the challenges of using software that is not intentionally designed for users with ADHD might be like. They also got some experience of the numerous ways in which this lack of consideration for ADHD symptoms limits software accessibility. This leads to the elicitation of empathy among software engineers that contributes to an increase in understanding of how software should be designed in order to better accommodate users belonging to this demographic. This is an advantage that using VR for RE possesses over traditional RE methods [20]. Requirements Engineers have the ability to develop an intrinsic perception of the ADHD experience, instead of solely relying on external accounts from questionnaires and interviews that are prevalent in traditional RE methods. As such, the responses of the pre and post-questionnaire have reflected positively on the capability of this VR simulation to serve as an initial measure for HCRE using VR technology, as it is able to elicit empathy among software engineers for people with ADHD.

B. Observations

In addition to the pre- and post-questionnaire, the articulations of participants’ thoughts that we recorded using the “Think-Aloud Technique” also demonstrate that empathy was elicited during the experiment. As reported by a participant during the user testing session, the VR simulation new level of empathy after attempting to use the workout app to complete a set of exercises, whilst being subject to various visual and auditory distractions. Other participants shared similar experiences during the simulation, claiming that the distractions made using the workout app to complete the exercises more difficult. The simulation can help to understand what ADHD might feel like, and the challenges that people with ADHD face not only when using software, but when performing everyday tasks, they get distracted by everything around them and it’s hard to stay focused.

C. Threats to Validity

There are numerous factors that potentially threaten the validity of the results obtained during this study. Participants are asked to perform different exercises for each combination of visual and auditory distractions (visual distraction only, audio distraction only, and both audio and visual distractions) to ascertain which combination made it more difficult to complete a certain exercise. This could have caused the inherent difficulty of each exercise to affect which combination of distractions proved to be the most distracting. The relatively small sample size of 13 users along with the disproportionate number of 12 male participants and 1 female participant, and the lack of an ADHD expert to verify the correctness of the visual and auditory distractions based on ADHD symptoms could have also skewed the results. In addition, we found that the wording of Q3.4 in our pre-questionnaire was too vague, resulting in an ambiguous increase in participant mean scores in the pre- and post-experiment questionnaire. Similarly, we found that the wording of Q4 in the post-questionnaire produced some invalid short-form responses.

D. Limitations and Future Research

In this study, we did not have an expert on ADHD in our team. Moreover, by not having anyone diagnosed with ADHD in our research team, we were limited to using a few ADHD symptoms that were well documented in medical and HCI literature, and only replicating symptoms based on past research [15], [21], [22]. Some ADHD symptoms we considered difficult to replicate or could not be replicated accurately in our VR environment without experiencing them firsthand or interviewing someone who experienced them directly. Performing exercises within a virtual gym environment was limited due to mobility issues, the headset's cords hindering the ability to move freely, and the lack of weight in the VR controllers, breaking the participant's sense of immersion. This may also have impacted the validity of some of our findings.

We plan to improve the effectiveness of our VR environment by reviewing our simulation of ADHD symptoms with experts on ADHD and with people who are clinically diagnosed with ADHD, to ensure the symptoms represented in the VR experiment are accurate. As this VR experiment was designed using secondary research, adding more simulated ADHD symptoms and assessing the accuracy of these simulated symptoms of ADHD distractions would help in better understanding ADHD users. Thus, this would help software engineers elicit user requirements that are more beneficial for their ADHD-impacted end users. Additionally, we would like to experiment with different virtual environments which involve an everyday use case not specifically targeted toward gym users. Scenarios such as classroom environment with a computer or portable device, or similar everyday activities we plan to explore. These applications would be more familiar to a larger proportion of software engineers, and thus they would be better immersed within the VR environment. We also hope to explore further research on neuro-diverse conditions that could potentially impact users' ability to use software e.g. autism and dyslexia.

VI. Summary

Requirements elicitation is vital in ensuring the results and success of software applications. Conventional requirements elicitation often faces challenges in having requirements engineers sufficiently understand and empathise with different groups of users, especially those with impairments they do not experience. Inspired by the wide success of VR in other domains, our research has demonstrated how the utilisation of VR as an empathetic approach to human-centric requirements engineering may help software engineers design better solutions for diverse end users.

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