BMC Digital Health

RESEARCH

Open Access

Technical feasibility of the implementation of an intensive upper-limb rehabilitation system (NeuroVirt) intervention for stroke survivors

Kathryn Mares[1*], Maria del Rocio Hidalgo Mas[1], Alison Watt[2], Evridiki Gregoriou[3] and Allan Clark[1]

Abstract

Background 80% of stroke survivors have upper limb (UL) disability. NeuroVirt is a portable immersive virtual reality (VR) platform that is designed to encourage high-repetition and high-quality UL movement training. The aim of the study is to investigate the technical feasibility, usability and acceptability of NeuroVirt.

Methods Eight adults with a stroke (≥ 3months) completed the study. Participants used the device at home for two 1 h sessions each day, 6 days a week, for 6 weeks. Participants also received a 15-min weekly telephone call. Technical feasibility was measured by the percentage of Wi-Fi disconnections, data push failures, and mean scene frames per second (fps). Usability and acceptability were explored through interview feedback and analysed with a thematic inductive analysis approach. We also recorded the number of movement repetitions per session as an indication of compliance.

Results From 12 participants enrolled in the study, 8 (67%) participants started the NeuroVirt exercise program and were included in the study analysis. Results indicated good Wi-Fi stability with 1(1.51%) disconnection out of 198 sessions, 1 (0.09%) push attempt failed out of 1052 data pushes and no data loss. An overall mean of 67.5 (2.27) fps during a session. Data from the interviews suggested that participants found NeuroVirt acceptable and indicated improvements in function. Participants completed on average 3.5 (1.3) sessions per week and performed on average 338.2 (172.7) movement repetitions per session.

Conclusion NeuroVirt had no data loss and consistent Wi-Fi stability. The frame rate was above the minimum industry standards of 60-fps required to prevent motion sickness. Preliminary usability and acceptability results showed that a home-based NeuroVirt program for stroke survivors with UL impairments was both, feasible and well accepted.

Trial registration Registration number ISRCTN46051085; prospectively registered the 24/02/2023.

Keywords Stroke, Upper limb, Virtual reality, Rehabilitation

*Correspondence:
Kathryn Mares
k.mares@uea.ac.uk
[1] Faculty of medicine and Health, University of East Anglia, Norwich NR47 TJ, England
[2] Hobbs Rehabilitation, Ham Green, Pill, Bristol BS20 0DD, England
[3] NeuroVirt Limited, Shelton Street, London WC2H 9JQ, England

Introduction

Stroke is a major cause of disability in the world [1] including in the United Kingdom (UK) where it is estimated that one in five people will have a stroke at some point in their lifetime [2]. The consequence of a stroke leads to a substantial economic burden in society (£26 billion a year in the UK) [3] and also has a profound

impact on the quality of life of stroke survivors and families [4]. Around 80% of stroke survivors suffer from an upper limb long-term disability [5]. Upper limb (UL) rehabilitation can be a lengthy process and may require hundreds of movement repetitions to enable an improvement in motor function after a stroke [6]. Stroke rehabilitation usually commences in the hospital setting and extends into the community and people's own homes. After being discharged from the hospital, stroke survivors have however reported that they feel abandoned [7], and that their UL rehabilitation needs are not addressed [8].

Technological innovation aimed at improving adherence to higher-intensity self-therapy at home may increase the efficacy and efficiency of UL stroke rehabilitation in comparison to usual low-level care [9]. As a result, there could be improvements in UL motor outcomes and quality of life. Moreover, it might decrease care requirements in the hospital alleviating healthcare systems bottlenecks and saving costs. NeuroVirt is a fully immersive virtual reality (VR) platform that is designed to encourage high-repetition UL movement training via games. The platform is designed for in clinic and home use. It allows users to be immersed in an engaging and challenging virtual scenario where the interaction emulates the exercises required in conventional therapy. It uses a VR headset to enable individuals to play games that involve moving their arm, wrist, hand, and fingers. NeuroVirt software has been co-designed with stroke survivors and clinicians and has been iteratively shaped through ongoing testing and feedback.

The problem with conducting trials with new technologies is challenging because of technical bugs or hardware malfunction [10]. This has disrupted the ability to gather robust clinical data needed to inform the development of future trials [11]. The aim of this study therefore is to investigate the technical feasibility, safety, and the preliminary usability and acceptability of delivering a 6-week upper-limb rehabilitation intervention with the use of the NeuroVirt platform in stroke survivor´s own homes. This work is being done prior to a clinical feasibility study to ensure that NeuroVirt functions as expected before collecting data that will lead to a clinical evaluation study.

Methods

Trial design

This was a single-arm, non-randomised study [12]. Participants that consented to be part of the study were assessed and taught how to use NeuroVirt in an in-person session carried out by a therapist who specialises in working with people with stroke. If requested by the participant, the caregiver was also present during the session.

Following informed consent, included participants received a personalised UL exercise programme using the NeuroVirt system, based on the assessment findings. After the session, participants were provided with an instruction booklet and the NeuroVirt system to take home and use for six weeks. Following the six weeks, participants returned the NeuroVirt system and took part in a semi-structured interview conducted by either a member of the research team (AW) or a clinical colleague, who both had experience of conducting interviews and who were not involved in delivering a participant's therapy. Both interviewers had been involved in previous earlier development of NeuroVirt. See Fig. 1 for flow chart of participants through the study. Importantly, during the study period, participants were asked to continue with their daily routines, including rehabilitation therapy.

Participants and recruitment

Participants were recruited from across the south of England through an independent private rehabilitation company in two of their out-patient centres between February 2023 and June 2023. Inclusion criteria were: (1) aged 18 years or over; (2) a stroke (ischaemic or haemorrhagic) at least 3-months previously; (3) have at least a little motion of the upper limb, but not have full dexterity; i.e. be able to independently lift their arm from their lap and place on a table in front of them but not be able to stack 5 £1 coins. (4) can navigate the NeuroVirt device independently following a trial during the first day with a researcher present; (5) can demonstrate wearing the NeuroVirt device independently at the first trial day OR a family member/carer is available on a daily basis to assist with applying the NeuroVirt device to the patient in their home; (6) has at least a weak Wi-Fi connection at their home. Exclusion criteria were: (1) other neurological diagnoses; (2) communication, cognitive and language deficits such that they are unable to follow a one stage command and give informed consent; (3) frozen shoulder or other impairments affecting the movement of their arm such as arthritis (4) any episode of photosensitive epilepsy within the last 12 months; (5) refuse to consent to GP being contacted.

Intervention

NeuroVirt is a fully immersive VR rehabilitation software and web-application platform that is UKCA-marked as a medical device. The NeuroVirt platform targets the entire upper-limb and includes six immersive training modules: three for Arm Reach (Buzz, Saw, Catch); one for all Wrist movements; one for Hand Extension which includes finger flexion and extension, and one for Grip Strength. NeuroVirt device includes adaptable straps for the hand controllers and a small ball to help clinicians tailor the

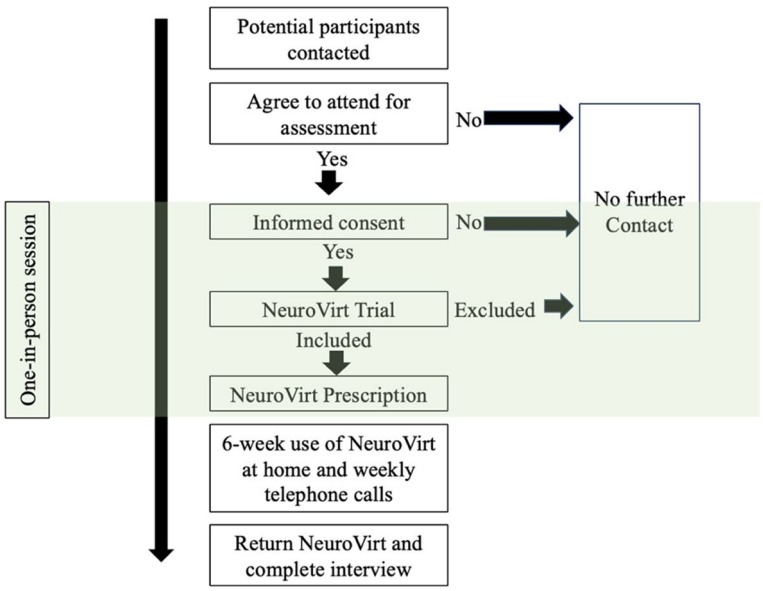

Fig. 1 Flow chart of participants through study

therapy for each patient. Utilizing the Head-Mounted Display's (HMD) cameras and positional sensors, the NeuroVirt software quantifies the angles of each joint of the hand and wrist as well as the position of the user's arm relative to their body at 6 degrees of freedom. The artificial intelligence (AI) software adjusts to the patient's impairment levels following a brief calibration process so that the games can be accessible for people with little or no movement recovery as well as those who have started to make a good recovery. Users receive in-game feedback as well as summary feedback on how well they have done at the end of their prescribed exercise session.

Participants were asked to set NeuroVirt up at home by a clinician taking part in the research study and who was expert in delivering upper limb therapy to stroke survivors. Therapists were comprised of occupational therapists ($n=2$, qualified 4 and 18 years) and physiotherapists ($n=2$, qualified 6 and 12 years) who were all employed by a specialist independent provider of rehabilitation for stroke survivors (employed 1 to 4 years). Participants were asked to undertake up to two 1-h sessions each day, 6 days a week, for 6 weeks. The structure of each session consisted of 15 min warm-up of the hand and arm and up to a 45-min training session using the NeuroVirt system. Participants could choose to play the rehabilitation games at a time that suited them, and they were advised to rest at any time and remove the HMD during any training session if needed.

Throughout the six-week intervention period, participants received a 15-min weekly phone call from the therapist. During the call, participants were asked a standardized set of questions developed specifically for this study (supplementary file 1) to ensure effective management of the technology and to monitor safety.

Measurement

Demographic and clinical data

Demographic (age, ethnicity, and sex) and clinical (stroke onset, stroke classification, UL impairment and activity, self-recorded exercise routine) characteristics were recorded. Clinical data was collected to help monitor for any adverse reactions and to describe our population. UL impairment was measured with the Fugl Meyer Assessment Upper Extremity (FMA-UE) [13] and UL activity was measured with the Chedoke Arm and Hand Activity Inventory-13 (CAHAI-13) [14]. The FMA-UE has a scoring system from 0 to 126 points, higher scores indicating less impairment in the UL. The CAHAI-13 uses a scoring system from 0 to 96 higher scores indicating better activity in the UL. Both these measures are feely accessible and no special permission is required for their use. A visual analogue scale from 0 to 10 was used to measure participants'initial pain and fatigue levels [15].

Technical feasibility

Technical validation

We recorded NeuroVirt technical data in a cloud backend system following each session of use. To measure the average Wi-Fi connection stability, we recorded the device Wi-Fi connection and counted the number of disconnections that occurred during a session. To measure backend stability in multiple concurrent operations and

NeuroVirt backup system, we monitored the number of data 'push' fails from total data pushes, as well as the percentage of successful uploads of previously failed-to-push data.

The frame rate is important to deliver simulator-sickness-free experience, to understand the performance of the application, we recorded the average frames per second during a session for each game modality.

From the weekly telephone calls and final interview, we collected information about any technical bugs present in the NeuroVirt system during the trial.

Duration of rehabilitation material

To assess the duration of the rehabilitation material provided by the NeuroVirt web-application platform, we recorded the percentage of participants that completed all levels in each individual game, and the average time taken to complete each level of the games.

Safety

Safety was determined by an Adverse Event (AE) reporting system. In this study, we reported a Serious Adverse Event (SAE) if the AE resulted in death, a life-threatening injury, permanent impairment of a body structure or body function, or required hospitalization. A further vascular event and epileptic seizures were reported as expected disease-related adverse events unless their causality was determined to be because of the NeuroVirt intervention in which case they were also reported as SAEs. Treatment related adverse events were reported if the participant had pain following the NeuroVirt exercise, which persisted for longer than 1 h after the exercise program had stopped and could not be related to any other intervention.

Usability and acceptability feedback

Adherence

To assess the participants' adherence, we collected data from the NeuroVirt System on the number of sessions completed by the participants in the 6-week period; the average duration of the sessions; and the number of movements per session. Additionally, we counted the number of times a participant removed the HMD during a session.

Stroke survivors' experience

To understand stroke survivors' experience of using NeuroVirt, we collected usability and acceptability feedback through the weekly telephone calls, and through face-to-face semi-structured interviews. All interviews were carried out using an online platform and recorded through the same media. We included questions about the NeuroVirt hardware, software, and instruction booklet. The interview guide was developed for this study (supplementary file 2).

Data analysis

Quantitative data was analyzed using descriptive statistics, mean (standard deviation) and median (interquartile range) to describe continuous data, and percentages to describe categorical data. Qualitative data from the telephone calls and interviews was analysed by two researchers following a thematic inductive analysis approach. We applied the six phases of the thematic analysis described by Braun and Clarke, 2006 [16]: (1) familiarizing oneself with the data, (2) generating codes, (3) constructing themes, (4) reviewing potential themes, (5) defining and naming themes, and (6) producing the report.

Results

In this section we will present the quantitative data followed by the qualitative data. From 12 participants enrolled in the study, 4 (33%) people did not start the NeuroVirt exercise program, and 8 (67%) participants started the NeuroVirt exercise program. Reasons given for not starting the NeuroVirt program were: not able to use NeuroVirt ($n=1$); did not want to take NeuroVirt home ($n=2$); took NeuroVirt at home, did not want to use it ($n=1$). Eight participants were included in the study analysis. Participants mean age was 59. 25 (15.29) years old, 4 (50%) were female, mean time since last stroke was 2.86 (2.91) years, and with a FMA-UE mean score of 73.38 (28.42) (Table 1).

Technical feasibility

Technical validation

The results on Wi-Fi stability showed that Wi-Fi disconnection occurred in 3 instances (1.51%) out of 198 sessions. From 1052 data pushes during the study, there was 1 (0.09%) failed push data attempt. The percentage of successful uploads of previously failed-to-push data was 100%, which indicates that there was 0% data loss during the study.

The results on frame rate showed that the NeuroVirt platform had an overall mean of 67.5 (2.27) fps during a session. Table 2 shows the mean frames per second during a session for each game modality.

Finally, two technical bugs in the NeuroVirt games were identified during the trial, one in the Arm Reach games calibration and the other in two final levels of the Hand Extension game.

Adherence and duration of rehabilitation material

Performance: The mean (SD) sessions completed by participants in the 6 weeks period was 24.7 (9.5) sessions (minimum–maximum:10–36 sessions),

Table 1 Demographics and clinical characteristics of participants ($N = 8$)

Age	
Mean (SD), min–max	59.25 (15.29), 33–80
Ethnicity	
White-British, n (%)	7 (87.5)
White-European, n (%)	1 (12.5)
Sex	
Male, n (%)	4 (50)
Female, n (%)	4 (50)
Time since last stroke in months	
Median (IQR), min–max	22 (15–68), 6–96
Stroke side	
Left, n (%)	5 (62.50)
Right, n (%)	3 (37.50)
Stroke classification	
ICH, n (%)	4 (50)
LACS, n (%)	1 (12.50)
PACS, n (%)	1 (12.50)
TACS, n (%)	2 (25)
Fugl-Meyer UE, mean (SD), min–max	73.38 (28.42), 13–108
CAHAI-13, mean (SD), min–max	36.75 (18.56), 19–78
Pain VAS, median (IQR)	0 (0–1)
Fatigue VAS, median (IQR)	2 (0.50–5.75)
Self-recorded exercise routine	
Yes, n (%)	6 (75)
No, n (%)	2 (25)

Abbreviations ICH Intracerebral haemorrhage, *LACS* Lacunar syndrome, *PACS* Partial anterior circulation syndrome, *TACS* Total anterior circulation syndrome, *UE* Upper Extremity, *CAHAI-13* Chedoke Arm and Hand Activity Inventory-13, *VAS* Visual Analogue Scale

Table 2 Frame Rate for each game

Scene	Frames per second Mean (SD)
Lobby	68.24 (2.6)
Grip Strength	64.14 (4.1)
Hand Extension	66.40 (3.4)
Wrist	68.80 (2.0)
Arm Reach games	69.90 (2.0)

equivalent to 3.5 (1.3) sessions per week. 188 (94.9%) out of 198 total sessions were completed in different days. The mean (SD) time on task was 20 (9.4) minutes per session (minimum–maximum: 6.6–31.8 min). The mean (SD) movements per session was 338.2 (172.7), (minimum–maximum: 133–605 movements). Figure 2 shows the number of movements per session for each participant. Two (25%) participants removed the HMD more than once during half or more of the sessions.

Duration of rehabilitation material: therapists prescribed the Hand Extension, Wrist, Arm Reach Saw and Arm reach Cath game to all 8 (100%) participants. Grip Strength and Arm Reach Buzz was prescribed to 6 (75%) participants. All the levels of the Wrist game were completed by 4 (50%) participants. No (0%) participants completed all levels in the Arm reach games, Hand Extension, or Grip game. The levels of the Arm Reach Buzz game were the longest to complete, 166 (164.3) seconds, (minimum–maximum: 15.9–452.6) whilst the levels of the Wrist game were the shortest to complete by the participants, 16.7 (4.7) seconds (minimum–maximum: 9–25.1). Table 3 for further information.

Safety

No SAE or a treatment-related AE have been reported in this study.

Usability and acceptability

Usability is divided into three themes: 1) On boarding and User support, 2) Instruction Booklet, and 3) Additional support.

Acceptability is divided into two themes: 1) User satisfaction, and 2) Noticeable Physical and Non-physical impact.

Usability

On boarding and user support

In this theme we identified the types of support provided to the users. Participants agreed that the face-to-face assessment and training session was useful to help them with setting NeuroVirt up at home. Some participants thought that one session was enough, and they did not ever look at the instruction booklet after the session. Others felt that they needed more training with one participant saying:

> *"Probably should have done more use in the beginning with a physio" (P.114, age range 80–90 years).*

During the interview it was found that not all participants that wore glasses were provided with the glasses´ adaptor, those participants reported that the use of the HMD without the glasses ' adaptor was uncomfortable.

Participants described the 15 min weekly telephone call as useful and long enough and frequent enough. Having a therapist checking up was also perceived as a motivator factor to complete the exercises.

> *"Yes, being accountable for stuff is really important for me so I think it has been good in that sense."(P121, age range 30-40 years)*

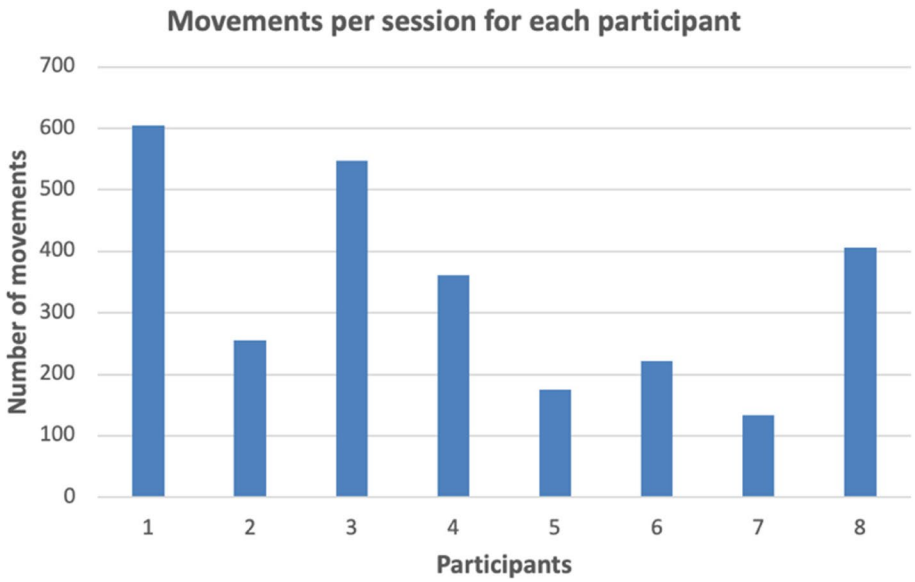

Fig. 2 The graph shows the mean number of movements per session for each participant ($N = 8$)

Table 3 Completion of developed rehabilitation material provided in the NeuroVirt system ($N = 8$)

Games	Total number of levels	Reach level Mean (SD), min–max	Completed all levels Number (%)	Seconds to complete each level Mean (SD), min–max
Grip Strength	69 × 3 difficulty variations	7.3 (5.7), 4–19	0 (0)	32.1 (6.2), 23.6–40.6
Hand Extension	28 × 3 difficulty variations	18.8 (11.3), 2–28	0 (0)	90.4 (7.9), 73.1–99.1
Wrist	54	30.9 (24.8), 5–54	4 (50)	16.7 (4.7), 8.9–25.1
Arm Reach Buzz	Infinitely generating	-	0 (0)	166.0(164.0), 15.9–452.6
Arm Reach Saw	Infinitely generating	-	0 (0)	85.3 (27.1), 59.7–136.1
Arm Reach Catch	Infinitely generating	-	0 (0)	104.2 (42.3), 61–144

Instruction booklet

Participants felt that the information provided in the instruction booklet for the hardware and software setup and NeuroVirt App navigation was adequate. Some participants recommended that NeuroVirt create a section with more specific instructions for the games. The participants were happy with the format as they expressed their preference for printed training material.

> *"You know, I have an e-book reader, never use it, I prefer my stuff in hard print, but that's the way my mind is wired"(P123,age range 70-80 years)*

Additional support

While many participants could independently operate the hardware, a few required assistances from their caregiver during the initial hardware setup. In contrast, when it came to the software, all participants indicated their dependence on caregiver support for its setup.

Participants that needed more support from the carer at the beginning, eventually starting to use NeuroVirt more independently. One family member of the participant stated:

> *"Towards the end you didn't need me anywhere near really" (P.114 family, age range 80-90 years)*

Another family member said:

> *Come the last probably week, in the last week when you were using it, I would come into a room, she'd already be using it. Whereas before, we will sit down together, yes, we're doing this now" (P.112 family, age range 50-60 years)*

Acceptability

User satisfaction

Majority of participants reported to feel motivated with the NeuroVirt UL home-program. Some participants

described their experience using words such as *"really good" (age range 50–60 years),* or *"really happy with it" (P.121, age range 30–40 years).* Some participants mentioned that a greater variety of games could enhance their motivation during training. Examples of proposed games by one participant were formula one, football, rugby; another participant proposed games similar to the beat sabre game or the pong.

Participants did however express that when there were technical issues which meant they were unable to progress in the game, they felt frustrated and would stop using it. One participant reported:

> *"Now in all of those games, you have to complete fairly adequately the previous bits of the game to progress, and it wasn't progressing beyond the middle of the jazz one and then one day it did. Hoorah, hoorah, and I thought oh thank god for that" (P.123, age range 70–80 years).*

Another participant also reported that the lack of in game feedback meant that the exercises became a *"chore"* and that they would have preferred an acknowledgement that they had *"gone up a level"*.

The flexibility of the home-based program was perceived as positive because it allowed participants to fit the NeuroVirt training program into their daily routines. One participant said:

> *" It fitted into the daily routine, yeah. I didn't really… Well it just fitted in didn't it?" (P.114, age range 80–90 years).*

Advantages identified in the context of immersing oneself in VR were that you do not realize that you are exercising and that participants felt that VR allowed them to do more movement repetitions than they would do otherwise. A challenge identified was that stroke survivors with severe sensory problems might struggle to discern the position of their arm within the immersive environment. Participants that reported cognitive or visual fatigue using the VR device had overcome this problem by splitting their exercise in two chunks, one participant stated:

> *" I tended to do my exercises in two chunks" (P.123, age range 70-80 years).*

Noticeable physical and non-physical impact

All participants noticed motor improvements in their affected upper limb after using NeuroVirt for 6 weeks. Six of them, were confident that these enhancements were attributed to NeuroVirt. Many participants reported that their affected arm was getting stronger or more mobile while others also reported functional improvements. One participant stated:

> *"Yes. I think it is helpful, even when I am turning over in bed or something I think having that bit of extra movement is useful. Sometimes I wake up and I am laying on my arm and I can actually roll over and get my arm out now" (P.121, age range 30–40 years).*

Another participant commented:

> *"Oh. Carrying things is much more easy. I can carry things in my … my arm crooks and things … I can carry over my arm" (P.113, age range 70-80 years)*

In addition to motor improvements, two participants reported sleeping better, and one participant also expressed her view about the benefits of NeuroVirt for other stroke survivors,

> *"I can really see the benefits for others doing it" (P.114, age range 80-90 years)*

Of the two participants one felt that they had improved arm function but felt that their grip wasn't as good although wasn't sure this was because of NeuroVirt or whether this had been happening anyway. The other participant was engaged in another trial of a different device at the same time and therefore was unable to apportion any improvement solely to NeuroVirt. Future studies aimed at determining the effectiveness of NeuroVirt need to ensure that participants are excluded if they are taking part in any other upper limb trials.

Discussion

NeuroVirt is an immersive virtual reality (VR) platform that was designed to encourage high-movement-repetitions UL rehabilitation training via games. However, the delivering of an UL rehabilitation intervention with the use of NeuroVirt at stroke survivors' own homes had not been tested. For that reason, the aim of the study was to investigate the technical feasibility, safety, and the preliminary usability and acceptability of delivering a 6-week upper-limb rehabilitation intervention with the use of the NeuroVirt system in stroke survivors´ own homes. Our participants represented a breadth of stroke survivors in terms of both age (33–80 years), stroke severity (Fugl-Meyer UL; 13 (severe) −108 (mild)) and time since stroke (6–96 months). The study has a small sample size, which therefore limits how representative the findings can be of the wider population of stroke survivors. We aimed to include people who were at least 3 months post stroke because we were recruiting from independent physiotherapy providers and this they felt was reflective of their client group. We did recruit however only people who

were between 6 and 96 months post stroke meaning our results are reflective of this group of people rather than those who were between 3 and 6 months.

Technical feasibility

The results revealed that during the study, there were 3 (1.51%) instances of Wi-Fi disconnection out of 198 sessions conducted in participants'own homes. Additionally, only 1 (0.09%) instance out of 1052 data push attempts failed, resulting in 0% data loss. These results suggest that the NeuroVirt platform has a high-backed stability and consistent Wi-Fi stability.

The results on frame rate showed that the NeuroVirt platform had an overall mean of 67.5 (2.27) fps during a session. The frame rate during a session for each game modality was above the 60-fps minimum industry standards recommendation for VR devices [17]. These results are important because evidence has shown that below 50 fps, gamers using VR are more likely to experience motion sickness, dizziness, headaches, nausea, fatigue, disorientation, and even pain [18]. Two technical bugs in the NeuroVirt games were promptly identified and resolved after the trial. While encountering technological issues in VR devices is not unusual, it is important to promptly detect and rectify them, as they can potentially lead to frustration for both therapists and patients [19, 20].

Performance and duration of rehabilitation material

In this study, participants trained the UL with NeuroVirt an average of 3.5 (1.3) sessions per week, and an average of 20 (9.4) minutes per session for a period of 6 weeks. These numbers are less than the 5 sessions per week, 45 min recommended in clinical guidelines for stroke survivors'rehabilitation programs [21]. However, in our study, the 20 (9.4) minutes per session exercising the UL, is superior to the 4 min in a conventional PT session and 11 min in an OT session reported in previous literature [22]. Additionally, our participants were a minimum of six months post-stroke where typically the amount of therapy that stroke survivors receive is scarce or non-existent [23] and compliance with a new exercise regime is likely to be less. Regarding movement repetitions, we found that the mean (SD) number of UL movements per session was 338.2 (172.7) (minimum–maximum: 133–605 movements) which is in the range of movements recommended in previous studies to enhance UL recovery [24], and on average ten times more intensive and superior to the 35 UL movements repetitions performed in a conventional therapy session [22]. 25% of participants removed the HMD more than once during half or more of the sessions. This is likely due to a combination of factors associated to VR devices, such as eye strain [25], and factors derived from the stroke such as post-stroke fatigue [26].

Safety, usability, and acceptability

Safety

No serious adverse events or a treatment-related adverse event was reported in this study, suggesting that the 6-week NeuroVirt UL rehabilitation program at home is safe for stroke survivors.

Usability

Assistive technology devices that are suitable for home use and do not require professional supervision are more often utilized for stroke survivors [27]. Our study shows that NeuroVirt is a device that could be used by stroke survivors to exercise the UL in their own houses with minimal contact with the therapist. Participants described face-to-face training with a therapist before taking a NeuroVirt device home was useful. In this study, participants received one session of face-to-face NeuroVirt training, and some participants reported that it would be helpful to have more than one session. Similarly, one study that explored the use of a new VR device with stroke patients in their own homes found that 10% of the participants required a second training session before independent use of the device [25].

The comfort of using a VR device is important for engagement [27]. A challenge identified in this study was the potential discomfort associated with wearing glasses while using the HMD. This matter should be addressed in a future study by providing the glasses adaptor, to each participant with glasses.

We found that the 15-min weekly telephone calls were enough to facilitate use of the NeuroVirt platform at home and these served to provide motivation and technical support without face-to-face contact. Previous studies have also reported the positive effects of having a therapist checking on the patients to improve engagement in home exercise programs [9]. If devices such as NeuroVirt are able to effectively support exercise delivery and adherence without face-to-face contact then there is significant potential for efficiency savings in the future, meaning more people may be able to access health services for longer.

For some people caregiver support was also identified as being important. In this study, we found that participants described needing more support from their caregiver at the beginning but were able to use the NeuroVirt platform independently towards the end of the six weeks. Feeling more independent is key for the majority of stroke survivors [28]. Evaluation of NeuroVirt in future studies needs to include the impact that its use may have on caregivers.

Acceptability

We found that 33% of our potential participants did not want to use NeuroVirt. Future studies would need to consider this and collect data to understand why this was the case or take this into account in the design of the study so that NeuroVirt could be evaluated effectively.

In this study, NeuroVirt platform included 6 games, and some participants felt that more variety of games would help to improve motivation during training as well as additional feedback. This issue has been previously reported in other VR device studies [25]. Before this article was finished NeuroVirt company added a new game into the platform and have responded to comments regarding how progress in games is fed back to the participant.

In this study, participants reported that they were able to fit the UL training home program into their daily routines, albeit at doses that were less than prescribed. However, participants perceived that the fully immersive VR modality allowed them to do more movement repetitions that they would do with conventional therapy, perhaps because the focus during training with fully immersive VR tends to be on gaming rather than exercise [29]. Interestingly, all participants who finished the six-week programme perceived UL motor improvements after the 6-week program. Nevertheless, additional research is essential to comprehensively assess the clinical and cost effectiveness of the NeuroVirt platform.

Conclusions

NeuroVirt immersive VR platform is safe to use in exercising the UL in stroke survivors' own houses with minimal therapist support. The results in technical feasibility found that the NeuroVirt platform is stable, and has consistent Wi-Fi stability, and the NeuroVirt scenes frame rate is above the 60 fps minimum industry standards. Qualitative findings identified that the participants were able to train their affected UL with the NeuroVirt platform at home, the majority expressed feeling motivated during the program, and all perceived UL motor improvements after 6 weeks.

Subsequent studies using the NeuroVirt platform would benefit from enhancing the onboarding process by incorporating a minimum of two in-person training sessions for participants to become well-familiarized with the NeuroVirt platform before commencing the home program.

Abbreviations

UL	Upper limb
Fps	Frames per second
UK	United Kingdom
VR	Virtual reality
AI	Artificial intelligence
FMA-UE	Fugl Meyer Assessment Upper Extremity
CAHAI-13	Chedoke Arm and Hand Activity Inventory-13
AE	Adverse event
SAE	Serious adverse event

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44247-025-00169-1.

Supplementary Material 1.

Supplementary Material 2.

Authors' contributions

KM: protocol creation, project coordinator, data analysis, major contributor in writing the manuscript MRHM: data analysis, major contributor in writing the manuscript. AW: protocol creation, project coordinator. EG: protocol creation, project coordinator for technology use. AC: protocol creation, data analysis, writing the manuscript. All authors read and approved the final manuscript.

Funding

NIHR i4i Connect: NIHR204467.

Data availability

The datasets generated and/or analysed during the current study are not publicly available. Data is provided within the manuscript or supplementary information files. Data requests of anonymised datasets can be made to the CI to access the data for scholarly or research purposes only. The CI will work with UEA Research and Innovation services to assess the appropriateness of each request on an individual basis. To request access to data please contact Dr Kathryn Mares (k.mares@uea.ac.uk).

Declarations

Ethics approval and consent to participate

This study was approved by the University of East Anglia ethics committee (Norwich Research Park, Norwich, NR4 7TJ, United Kingdom; All participants provided written informed consent.

Consent for publication

N/A.

Competing interests

The rest of the authors declare that they have no competing interests. Evridiki Gregoriou is the Co-Founder & CEO at NeuroVirt, she was involved in the protocol creation and project coordination, but not in the data collection or analysis.

Received: 28 October 2024 Accepted: 1 May 2025
Published online: 27 May 2025

References

1. Katan M, Luft A. Global burden of stroke. Semin Neurol. 2018;38(02):208–11.
2. Stroke Association. Stroke statistics. 2025. Available from https://www.stroke.org.uk/stroke/statistics. Accessed 6 May 2025.

3. Patel A, Berdunov V, King D, Quayyum Z, Wittenberg R, Knapp M. Current, future and avoidable costs of stroke in the UK. 2018. Available from: https://www.stroke.org.uk/sites/default/files/costs_of_stroke_in_the_uk_summary_report_0.pdf.
4. Barclay-Goddard R, Lix LM, Tate R, Weinberg L, Mayo NE. Health-related quality of life after stroke: does response shift occur in self-perceived physical function? Arch Phys Med Rehabil. 2011;92(11):1762–9.
5. Parker VM, Wade DT, Hewer RL. Loss of arm function after stroke: measurement, frequency, and recovery. Int Rehabil Med. 1986;8(2):69–73.
6. Birkenmeier RL, Prager EM, Lang CE. Translating animal doses of task-specific training to people with chronic stroke in 1-hour therapy sessions: a proof-of-concept study. Neurorehabil Neural Repair. 2010;24(7):620–35.
7. Pindus DM, Mullis R, Lim L, Wellwood I, Rundell AV, Abd Aziz NA, et al. Stroke survivors' and informal caregivers' experiences of primary care and community healthcare services – A systematic review and meta-ethnography. Woloschak GE, editor. PLoS ONE. 2018;13(2):e0192533.
8. Temehy B, Rosewilliam S, Alvey G, Soundy A. Exploring stroke patients' needs after discharge from rehabilitation centres: meta-ethnography. Behav Sci. 2022;12(10):404.
9. Donoso Brown EV, Dudgeon BJ, Gutman K, Moritz CT, McCoy SW. Understanding upper extremity home programs and the use of gaming technology for persons after stroke. Disabil Health J. 2015;8(4):507–13.
10. Gelineau A, Perrochon A, Daviet JC, Mandigout S. Compliance with upper limb home-based exergaming interventions for stroke patients: a narrative review. J Rehabil Med. 2022;24(54):jrm00325.
11. Murphy MA, Pradhan S, Levin MF, Hancock NJ. Uptake of technology for neurorehabilitation in clinical practice: a scoping review. Physical Therapy. 2024;104(2):pzad140. https://doi.org/10.1093/ptj/pzad140.
12. Wang M, Ma H, Shi Y, et al. Single-arm clinical trials: design, ethics, principles. BMJ Support Palliative Care. 2025;15:46–54.
13. Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med. 1975;7(1):13–31.
14. Barreca S, Gowland CK, Stratford P, Huijbregts M, Griffiths J, Torresin W, et al. Development of the Chedoke arm and hand activity inventory: theoretical constructs, item generation, and selection. Top Stroke Rehabil. 2004;11(4):31–42.
15. Price CIM, Curless RH, Rodgers H. Can stroke patients use visual analogue scales? Stroke. 1999;30(7):1357–61.
16. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77–101.
17. Zhang C. Investigation on Motion Sickness in Virtual Reality Environment from the Perspective of User Experience. In: 2020 IEEE 3rd International Conference on Information Systems and Computer Aided Education (ICISCAE). Dalian, China: IEEE; 2020. p. 393–6. Available from: https://ieeexplore.ieee.org/document/9236907/. Cited 2024 Mar 9.
18. Jerdan S, Grindle M, van Woerden H, Kamel BM. Head-mounted virtual reality and mental health: critical review of current research. JMIR Serious Games. 2018;6(3):e14. https://doi.org/10.2196/games.9226.
19. Pallesen H, Andersen MB, Hansen GM, Lundquist CB, Brunner I. Patients' and health professionals' experiences of using virtual reality technology for upper limb training after stroke: a qualitative substudy. Rehabil Res Pract. 2018;2018:1–11.
20. Levac D, Glegg SMN, Sveistrup H, Colquhoun H, Miller PA, Finestone H, et al. A knowledge translation intervention to enhance clinical application of a virtual reality system in stroke rehabilitation. BMC Health Serv Res. 2016;16(1):557.
21. Royal College of Physicians. SSNAP - Full 2016 guideline. Strokeaudit.org. 2016. Availablefrom: https://www.strokeaudit.org/Guideline/Full-Guideline.aspx.
22. Hayward KS, Brauer SG. Dose of arm activity training during acute and subacute rehabilitation post stroke: a systematic review of the literature. Clin Rehabil. 2015;29(12):1234–43.
23. Teasell R, Mehta S, Pereira S, McIntyre A, Janzen S, Allen L, et al. Time to rethink long-term rehabilitation management of stroke patients. Top Stroke Rehabil. 2012;19(6):457–62.
24. van Vliet P, Carey LM, Turton A, Kwakkel G, Palazzi K, Oldmeadow C, et al. Task-specific training versus usual care to improve upper limb function after stroke: the 'Task-AT Home' randomised controlled trial protocol. Front Neurol. 2023;14:1140017.
25. Kilbride C, Scott DJM, Butcher T, Norris M, Warland A, Anokye N, et al. Safety, feasibility, acceptability and preliminary effects of the Neurofenix platform for Rehabilitation via HOMe Based gaming exercise for the Upper-limb post Stroke (RHOMBUS): results of a feasibility intervention study. BMJ Open. 2022;12(2):e052555.
26. De Doncker W, Brown KE, Kuppuswamy A. Influence of post-stroke fatigue on reaction times and corticospinal excitability during movement preparation. Clin Neurophysiol. 2021;132(1):191–9.
27. Hughes AM, Burridge JH, Demain SH, Ellis-Hill C, Meagher C, Tedesco-Triccas L, et al. Translation of evidence-based assistive technologies into stroke rehabilitation: users' perceptions of the barriers and opportunities. BMC Health Serv Res. 2014;14(1):124.
28. Luker J, Lynch E, Bernhardsson S, Bennett L, Bernhardt J. Stroke survivors' experiences of physical rehabilitation: a systematic review of qualitative studies. Arch Phys Med Rehabil. 2015;96(9):1698-1708.e10.
29. Moan ME, Vonstad EK, Su X, Vereijken B, Solbjør M, Skjæret-Maroni N. Experiences of stroke survivors and clinicians with a fully immersive virtual reality treadmill exergame for stroke rehabilitation: a qualitative pilot study. Front Aging Neurosci. 2021;2(13):735251.

Publisher's Note