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Improving Engagement of Stroke Survivors Using Desktop Virtual Reality-Based Serious Games for Upper Limb Rehabilitation: A Multiple Case Study

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ABSTRACT Engagement with upper limb rehabilitation post-stroke can improve rehabilitation outcomes. Virtual Reality can be used to make rehabilitation more engaging. In this paper, we propose a multiple case study to determine: (1) whether game design principles (identified in an earlier study as being likely to engage) actually do engage, in practice, a sample of stroke survivors with a Desktop Virtual Reality-based Serious Game designed for upper limb rehabilitation; and (2) what game design factors support the existence of these principles in the game. In this study, we considered 15 principles: *awareness*, *feedback*, *interactivity*, *flow*, *challenge*, *attention*, *interest*, *involvement*, *psychological absorption*, *motivation*, *effort*, *clear instructions*, *usability*, *purpose*, and a *first-person view*. Four stroke survivors used, for a period of 12 weeks, a Virtual Reality-based upper limb rehabilitation system called the Neuromender Rehabilitation System. The stroke survivors were then asked how well each of the 15 principles was supported by the Neuromender Rehabilitation System and how much they felt each principle supported their engagement with the system. All the 15 tested principles had good or reasonable support from the participants as being engaging. Use of feedback was emphasised as an important design factor for supporting the design principles, but there was otherwise little agreement in important design factors among the participants. This indicates that more personalised experiences may be necessary for optimised engagement. The insight gained can be used to inform the design of a larger scale statistical study into what engages stroke survivors with Desktop Virtual Reality-based upper limb rehabilitation.

INDEX TERMS Game design, rehabilitation, serious games, stroke, upper-limb, virtual reality.

I. INTRODUCTION

Upper limb movement is crucial in maintaining an independent lifestyle, being important for activities like washing, dressing, and performing other tasks that require two hands. Despite this, much less emphasis is given to upper limb rehabilitation post-stroke [1]. Previous studies have demonstrated the benefits of using Virtual Reality (VR) for different types of stroke rehabilitation, including lower [2] and upper limb rehabilitation [2]–[4], along with upper limb motor assessment [5]. Other rehabilitation areas which benefit from the use of VR include balance [6] and gait training [7], physical rehabilitation [8], and cognitive rehabilitation [9]. VR-based rehabilitation can also be used by stroke survivors in their homes [10], improving regular accessibility to rehabilitation at low cost.

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An important factor in the success of post-stroke rehabilitation, including upper limb rehabilitation, is engagement. In fact, engagement influences the speed of recovery and outcomes of rehabilitation [11]. Specifically, a study involving 10 stroke survivors has demonstrated a positive correlation between engagement and upper limb rehabilitation outcomes [12].

VR [13]–[16] and Serious Games [17], [18], which form the basis of VR rehabilitation, have been used as a method of engaging stroke survivors with rehabilitation. Despite this, Serious Games are not always successful at engaging users, particularly when compared to games that have the singular aim to entertain — non-Serious Games [19]. Given their use in non-Serious Games, design principles may also be used to improve the engagement level of Serious Games. However, game design principles that engage healthy individuals with Serious Games cannot be assumed to engage stroke survivors due to the cognitive impairment post-stroke [20].

In this paper, we undertake and discuss the outcomes of an in-depth multiple case study, which examines 15 game design principles that have good support from a sample of four stroke survivors as being engaging with VR-based upper limb rehabilitation. This paper also discusses game design factors that support the existence of these game design principles in an example desktop VR-based upper limb rehabilitation system, from the perspective of the four stroke survivor participants.

The main contribution of this study is that it provides an insight into: (1) what game design principles engage the participants of this multiple case study, and (2) what game design factors support these game design principles from the participants' point of view. This insight can be used to inform the design of a larger scale statistical study into what engages stroke survivors with desktop VR-based Serious Games designed for upper limb rehabilitation post-stroke.

This study focuses on what engages stroke survivors with VR-based upper limb rehabilitation in terms of game design principles and game design factors. The benefits from such rehabilitation can be evaluated in a separate study once the game design principles and game design factors are established.

II. RELATED WORK

A. VIRTUAL REALITY

Henderson *et al.* [15] define Virtual Reality as: ''a computer-based, interactive, multisensory simulation environment that occurs in real-time. VR presents users with opportunities to engage in activities within environments that appear, to various extents, similar to real-world objects and events.''

The two classifications of gamified VR are [21]:

1) Immersive VR that presents the game world using a head-mounted display (HMD) [22]; and
2) Non-Immersive (including Desktop) VR, which is: ''a subset of traditional virtual reality systems. Instead of a head-mounted display, a large computer monitor or projection system is used to present the virtual world [23].''

VR is used in many practical settings, including education and training (such as for schooling [24], business [25], aviation [26], military [27], and astronaut training [28]), and mining [29]. In health, VR is used for rehabilitation of disabilities like Parkinson's disease [30], acquired brain injury [31], and stroke [13]–[16]). In general, non-immersive Desktop VR is preferable over immersive ones when used in rehabilitation, because HMDs may cause cybersickness [22], [32]. Approaches for physical rehabilitation using non-immersive gamified VR include complete off-the-shelf products like Xbox 360 motion games or Nintendo Wii Fit games [33], plus input methods for VR rehabilitation programs like the Kinect motion sensor [34], electromagnetic motion trackers [34], handheld remote controllers [34] or tablets [34]. One example of fully immersive VR-based upper limb rehabilitation is called TRAVEE [35], [36]. The system uses HMDs, brain-computer interfaces, robotics, electrical stimulation, electromyography, haptics, multimodal feedback and visual augmentation-based feedback as part of the rehabilitation [35], [36].

B. EFFECTIVENESS OF VR-BASED REHABILITATION

Viñas-Diz and Sobrido-Prieto [3]'s systematic review supports VR-based upper limb rehabilitation being effective. However, the authors say that more research into what types of VR are most beneficial, their effects on the brain, the optimal intensity of the therapy, and how long the training remains is needed. Lee *et al.* [2] determined that for lower and upper limb movement, VR is beneficial for post-stroke rehabilitation. Also, Aminov *et al.* [9] found that VR can positively impact activity level outcomes and body structure and function in stroke survivors.

Howard [8] found that VR-based physical rehabilitation to be of greater effectiveness than conventional physical rehabilitation, while Laver *et al.* [37] found it to be of no greater effectiveness, specifically in upper limb rehabilitation. While VR-based therapy may or may not be more effective than conventional therapy, its engaging nature is likely to have its benefits, given the importance of engagement in rehabilitation.

C. IMPROVING ENGAGEMENT WITH VR-BASED REHABILITATION

The problem remains that Serious Games, i.e., games designed to engage users with activities that have specific intended outcomes [38], which form the basis of VR-based rehabilitation, do not always engage users [19]. Thus, determining what specifically engages stroke survivors with Serious Games and VR designed for rehabilitation, will significantly improve the outcome of VR-based rehabilitation systems.

In a previous study [1], [21], [39] game design principles were evaluated to identify which are or would be important for engaging stroke survivors with Desktop VR-based Serious Games designed for upper limb rehabilitation. The study took the form of a user experience case study. Six stroke

TABLE 1. Game design principles and definitions used.

Principle	Definition
Awareness	The Oxford Dictionary of English [42] defines awareness as "knowledge or perception of a situation."
Feedback	Lohse et al.[43] defined feedback as: "any information about how a skill was performed and/or the effectiveness with which the skill was performed."
Interactivity	The Oxford Dictionary of English [42] defines interactivity as: "the ability of a computer to respond to a user's input." In this case, this means the ability of Neuromender Upper Limb to respond to a variety of your input.
Flow	Flow is caused by a balance between player challenge and skill, avoiding player frustration and boredom [44]. This means you will feel the game is not easy enough for you to become bored and not hard enough to cause you to become frustrated.
Challenge	The Oxford Dictionary of English [42] defines a challenge as: "a task or situation that tests someone's abilities."
Attention	The Oxford Dictionary of English [42] defines attention as: "notice taken of someone or something; the regarding of someone or something as interesting or important."
Interest	The Oxford Dictionary of English [42] defines interest as: "excite the curiosity or attention of (someone)."
Involvement	The Oxford Dictionary of English [42] defines involvement as "be or become occupied or engrossed in something."
Psychological Absorption	Psychological absorption means complete engagement with an experience that is currently occurring [45].
Motivation	The Oxford Dictionary of English [42] defines to motivate as: "provide (someone) with a reason for doing something; cause (someone) to have interest in or enthusiasm for something."
Effort	The Oxford Dictionary of English [42] defines effort as: "a vigorous or determined attempt."
Clear Instructions	Clear instructions are instructions that make it clear how to use Neuromender Upper Limb in an unambiguous and easy to understand manner.
Usability	The Oxford Dictionary of English [42] defines usability as: "the degree to which something is able or fit to be used."
Purpose	The Oxford Dictionary of English [42] defines purpose as: "the reason for which something is done or created or for which something exists." The three questions below refer to the purpose you feel Neuromender Upper Limb may or may not have.
First-Person View	A first-person view is where the player (you) sees the game world (the Neuromender Upper Limb environment) through the eyes of the controlled character (in this case: the Wingman).

survivors used the Neuromender Rehabilitation System (NRS), a Desktop VR-based Serious Game [1], [39], [40], in their homes for 12 weeks. Upon using the NRS, for each principle, each participant was asked: "How important do you feel [the principle] is or would be for you to become engaged with Neuromender Upper Limb?" They were able to answer on a Likert scale with answers derived from Brown [41]: "To a Great Extent / Somewhat / Very Little / Not at All." The descriptions of the answers were [1]:

- *To a Great Extent* has an associated score of 4 and means the participant feels the principle is or would be important to a great extent for them to be engaged.
- *Somewhat* has an associated score of 3 and means the participant feels the principle is or would be somewhat important for them to be engaged.
- *Very Little* means participant feels the principle is or would be of very little importance for them to be engaged.
- *Not at All* means the participant feels the principle is not at all important for them to become engaged.

Each game design principle was given a score based on the sum of the associated score of each participant's answer. The game design principles' overall likely importance for engaging stroke survivors with the NRS were ranked into groups. 15 principles (defined in Table 1 and as given in the previous study [1], [21]) from the highest two groups of principles were determined to likely have the highest importance. These principles were:

1) Determined to warrant the focus of further investigation: *awareness*, *feedback*, *interactivity*, *flow*, and *challenge*.
2) Important to a great extent: *attention*, *interest*, *involvement*, *psychological absorption*, *motivation*, *effort*, *clear instructions*, *usability*, *purpose*, and a *first-person view*.

Table 1 provides the definitions of these 15 game design principles that were given to the study participants (as given in the previous study [1], [21]).

Given that these game design principles were determined to be likely to engage, the next logical stage was to validate and confirm this hypothesis in practice, which is the focus of this paper. The crucial difference between this study and the previous study [1], [21] is this: the previous study identified what game design principles were *likely* to engage that study's participants; this study determined whether the 15 game design principles identified as likely to engage in the previous study do engage the stroke survivor participants of this study (three returning from the previous study), *in practice*. In this study, the findings of the previous study were tested by intervention where changes were made to the rehabilitation system. The changes were guided by the findings in the previous study. The changes are discussed in section III-D. The outcome of this intervention is the subject of this paper.

III. METHODOLOGY

The research had been approved by Sir Charles Gairdner Hospital: Human Research Ethics Committee (HREC) #2015-114 and Murdoch University Ethics: #2016/088. Written consent was obtained from all the participants.

A. MULTIPLE CASE STUDY APPROACH

Each stroke is different, as they are of different types (e.g., caused by a clot, being ischaemic or by a bleed, being haemorrhagic), occur in different parts of the brain, and are of

TABLE 2. Participant demographics.

#	Gender	Age	Side-Affected	Stroke Occurred (Time Before Study)
1 (1)	Male	73	Left	8 years, 3 months
2 (5)	Male	62	Right	2 years, 7 months
3 (6)	Male	72	Right	2 years, 1 month
4 (N/A)	Female	82	Left	12 years, 2 months

different severity. A stroke survivor may have suffered from more than one stroke, each with potentially different effects. Stroke survivors also differ in age at the time of their stroke and, during the research, overall health and lifestyle. These factors make each stroke survivor's case different. Thus, this research used a multiple case study approach. Case studies are used to study a single instance of something in-depth [46]. They allows an in-depth understanding of a case and the complex processes and relationships of which it consists to be obtained [46]. A multiple case study is when more than one case study is performed, and then the different case studies are compared for similarities and differences [46]. Any similar findings from multiple cases can be used to solidify their conclusions, with differences also providing useful information [46]. In terms of sample size, we followed the advice advocated by Schoch [47] for multiple-case studies: ''having three to four distinct cases for comparison is probably the most cases that one can realistically handle.'' Thus, four stroke survivors participated in this study, which was descriptive, since the aim was to analyse whether the design changes made to the system and identified principles thought to actually engage, do engage.

B. PARTICIPANT DEMOGRAPHICS

The study utilised purposive sampling, which is when an expert judges whether cases should be selected or a researcher selects cases based on their usefulness for a purpose [48]. In this study, the main supervising neurologist selected cases based on whether a stroke survivor's disability could meaningfully be attributed to stroke. For example, one individual was determined to be unsuitable for this study because she previously had a brain tumour, and therefore her disability could not firmly be attributed to her stroke.

Four stroke survivors participated in this study, three returning from the previous study. Their demographics are outlined in Table 2. The participant IDs in the previous study are included in brackets (participant 4 did not participate in the previous study).

All participants suffered from an ischaemic stroke (caused by a clot, in the case of participant 4, multiple). According to the supervising neurologist — all the participants had preserved their cognition, their capacity to give consent and had no dementia. All had previously used computers and owned mobile phones. Participant 2 had previously been employed as a senior IT and business consultant. Within Australia in 2020, the worst affected age groups for stroke survivors were males aged between 70 and 74 and women aged 85 and over [49]. Participants 1 and 3 fall within the worst affected group of their gender, while Participant 4 is close in age to the worst affected group for females (but still within the second-largest group affected for women, 80 to 84, overall). While Participant 2 is younger than the others, there are still about 22,200 males in the 60 to 64 age bracket who are stroke survivors in Australia. Thus, the participant's ages are relatively common and representative of stroke survivors. The reason for the larger timespan after a stroke is because the participants needed prior rehabilitation (including speech and cognitive rehabilitation to be able to understand how to use the VR system) to reach a level where they can use this rehabilitation.

C. NRS UPPER LIMB REHABILITATION MODULE

Following the previous study [1], [21], a Desktop VR-based Serious Game, called the Neuromender Rehabilitation System (NRS) [1], [21], [39], [40], was used as the intervention tool. The NRS is comprised of six modules to help with post-stroke rehabilitation. It is designed for use by stroke survivors in their own homes, with supervising clinicians remotely monitoring and controlling the rehabilitation [1], [21], [39]. A desktop VR setup with a desktop PC tower running Windows 10, a regular widescreen computer monitor, keyboard, mouse and Kinect sensor was used.

Similar to [1], [21], this study used the NRS rehabilitation module 3 for upper limb rehabilitation: ''The Wingman'' (see Fig. 1), which focuses on arm raising and control. In the game, a stroke survivor angles their arm into the position that aims the Wingman towards the centre of on-screen rings. Their arm movement is captured by the Kinect, which in turn moves the Wingman in an up or downward direction. The repetitive moment aims to increase the angle of movement that the arm can reach.

The reason for focussing on arm raising and controlling was because the supervising neurologists made it clear that stroke survivors must take rehabilitation in stages. Stroke survivors should gradually work on regaining more complex movement in the affected arm, and this should start with arm raising and controlling. Once they are able to raise and control the arm, they can proceed to other activities that can also be enabled on the NRS — like arm extension and then grasping. For this reason, only arm raising and controlling were offered as an activity by the supervising neurologists. An advantage of this approach is that it enables us to study design principles and factors at every stage of the rehabilitation process, starting from this stage to more complicated movements of the arm. We do not know if the importance of the various principles and factors shift as more neuromuscular coordination is achieved over a period of time.

Stroke survivors can choose three different courses (beach, forest, or temple) to play each game, each with different visuals and ring counts. Stroke survivors are also given the option of three speeds: slow (duration: 240 seconds), medium (duration: 180 seconds), and fast (duration: 120 seconds).

(a) (b)

FIGURE 1. The NRS rehabilitation system — Pre-Changes (a), Post-Changes (b).

The shorter the duration, the quicker each ring appears. The supervising neurologists stated during development that it would be best to give the users the choice of speed so that they could choose the one with which they felt comfortable while playing the game (which could be affected by their mood, energy levels or any number of other life-related factors). The focus of the rehabilitation was arm control, not speed of movement through the game.

The stroke survivors start with an arm angle threshold of 30 degrees. The angle threshold defines the angle at which the arm must be to score a full 10 points. Each degree off from the threshold results in 1 point being lost until no points are given. The score is calculated based on the arm angle the moment the player enters the centre of the ring. Therefore, to achieve a full score, the user has to have the black line (representing the player's arm angle) centred on the blue bar (representing the arm angle threshold) when the user enters the yellow circle in the ring's centre. If the black line is centred on the blue bar, the user will hit the centre of the yellow circle. The aim of this was to demonstrate the extent to which a player has mindful control of the arm in that they can hold it steady at a required angle. If a player scores well and is happy to do so, this threshold can be made higher so that the stroke survivor can practice moving their arm through a higher angular range. The intention of always setting the angle threshold to 30 degrees for all participants was, it was the lowest possible setting (as there will not be a sufficient gap between the threshold and reset angle for any lower angle) and so a user could have their threshold raised (in response to good scores), to the highest point to which they felt comfortable. The observation was also made that the stroke survivor's performance would differ from day-to-day because of their condition on a specific day. A stroke survivor would become frustrated if they could not reach the same angle as they did the day before because of factors related to their condition. The 30-degree starting angle also worked for each participant during the initial calibration of their systems. All participants were involved during calibration.

D. SYSTEM CHANGES

Design changes for the NRS were suggested by the participants of the previous study [21] to better support the principles. The NRS' core gameplay remained unchanged following the changes to make the system more engaging. However, the interface and feedback have been overhauled to better support the 15 important design principles.

Improvements to the NRS fall into two groups: changes to the Neuromender game itself and the inclusion of weekly summaries to replace the information given by the Neuromender website. These changes were made based on the feedback on how the system could better engage, given by the stroke survivors. These changes were intended to make the game better support the principles that were determined to warrant the focus of further investigation (*awareness*, *feedback*, *interactivity*, *flow*, and *challenge*) and those also of importance to a great extent (*attention*, *interest*, *involvement*, *psychological absorption*, *motivation*, *effort*, *clear instructions*, *usability*, *purpose*, and a *first-person view*). The multiple case study evaluates whether the changes do engage in reality. Fig. 1 illustrates the differences between the old and new versions of the serious game. An overview of the specific design changes made and which game design principles they were intended to support (based on feedback from participants in the previous study [21]) is shown in Table 3. Each of the design changes made are listed in the second header row, with the game design principles listed in the first column. If a design change was intended to impact a specific game design principle, then the cell where the relevant row and column intersect has an "×" placed within it. Specifics of each of the design changes are discussed following Table 3. Variety and "Next Ring Distance" are discussed below but are not described in Table 3 because they were not implemented as discussed below.

1) ARM ANGLE GAUGE

The player's arm angle (which the player can change by raising or lowering their arm — represented by the black bar) in relation to the angle threshold (represented by the blue bar) is displayed on the arm angle gauge at the bottom of the screen (the yellow quarter circle).

To improve awareness of how a stroke survivor is performing in the game, the black bar showing one's arm angle on the angle gauge has been made thinner (making it feel more like the rudder of a ship) and the blue bar showing

TABLE 3. NRS design changes and how they were intended to support the game design principles.

	NRS Game Changes				Weekly Summaries	
Principle	Arm Angle Gauge	First-Person View	Bullseye	In-Game Feedback	Graphs	Feedback
Awareness	×	×	×	×	×	×
Feedback	×		×	×	×	×
Interactivity	×		×			
Flow	×		×	×	×	×
Challenge	×			×	×	×
Attention	×	×	×	×	×	×
Interest	×	×		×	×	×
Involvement	×	×		×	×	×
Psychological Absorption		×		×	×	×
Motivation	×			×	×	×
Effort	×			×	×	×
Clear Instructions	×		×	×	×	×
Usability	×	×	×	×	×	×
Purpose	×			×	×	×
First-Person View		×				

the angle threshold has been given a gradient. This means that a stroke survivor can angle their arm, so the black bar slots into the white section in the middle of the blue bar, making it easier to see whether their arm is aligned with the threshold. The blue bar turns green when the stroke survivor's arm is aligned with the angle threshold, so once they have angled their arm correctly, they are given feedback that it is in the right position (shown in Fig. 1b). This information was intended to help the user feel more *awareness* and, by giving them more control, increases the feeling of *interactivity*. The gauge was intended to also improve the game's support of *clear instructions* and *usability*. With the player being more aware of what they have to do to perform in the game, the intention was to support *flow*, *challenge*, and *purpose*. With the required position of the arm being clearer, the intent was to support player *attention*, *interest*, and *involvement*, as well as their motivation and desire to put in the *effort*.

2) FIRST-PERSON VIEW

During the previous study, the participants overwhelmingly indicated that they would prefer a first-person view over the third-person view used initially, which showed the Wingman. Participants 4 and 6 from that study specifically indicated that they find that the Wingman blocks the view of the ring while they are trying to hit it. The intention was that without the Wingman blocking the player's view, this would increase their *awareness*, *attention*, and *interest*. Since they will feel like they are the Wingman (since they will be looking through his eyes), the intention was that they would feel more *involved* and *psychologically absorbed*. Not having the Wingman block the player view was also intended to improve the usability of the NRS.

3) BULLSEYE

While not necessarily as helpful for determining the correct positioning of the arm as the gauge, based on stroke survivor feedback — bullseyes have been added as a visual aid to mark the centre of the ring. The improved visual information was intended to increase their *awareness*, make them pay more *attention*, decrease frustration, increase *flow*, give them a greater feeling of *interactivity* from feeling like they are the Wingman and allow the game to give better visual *feedback*. The improved visual *feedback* was also intended to serve as *clearer instructions* and improve *usability*.

4) IN-GAME FEEDBACK

The on-screen information was simplified to ensure users are not overloaded with visual information. The on-screen messages giving positive praise have been replaced by a different number of chimes when going through a ring. If they received the full 10 points from the ring — three chimes are played; greater than or equal to five — two chimes are played; less than five, and then only a single chime is played. The ''lower your arm message'' has been removed, as the stroke survivor already knows they need to lower their arm when the threshold bar lowers on the gauge, that message, therefore, being too much information.

This streamlined information was intended to make it easier for the stroke survivors to understand the *feedback*, increasing support for that principle while further increasing

interest, *involvement*, *psychological absorption*, *motivation*, *effort*, *usability*, and the *clarity of the instructions*. The intention was, in turn, to impact a stroke survivor's level of *awareness* and *attention* during the game. With a player being more aware of what they need to do to perform in the game, the NRS would likely better support *flow* and *challenge*.

5) NEXT RING DISTANCE

The distance to the next ring was intended to be changed to seconds to the next ring. This information was intended to have been much more meaningful in helping stroke survivors prepare for the next ring, as they would know how long they have to prepare for the next ring. This was first intended to have a positive, meaningful impact on the game's support of *feedback*, *clear instructions*, and *usability*. This was also intended to impact a stroke survivor's level of *awareness* during the game. However, due to technical limitations, this change proved impractical. Since the Wingman accelerates as it approaches a ring, the NRS did not provide a workable manner to countdown time consistently. The timer would speed up upon approaching the ring, counting down seconds faster. The acceleration of the Wingman could not be changed without risking disrupting the already established and tested rhythm of its movement. A change in rhythm could have potentially made the NRS less engaging for the stroke survivors. In addition, we observed that the participants had to juggle the multiple pieces of information coming at them as they approached each ring. They had to read the changing distance count, evaluate their changing relative position to the ring and centre of the ring and make sure that blue and black bars were aligned so that they could enter the centre of the ring. The only thing that mattered was the alignment of the blue and black bars as that alignment would mean that the ring would be entered dead centre. The distance to the next ring metric was, therefore, dropped altogether because players did not find it overly useful and so a player would not be cognitively overloaded with visual information.

6) ARM RESET

Between rings, the player needs to drop their arm angle so they cannot just hold their arm at the correct angle for the entire game. However, the dropping arm angle required was too low for Participant 3 in the original study to reach. Thus, the reset angle was increased from 20 to 25 degrees.

7) VARIETY

Adding additional levels with different scenery would only add a superficial amount of variety. Given the number of times the game is played over the course of a week and a month, the additional scenery would only delay the feeling of a lack of variety for a very small amount of time. Adding a meaningful amount of variety would have been out of scope for this research. All these changes would likely have decreased a participant's level of frustration and therefore helped them feel the *flow*. These changes could have had a positive impact on their *attention*, *interest*, *involvement*, *psychological absorption*, and *motivation* they feel while benefitting the level of *effort* they give. All these factors, in turn, may have made them able to engage with a higher level of *challenge*. With all these factors being better supported, this would likely have positively impacted the level of *purpose* the system has to a stroke survivor.

The new weekly summaries are designed to provide improved feedback for players. The summaries take the form of PDF reports that summarise a participant's performance over the past week and month, allowing them to see their physical improvement over that period. The summary also gives written feedback on their performance and provides a target to achieve for the next week. These PDF reports (shown in Fig. 2) are sent to the stroke survivors via an email attachment upon completion of a week with the system. The reports were also discussed with the participants.

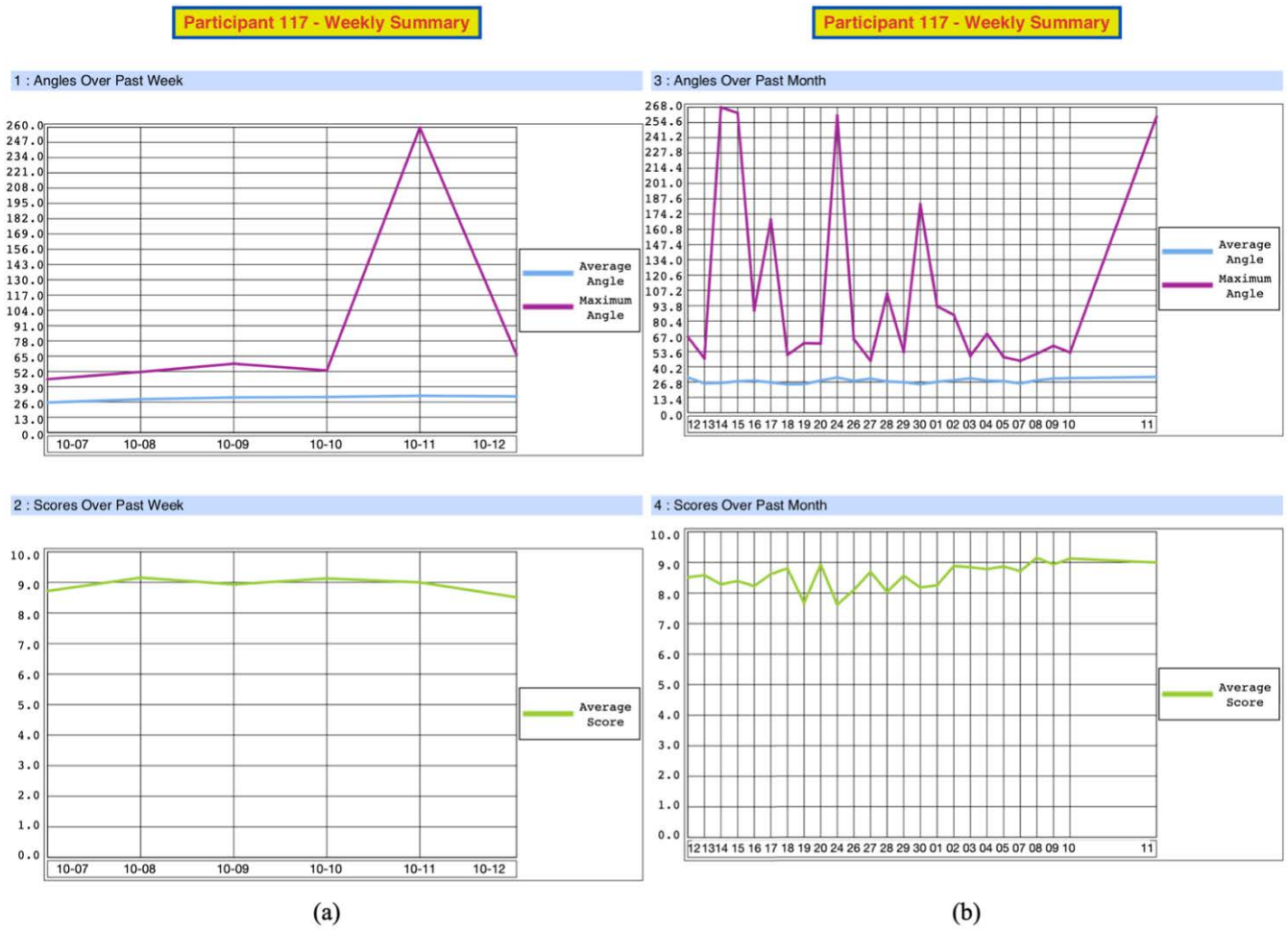
8) GRAPHS

The weekly summary begins with two-line graphs (Fig. 2a), the first showing the average and maximum angles achieved with a user's arm during each day of the week. The second one shows the average score achieved for rings during each day of that week. This is because the maximum score for each day would likely be 10. Another two graphs show the same type of data over the past month (Fig. 2b).

9) FEEDBACK

Feedback (Fig. 2c) in two areas is given:

1) How often the system is being used — if a user has played at least 70% of their maximum possible games that week (the maximum is 42), they will be told they are using the system often enough. If not, they will be told they need to use the system more and that they need to play at least 29 games a week. If they have played at least 70% of the possible games, they will be congratulated and told to aim for 34 games (80% of what is possible) for the next week. If they have played at least 80% of the possible games, they will be told to aim for 38 games (90% of what is possible). For 90% and above, they will be told to aim for the maximum number of games: 42. If they do play 42 games, they will be congratulated with no further target in this area given.
2) Scores — if they have played at least 29 games (70% of the maximum possible), they are given feedback on their scores. Scores are not considered if they have not played 70% of the games because they have not played enough to gain any meaningful improvement. The scoring average achieved for the rings in each game played in the past week is checked to see if it is equal to or greater than 7. If not, they are told they need to focus on improving their score. If they have achieved an average of at least 7, they are told they have done well and should focus on increasing their score to at least 8. If they achieve an average of 8, they are told they can either aim for an average of



5 : Feedback on Last Week's Performance

You played **30** out of **42** games this week.

You played a reasonable number of games this week.

Good, but aim to play more games next week (at least **34**).

Week's average score: **9**

Your scores are excellent, meaning arm control is excellent at this angle threshold.
If you feel comfortable, please ask the clinician to increase your angle threshold for increased difficulty.

(c)

FIGURE 2. **Weekly summaries — Angle and score graphs for past week (a), Angle and score graphs for past month (b), Feedback (c).**

9 the following week or ask the supervising clinician to increase their arm angle. If they achieve an average of at least 9, they are told their arm angle threshold can be increased by the supervising clinician, assuming they feel comfortable.

Both the weekly summaries and the in-game feedback are forms of feedback and were intended to support the same game design principles for the same reasons. These game design principles are *awareness*, *feedback*, *flow*, *challenge*, *attention*, *interest*, *involvement*, *psychological absorption*, *motivation*, *effort*, *clear instructions*, *usability*, and *purpose*.

E. SYSTEM USAGE

As in the previous study [1], [21], the participants used the NRS for 12 weeks (although Participant 2 became unwell after 7 weeks and could not continue). After an initial selection by the supervising neurologists, the participant would need a suitable place to set up the NRS with equipment provided by the supervising clinician. The NRS was set up in an area where background interference would be minimal (to ensure that the sensor would only detect movement from the foreground human-shaped object) and where the user could move far enough back that they would be detectable by the sensor (1.5 metres). The NRS was set up so that no additional calibration was necessary after setup. Background movement and changes in light can interfere with the Kinect sensor. While this was controlled for as best as possible when setting up the NRS, using it in an in-home environment could not always be fully controlled. This was particularly true for Participant 4 who had to have the NRS set up to the side of the public space of her nursing home, as her room was too small. The supervising clinician then showed the stroke survivors how to play the game, the limits on the number of games that can be played per day, and the weekly PDF summaries.

A limit of 6 games per day (42 per week), with a mandatory 3-hour break after 3 games, was enforced, as with the previous study. The supervising neurologists involved mandated this to ensure that the participants would not play too many games on a given day, causing arm and shoulder strain and fatigue. Therefore, the system will display an error message when attempting to play a 7th game on a given day. These NRS settings for each survivor are under the control of the supervising clinician. How to understand the information being imparted by the PDF reports were explained to the participants as part of the participative design, and they all understood. As it was a case study, a high level of contact was maintained with each participant. If there were any difficulties with understanding the reports or the NRS, the participants knew they could discuss these with the supervising clinician and the progress of their rehabilitation overall.

F. QUESTIONAIRE

The questionnaire given was modelled on the one used in the previous research [1] for consistency. For questions 1 and 4, a 4-point Likert scale was used, the same size as Bunz [50], De Angeli, *et al.* [51], Hariyanto and Köhler [52] and Williams [53], [54]. Questions 2 and 3 were open questions. With the NRS referred to as ''Neuromender Upper Limb'' and for all principles apart from the first-person view, participants were asked (with [the principle] being interchanged for one of the 15 principles being examined by the question):

1) To what extent do you feel Neuromender Upper Limb's design supports [the principle]?
   To a Great Extent / Somewhat / Very Little / Not at All
2) In what ways do you feel Neuromender Upper Limb's design supports [the principle]?
3) In what ways could Neuromender Upper Limb's design better support [the principle]?
4) To what extent does [the principle] engage you with Neuromender Upper Limb?
   To a Great Extent / Somewhat / Very Little / Not at All

The Likert scale answers mean this:

- *Not at All* (Associated Score: 1) — ''The participant feels that the principle is not at all important for them to become engaged with the system [21].''
- *Very Little* (Associated Score: 2) — ''The participant feels that the principle is or would be of very little importance for them to become engaged with the system [21].''
- *Somewhat* (Associated Score: 3) — ''The participant feels that the principle is or would be somewhat important for them to become engaged with the system [21].''
- *To a Great Extent* (Associated Score: 4) — ''The participant feels that the principle is or would be important to a great extent for them to become engaged with the system [21].''

For the first-person view, only Question 4 was asked since the game has a first-person view and the NRS can only have it or not, meaning the system could not better support it.

Question 1 aimed to determine to what extent the participant felt that the NRS supported the principle. This was used to determine whether the participant's answer for Question 2 was informed. Question 2 was asked, so what design aspects of the NRS (following updates made to it based on feedback from the previous study [21]) support the principle could be determined. Question 3 was asked to determine whether other ways the NRS could support the principle have been missed. This feedback can then be used to guide further development of the NRS and further research using the system. The feedback was obtained in such a way that no specific emphasis was given to any one feature of the NRS. The intention was that stroke survivors would emphasise the game design factors that they felt engaged them, without any biases introduced by the researcher. This was also done so that the lessons learnt could be applied to other rehabilitation systems. Question 4 was asked to determine to what extent the participant felt the principle, based on their experiences with the updated NRS, actually does support their engagement. This was specifically meant to act as criticism of the principles and not of the NRS' design itself.

Each principle was also assigned a score for Questions 1 and 4, based on the average score of the Likert scale answers given by the 4 participants. This was done to evaluate how

TABLE 4. Question 1 likert scale results (how well supported?).

Principle	Average Score (/4)	Participant 1 (1)	Participant 2 (5)	Participant 3 (6)	Participant 4 (N/A)
Awareness	3.25	To a Great Extent	Very Little	To a Great Extent	Somewhat
Feedback	3.5	To a Great Extent	Somewhat	To a Great Extent	Somewhat
Interactivity	3.5	To a Great Extent	Somewhat	Somewhat	To a Great Extent
Flow	3.75	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Challenge	3.75	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Attention	3	To a Great Extent	Very Little	Somewhat	Somewhat
Interest	3	To a Great Extent	Very Little	Somewhat	Somewhat
Involvement	3.5	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Psychological Absorption	4	To a Great Extent	To a Great Extent	To a Great Extent	To a Great Extent
Motivation	3.5	To a Great Extent	Somewhat	Somewhat	To a Great Extent
Effort	3.5	To a Great Extent	Very Little	To a Great Extent	To a Great Extent
Clear Instructions	3.25	To a Great Extent	Very Little	To a Great Extent	Somewhat
Usability	3.75	To a Great Extent	To a Great Extent	Somewhat	To a Great Extent
Purpose	2.75	Somewhat	Somewhat	Very Little	Somewhat

well the principles are supported by the NRS and how well they support the participants' engagement overall. The same Likert scale options as with the individual answers were used for evaluation and ranking, with scores rounded down (so all participants must answer "to a great extent" for the principle to be supported "to a great extent," giving the principle a perfect 4).

However, a participant's opinion was only said to be informed if they stated that the principle was supported *to a great extent* or *somewhat*. They were said to not have an informed opinion on the principle and to what extent it engages them if their support was *very little* or *not at all*. Without an informed opinion, they could not support the principle being engaging because there was no way they could. With an informed opinion, a principle was supported as engaging by them if they felt that the principle engaged them *to a great extent* or *somewhat*. If they indicated the principle engaged them either *very little* or *not at all*, they did not support the principle being engaging. The number of participants supporting a principle being engaging was then totalled to see if there were trends and agreement for a principle within the cohort, not as statistical analysis.

IV. RESULTS

The participants answered the questions as shown below:

- Participant 1 completed the questionnaire during a single interview via FaceTime;
- Participant 2 supplied the questionnaire's answers in a single Microsoft Word document via email;
- Participant 3 completed the questionnaire during a single, in-person interview;
- Participant 4 completed the questionnaire during a single, in-person interview.

A. LIKERT SCALE QUESTIONS

The results for Questions 1 and 4 are shown, respectively, in Tables 4 and 5. These are discussed in Section V.

B. GAME DESIGN FACTORS SUPPORTING ENGAGEMENT

This section summarises the answers given by the participants for Question 2 ("In what ways do you feel Neuromender Upper Limb'S design supports [the principle]?") for each principle.

1) PARTICIPANT 1

Participant 1 felt that the system supports overall engagement because the NRS challenges you to improve yourself. The support for *challenge* comes from the challenge to improve your score, as with golf. This self-challenge supports *interest* and *motivation,* while also meaning that the game is all about *psychological absorption*. You must feel *involvement* and *attention*, otherwise, scores will be low, and you will not perform. You must also be alert to have *awareness*. Because the game puts the shoulder in focus, the game has *purpose*. To play the whole trial requires *effort*, *effort* is needed for perfect positioning of the arm for a perfect score. He felt the NRS had *clear instructions* that were well explained. *Feedback* is supported by the score for each game and the

TABLE 5. Question 4 likert scale results (Engagement level).

Principle	Average Score (/4)	Participant 1 (1)	Participant 2 (5)	Participant 3 (6)	Participant 4 (N/A)
Awareness	3.25	To a Great Extent	Not at All	To a Great Extent	To a Great Extent
Feedback	3.75	To a Great Extent	To a Great Extent	To a Great Extent	Somewhat
Interactivity	3.75	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Flow	3.75	To a Great Extent	To a Great Extent	To a Great Extent	Somewhat
Challenge	4	To a Great Extent	To a Great Extent	To a Great Extent	To a Great Extent
Attention	3.5	To a Great Extent	Very Little	To a Great Extent	To a Great Extent
Interest	3.25	To a Great Extent	Very Little	To a Great Extent	Somewhat
Involvement	3.75	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Psychological Absorption	4	To a Great Extent	To a Great Extent	To a Great Extent	To a Great Extent
Motivation	3.75	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Effort	3	To a Great Extent	Not at All	To a Great Extent	Somewhat
Clear Instructions	3.25	To a Great Extent	Very Little	Somewhat	To a Great Extent
Usability	3.75	To a Great Extent	Somewhat	To a Great Extent	To a Great Extent
Purpose	3.75	Somewhat	To a Great Extent	To a Great Extent	To a Great Extent
First-Person View	3.5	To a Great Extent	Very Little	To a Great Extent	To a Great Extent

average ring score for each week. This feedback, in addition to the weekly average arm angles reached graph in the weekly summaries — supports *interactivity*. *Flow* is supported by the ability to play the game at different speeds. The ability to use it at home and at flexible times supports *usability*. The *first-person view* makes you feel up there, in it and in the driver's seat.

2) PARTICIPANT 2

Participant 2 felt that the system supports overall engagement because it provides an opportunity for exercise rehabilitation. Engagement is, therefore, about playing the game and getting the best score. He said that the simplicity of the game supported *usability* and meant that it required little additional instruction, supporting *clear instructions. Feedback* is supported by the scores provided by each ring and the total score for each game. *Challenge* is supported by choice of runs and speeds and the ability to request angle threshold increases. He said his only *involvement* was by the scores and angle threshold increase requests and that aiming for the best scores and gaining physical improvement supported *psychological absorption* and *motivation*.

3) PARTICIPANT 3

Participant 3 felt that the system supports overall engagement because it makes him do what is necessary to cross the line, and the more he uses the system, the more it stimulates and is supportive. The challenge to improve and drive to achieve better health creates *interest* in the system. He felt that the system has *purpose* because rehabilitation results from use (pain is gain, as he says). When you perform well, this supports *motivation* and *effort*, which are also supported by the visuals. He felt the choice of different speeds supports overall engagement, flow, challenge, attention, and *involvement*. He felt the arm angle gauge supports *interactivity*, *involvement*, *clear instructions,* and *usability*. While the gauge becomes green when the arm is perfectively positioned for a perfect score, he felt it supports *awareness*, *feedback,* and *interactivity*. The minimal stimuli he felt supported *awareness*. He felt the audio chimes support feedback, interactivity, motivation, effort, and *clear instructions*. The summary graphs from the weekly summaries support *feedback*; while the feedback generally supports *motivation*, the encouragement from the feedback supports *flow*. The increasing of the arm angle threshold supports *flow*, *challenge,* and *involvement*. The fact the games are played over two sessions a day supports *attention*. The sense of 3D movement in the shoulder, not just moving it up or down, supports *psychological absorption*. Finally, he said that the *first-person view* makes him feel more like a pilot using a joystick and being a pilot is better than controlling the Wingman and that this also supports *usability*.

4) PARTICIPANT 4

Participant 4 felt that the system supports overall engagement because it makes the player to concentrate on the arm's

position during the game. The name of the NRS, she said, supported the game having *purpose*. She felt that limiting the games to six over two sessions per day meant it could fit in with her schedule and prevented her from overdoing it, supporting *flow* and *challenge*. *Clear instructions* are supported by verbal instructions when initiated in the trial, learning how to play the game from other players, and the in-game tutorial. *Awareness* is supported by: the understanding of what the task is, the more understanding that is acquired, and the better you become at a task; the good explanation of the game provided; and the adequate tutorial. The scores and weekly summaries support *feedback*, and the way the game responds to the elbow supports *interactivity*. Understanding the objective supports *challenge*, and the simplicity of the NRS's design supports *attention*. The challenge of using the system daily supports *interest* while sharing performance with others via regular social connections with other players supports *involvement*. *Psychological absorption* is supported because *improvement* in the limb can be felt. Playing the game regularly and not too much supported *motivation*, while having the gauge go green when the arm is positioned for a perfect score supports *effort*. Finally, the system's overall design and how it fits together supports *usability*.

C. SUGGESTIONS FOR BETTER SUPPORT OF ENGAGEMENT

This section summarises the answers given by the participants for Question 3 (''In what ways could Neuromender Upper Limb's design better support [the principle]?'') for each principle.

1) PARTICIPANT 1

Since Participant 1 had participated in the first 12-week trial of the system in the planning phase, he felt the novelty of the NRS was no longer there — decreasing *overall engagement*. Additional features he suggested were:

- Giving a running tally of the score for the games within a session (for *awareness*, *feedback,* and *flow*).
- Providing a more frequent comparison of the scores (for *awareness*, *feedback,* and *flow*).
- Giving the average ring score at the end of a game, in addition to the total score (for *feedback* and *flow*);
- Providing more regular feedback on arm angles (for *interactivity* and *flow*);
- Providing more feedback generally (for *attention*, *interest*, *involvement*, *psychological absorption,* and *motivation*).
- In addition, he felt after becoming familiar with the different runs that the rings had a rhythm and that more variety in speed and spacing would help the NRS better support *effort*.

2) PARTICIPANT 2

Additional features Participant 2 suggested were:

- Exercises other than the arm lifting game (for overall engagement, *challenge*, *involvement*, *motivation,* and *purpose*).
- The game background is crude and needs to be made more complex and detailed (for *awareness* and *attention*);
- Provide summary information at the end of the game, like the average score for the week and display overall trends in angles and scores (for *feedback*);
- Provide more automated angle threshold changing, rather than having to discuss changes to angle threshold with the supervising clinician (for *flow*);
- Allow more games per day if physiotherapists advise this is okay (for *involvement* and *purpose*);
- Provide a frequency asked questions (FAQ) document for the game to assist with common problems, including technical ones (for *clear instructions*). He had two technical issues specifically related to the internet connection dropping out and interference with the Kinect motion sensor (causing it to behave erratically).

3) PARTICIPANT 3

Participant 3 felt the tutorial was not engaging and needed polishing; this impacted overall engagement, *motivation,* and *effort*. Participant 3 also suggested these additional features:

- Display the player's skeleton on-screen during a game for feedback (*awareness*, *feedback,* and *interactivity*). However, he admitted this might be too much extra stimuli for during the game;
- Make the gauge bigger (for *feedback*, *involvement*, *psychological absorption,* and *clear instructions*).
- Possibly make the chimes when achieving a score into ditties, with different ones for different score outcomes (for *feedback* and *challenge*);
- Provide monitoring from a specialist during a game to monitor movement and give feedback (for *interactivity*);
- Provide a replay of skeleton movement at the end (for *flow*, *interest,* and *involvement*).
- Provide encouragement with emoji and cartoons (for *interest*);
- Add more music (for *involvement* and *psychological absorption*);
- Add humour (for *involvement*, *psychological absorption,* and *purpose*).
- Include general facts about why survivors should use the system (for *motivation* and *effort*);
- Provide professional advice about stroke in-game, including stories about stroke survivors (for *effort* and *purpose*);
- Provide guidelines on the arm movement rhythms to use and how to sit and breathe while playing the game (for *clear instructions*);
- Provide guidelines about to what extent the non-affected hand can be used (for *clear instructions*).

4) PARTICIPANT 4

Participant 4 found that distractions caused by occasional technical issues and activities happening around her in her nursing home impacted overall engagement. She also felt that the rings should come at a consistent speed and angle to better support overall engagement. She found the chimes were an unnecessary detail, which impacted her *awareness* and *flow*. She felt that adding more detail in the runs, like birds in the forest, would help the NRS better support *attention* and *interest*. Players should be made aware of the details before starting a game so they can be deactivated if they feel they will not add anything. Participant 4 felt that *motivation* could be better supported if the supervising clinician clarified that if some days were missed or not all games were played on a given day, this is not a large issue. This is because there will be no benefit from a survivor playing a game if they are forcing themselves to play the game when they really do not wish to do so. Finally, she said that *involvement* could be better supported by showing all individual rings scores, the total ring score, and other game scores at the end of a game.

V. ANALYSIS AND DISCUSSION

A. INDIVIDUAL CASES

This section summarises each participant's involvement in the study and their questionnaire responses.

1) PARTICIPANT 1

For the Likert scale questions responses (as presented in Tables 4 and 5), Participant 1 felt all the principles were supported by the NRS ''to a great extent.'' All the principles also supported his engagement ''to a great extent,'' except for *purpose*, which he felt only supported his engagement ''somewhat.'' These results indicated that he overall found the NRS engaging. These results also demonstrated that he felt the principles were well supported. Therefore, he could say in his informed opinion that all the principles supported his engagement with the NRS, although with *purpose* — slightly less so. However, as he had participated in the previous study and had used the NRS for 12 weeks previously, the system felt less novel for him than previously, which impacted his overall engagement. In the future, when the NRS is deployed, the intention would be for a stroke survivor to play the arm raising game for a single period of 12 weeks so that a similar issue would not arise. When suggesting how the NRS could better engage, all his other responses were related to improved feedback. His requested improvements for the NRS in the previous study also largely related to feedback.

2) PARTICIPANT 2

Participant 2 gave a much more mixed response for the Likert scale responses presented in Tables 4 and 5 than the other participants. For 9 principles, when asked whether the NRS supports them, he responded positively (''somewhat'' or ''to a great extent'') and for 5 principles — negatively (''very little''). When asked whether each principle supported his engagement with the NRS, he gave an answer that was consistently positive or negative with whether he felt the NRS supported the principle. When he answered either ''somewhat'' or ''to a great extent'' to question 2, he answered ''somewhat'' or ''to a great extent'' to question 3, with the same principle applying for when he answered, ''very little'' or ''not at all.'' This relationship indicated that if he felt the NRS supported a principle, it, in turn, supported his engagement, which may indicate some biasing based on what he liked and disliked about the system. However, since he believed those 9 principles were supported by the NRS, he could then make an informed decision on whether those 9 principles supported his engagement. For a *first-person view*, since the NRS has one, his opinion of it supporting his engagement as ''very little'' can also be said to be informed. For the other 5 principles, as he could not create an informed opinion, we cannot say whether he would also say the principles would not engage him and if he felt the system supported the principles.

From his responses to Questions 2 and 3, Participant 2 was the most critical of the NRS and seemed the least engaged out of the four. He had also participated in the previous study, where he was also quite critical of the NRS. The fact that he had already used the NRS previously and both times was frustrated by it impacted his overall engagement. While he did seem to like the game's overall design from a rehabilitation perspective, he found it too simplistic from an engagement perspective. The reason that his engagement did not seem to improve between the previous study and this one was that certain requests he had made were not permissible according to the rehabilitation requirements, as set by the supervising neurologists. While in both studies, he had requested more rehabilitation exercises (such as arm extension, which he knew was available in the NRS), rehabilitation had to be taken in stages, starting with arm raising. Once a stroke survivor can raise and control the arm, only then can they continue to other more complex exercises according to the protocol set by supervising neuroscientists. Another request that could not be included was adding more detail to the NRS's background. The NRS could be used in high resolution with an immersive VR headset, but multiple neurologists had advised against that use for stroke survivors at this stage of rehabilitation. He also requested automatic arm angle threshold raising, which would not be workable since the NRS would not be able to figure out when the stroke survivor feels comfortable raising it, as the survivors capacity would change from one day to the next thus requiring the supervising clinician to make an informed decision on this. Finally, he also wanted to play more games per day, despite playing the maximum allowed by the supervising neurologists. Participant 2 also only used the NRS for 7 weeks, after which he became unwell and was unable to continue.

Based on the conflict between what he perceived would improve his engagement and the requirements for the rehabilitation to be successful, solving the engagement issues discussed by Participant 2 would be difficult. Further research would be needed to help determine whether there is a reason-

able benefit gained from relaxing the restrictions on rehabilitation applied here for the benefit of engagement in situations like Participant 2's. This is because a stroke survivor may only find the rehabilitation engaging when it has been set up in a less managed way to stop it from being simplistic. Such a study would examine whether improved engagement negates the effects of less controlled rehabilitation when looking at rehabilitation outcomes overall in his or similar cases.

In his responses, he mentioned technical issues. The internet connection issues were fixed by replacing the wireless connection dongle used by the Windows PC on which the NRS ran. The Kinect motion sensor issues appear to have been caused by infrared light interference from the sunlight streaming into the room. Future deployments of the NRS or other similar systems would have to ensure that sunlight is kept to a minimum in the room while engaged in rehabilitation.

3) PARTICIPANT 3

For the Likert scale responses presented in Tables 4 and 5, Participant 3 felt all the principles were supported by the NRS ''somewhat'' or ''to a great extent,'' except for *purpose*, which was supported ''very little.'' He also stated that all the principles supported his engagement ''somewhat'' or ''to a great extent.'' However, since he felt that *purpose* was not well supported, he could not provide an informed opinion on whether it supported his engagement. These results indicated that he overall found the NRS engaging. These results also demonstrated that he felt the principles were well supported. Therefore, he could say in his informed opinion that all the principles support his engagement with the NRS, except *purpose*. Responses on how the NRS could better engage were quite general and did not relate to one specific area.

Given that the only principle that he felt was not supported ''somewhat'' or ''to a great extent'' was *purpose*, the important responses relate to how the NRS could better support that principle. For improving support of *purpose*, he suggested adding humour and providing professional advice about stroke in-game, including stories about stroke survivors. These suggestions could even be supported together by giving humorous stories about stroke and stroke survivors.

4) PARTICIPANT 4

Participant 4 was the only participant who had not participated in the previous study and therefore had not used the NRS before, making it more novel for her than the other participants. For her Likert scale responses, as presented in Tables 4 and 5, she felt all the principles were supported by the NRS ''somewhat'' or ''to a great extent.'' She also felt that all the principles also supported her engagement ''somewhat'' or ''to a great extent.'' These results, coupled with the higher level of novelty for her than the other participants, indicated that she found the NRS engaging overall. These results also demonstrated that she felt the principles were well supported. Therefore, she could say in her informed opinion that all the principles support her engagement with the NRS. From her responses to questions 2 and 3 regarding game design factors supporting engagement, she mostly liked the NRS' design overall. She stated that she wished it was made clearer that missing days or not playing all possible games on a given day is not a huge problem, given the lack of benefit resulting from stroke survivors forcing themselves to do rehabilitation when they do not feel able to do so. In future studies or uses of the NRS the supervising clinician will have to make sure this is better emphasised. However, the factor that had the largest impact on her overall engagement was the setup of the NRS.

Unlike the other participants, she was a nursing home resident. Setting up the NRS to avoid background interference was harder with her room being too small. While setting the NRS up to the side of the public space (the only place big enough for the required setup) did largely mitigate issues with interference caused by background movement, this did not solve it entirely. The occasional technical issues that this caused impacted her overall engagement, as did other general, distracting activities also occurring in the public space. Because of the generally older age of stroke survivors and their disability, many will be in nursing homes, and so issues of space and setup will exist in their circumstances as well. The only way to mitigate issues with setup would be to have the NRS be set up somewhere else, such as a clinic or hospital where the environment can be better controlled. However, this would make the NRS less accessible since the stroke survivor would have to travel to another location to use it. For future studies and uses, the decision to have the stroke survivor use the NRS in the public space of a nursing home or at a clinic would be made by their supervising clinician. This would be based on how well the environment can be controlled within the nursing home, the accessibility of the clinic where the NRS would be set up, and the general circumstances of the stroke survivor (their ability to get to the clinic based on the availability of transport, their schedule otherwise and their ability to move from location to location generally).

B. CROSS CASE ANALYSIS –GAME DESIGN PRINCIPLES

1) HOW WELL SUPPORTED?

When looking at the average scores of how each game design principle is supported by the NRS, based on the individual Likert responses given by each participant:

- *Psychological absorption* was supported ''to a great extent,'' having an average score of 4;
- *Awareness*, *feedback*, *interactivity*, *flow*, *challenge*, *attention*, *interest*, *involvement*, *motivation*, *effort*, *clear instructions* and *usability* were supported ''somewhat,'' with average scores of 3 or higher, but less than 4;
- *Purpose* was supported ''very little,'' having a score of 2.75.

2) ENGAGEMENT LEVEL

When looking at the average scores of how each participant felt each game design principle supported their engagement, based on the individual Likert responses given by them:

- *Challenge* and *psychological absorption* were supported "to a great extent," having average scores of 4;
- *Awareness*, *feedback*, *interactivity*, *flow*, *attention*, *interest*, *involvement*, *motivation*, *effort*, *clear instructions*, *usability*, *purpose* and a *first-person view* were supported "somewhat," with average scores of 3 or higher, but less than 4.

3) OVERALL SUPPORT FROM PARTICIPANTS

While all principles were supported as being engaging by the participants on average "somewhat" or "to a great extent," participant 2 for 5 principles (*awareness*, *attention*, *interest*, *effort* and *clear instructions*) and participant 3 for 1 principle (*purpose*) felt the NRS supported the principle "very little." This meant that as the principle was not supported in their view, they could not make an informed opinion on whether the principle supported their engagement.

The eight principles that were indicated as engaging for four participants (in their informed opinion, answering either "somewhat" or "to a great extent" in response to questions 2 and 3 for the principle) and therefore had good support by the sample were: *feedback, interactivity, flow, challenge, involvement, psychological absorption, motivation*, and *usability*. The 7 principles that engaged three participants and therefore had reasonable support from the sample were: *awareness, attention, interest, effort, clear instructions, purpose*, and a *first-person view*.

C. CROSS CASE ANALYSIS –GAME DESIGN FACTORS

1) GAME DESIGN FACTORS SUPPORTING ENGAGEMENT

Opinions on what specific design features of the NRS support the various game design principles were diverse. Results shown in sections IV-B and IV-C demonstrated just how little crossover there was in responses. Emphasis by participants 1, 2, and 4 was placed on the rings scores, both average and total, supporting *feedback*. Participants 1, 3, and 4 also felt the weekly summaries supported principles like *feedback* and *interactivity*. Participants 3 and 4 also liked how the gauge goes green when the arm is positioned for a perfect score, supporting principles such as *awareness*, *feedback, interactivity*, and *effort*. Participants 1 and 3 felt the choice of different speeds for a run supported principles like *flow*, *challenge*, *attention*, and *involvement*. Finally, participants 2 and 3 emphasised the angle threshold increasing as supporting principles like *flow*, *challenge*, and *involvement*. In summary, the participants generally emphasised different game design factors as supporting engagement, with little crossover.

2) SUGGESTIONS FOR BETTER SUPPORT OF ENGAGEMENT

As with opinions on what specific design features of the NRS support the various game design principles, opinions on how the system could better support the principles were diverse. Once again, results in sections IV-B and IV-C demonstrated the minimal crossover in responses. Most emphases were placed on aspects of the score for *feedback*. This included: showing individual rings scores and the average ring score at the end of a game, in addition to the total score, and showing a comparison of games scores and trends within them more frequently, potentially at the end of a game. In summary, the participants suggested a plurality of design features, often relating to score, for potentially better supporting engagement.

3) GAME DESIGN FACTOR DISCUSSION

While large emphasis was placed on feedback as a game design factor as supporting engagement, there was little agreement on other important game design factors, unlike game design principles. However, more changes may not be needed to engage participants 1, 3 and 4, given how they already believe the NRS supports the game design principles (excluding participant 3 with *purpose*). If further optimisations to their engagement from a game design factor perspective are made, they may have to rely on personalisation to tailor the NRS to their specific tastes. How to personalise the NRS and VR-based upper limb stroke rehabilitation for individual stroke survivors would need to be the focus of a separate study.

VI. CONCLUSION

Of the 15 game design principles, only *psychological absorption* was seen as supported by the NRS "to a great extent" from the perspective of all participants. *Awareness*, *feedback*, *interactivity*, *flow*, *attention*, *interest*, *involvement*, *motivation*, *effort*, *clear instructions*, *usability*, *purpose* and a *first-person view* were supported "somewhat," and *purpose* was supported "very little." The principles were said to be generally well supported in the participants' opinions, with the noticeable exception of participant 2. Therefore, their opinions on whether the principles support their engagement or not can be said to be mostly informed.

All 15 principles were found to have good or reasonable support from the sample for supporting engagement with the NRS. While the participants felt the principles were well supported by the design of the system, again, except for participant 2, they provided additional, diverse feedback on how to make the system even more engaging. The use of feedback was emphasised as an important design factor for supporting the game design principles, but there was otherwise little agreement in important design factors among the participants. This indicates more personalised experiences may be necessary for optimised support of important game design principles. Such a personalised experience can form the basis of a future study.

Regarding problems that emerged in individual cases:

- Participant 2 indicated that his engagement would be supported by changes to the NRS that violate restrictions on the rehabilitation set by the supervising neurologists. A future study may look at whether improved engagement negates the effects of less controlled rehabilitation

when looking at overall rehabilitation outcomes in his and similar cases.

- Participant 4, living in a nursing home (which is not uncommon for stroke survivors, generally being older and having a disability), had to have the NRS set up in a public space of the nursing home due to her room being too small. This created problems with background interference, causing technical issues with the motion sensor (despite attempts to control these issues with placement of the setup) and her being distracted by activities occurring in the room. Future studies or deployments of the NRS would need to evaluate whether a stroke survivor living in a nursing home would be better off using the system at a clinic. This would be based on individual case assessment by the supervising clinician, taking into account how well a setup in the nursing home can be controlled for motion sensor interference and the lower accessibility of a clinical setup (which can be affected by the location of the clinic and the individual ability of the stroke survivor to actually get there).

Overall, the insight gained in this study can be used to inform the design of a larger scale statistical study into what engages stroke survivors with Desktop Virtual Reality-based Serious Games designed for upper limb rehabilitation.

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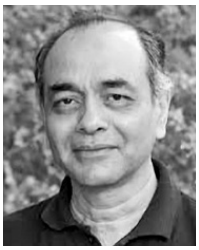

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