

The Co-Design of Immersive Virtual Reality Upper Limb Activities for People with Tetraplegia during Acute Rehabilitation: A Focus Group Study

Andrew Goodsell, Mariel Purcell, Matthieu Poyade, Louise Cownie, Co-designers,
Lorna Paul

Submitted to: JMIR Rehabilitation and Assistive Technologies
on: April 08, 2025

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on its website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressly prohibit redistribution of this draft paper other than for review purposes.

Table of Contents

Original Manuscript..... 5
Supplementary Files..... 28
..... 28
Figures 29
Figure 1..... 30



The Co-Design of Immersive Virtual Reality Upper Limb Activities for People with Tetraplegia during Acute Rehabilitation: A Focus Group Study

Andrew Goodsell¹ BSc, MSc; Mariel Purcell² MB, BCh, BAO, FRCP, MRCP; Matthieu Poyade³ BTECH, BEng, MSc, MPhil, PhD; Louise Cownie² BSc, MSc; Co-designers¹; Lorna Paul^{1,4} BSc, MPhil, PhD

¹ School of Health and Life Sciences Glasgow Caledonian University Glasgow GB

² Queen Elizabeth National Spinal Injuries Unit NHS Greater Glasgow and Clyde Glasgow GB

³ School of Innovation & Technology Glasgow School of Art Glasgow GB

⁴ UK & Northern Ireland Spinal Injuries Rehabilitation Specialists Glasgow GB

Corresponding Author:

Andrew Goodsell BSc, MSc

School of Health and Life Sciences
Glasgow Caledonian University
Cowcaddens Road
Glasgow
GB

Abstract

Background: The global incidence of spinal cord injury (SCI) is between 10 and 80 new cases per million people each year, with more traumatic injuries occurring than non-traumatic. This equates to between 250,000 and 500,000 injuries worldwide, per year. In the UK it is estimated that 4400 people per year sustain a SCI. People with tetraplegia report upper limb function as their highest priority for improvement after SCI. Using immersive virtual reality (VR) headsets, physical rehabilitation exercises can be completed in engaging digital environments. Immersive VR therefore has the potential to increase the amount of therapy undertaken, leading to improvements in arm and hand function. There is little evidence supporting immersive VR as exercise in SCI, especially while SCI patients are undergoing acute rehabilitation. This study recruited people with tetraplegia and therapists to establish the design direction for a VR-based upper limb exercise platform. In spinal cord injury research, co-design of new interventions is not a widely adopted approach, yet people with SCI want to contribute with their expert knowledge on their experiences of SCI.

Objective: To explore the lived experiences of people with tetraplegia and specialist SCI therapists related to acute upper limb rehabilitation and to co-design immersive virtual reality-based upper limb activities.

Methods: Seven focus groups were conducted online using Microsoft Teams: four with people with tetraplegia (n = 15, age range 36-65 years) and three with occupational therapists and physiotherapists specialising in spinal cord injury rehabilitation (n = 11). Participants were asked to discuss their experiences and expertise about acute SCI upper limb rehabilitation and their opinions on the use of VR for upper limb rehabilitation. The transcripts were analysed using content analysis enabling the proposition of design characteristics of a VR-based intervention for upper limb exercise.

Results: The study identified five major themes describing the clinical features, treatment, and recovery of spinal cord injured people during the acute stage of SCI, and suggestions for the design of a VR intervention in treating the upper limbs following SCI. The results highlighted what motivates people with SCI to participate in therapy and how these motivators could be encouraged and maintained using VR. These findings can be used to design accessible VR applications for use by people with SCI and their therapists. They can also contribute to the better understanding of the advantages of using VR as an adjunct to upper limb rehabilitation, as well as features of VR-based interventions to avoid.

Conclusions: The themes identified in this study allow the elicitation of software requirements for a bespoke immersive VR platform for upper limb rehabilitation following spinal cord injury. Additionally, participants used their expertise to suggest factors that would enable the development of a usable and effective intervention as well as identifying potential pitfalls and software features to avoid during the intervention development.

(JMIR Preprints 08/04/2025:66832)

DOI: <https://doi.org/10.2196/preprints.66832>

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible to all users.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in a JMIR publication, my accepted manuscript PDF will be visible to all users.

No. Please do not make my accepted manuscript PDF available to anyone.

Original Manuscript

The Co-Design of Immersive Virtual Reality Upper Limb Activities for People with Tetraplegia during Acute Rehabilitation: A Focus Group Study

Abstract

Background: The global incidence of spinal cord injury (SCI) is between 10 and 80 new cases per million people each year. This equates to between 250,000 and 500,000 injuries worldwide, per year. In the UK approximately 4400 people per year sustain a SCI. People with tetraplegia report upper limb function as their highest priority for improvement after SCI. Using immersive virtual reality (VR) headsets, physical rehabilitation exercises can be completed in engaging digital environments. Immersive VR therefore has the potential to increase the amount of therapy undertaken, leading to improvements in arm and hand function. There is little evidence supporting immersive VR as exercise in SCI, especially while SCI patients are undergoing acute rehabilitation. In spinal cord injury research, co-design of new interventions is not a widely adopted approach, yet people with SCI want to contribute with their expert knowledge on their experiences of SCI.

Objective: To explore the lived experiences of people with tetraplegia and specialist SCI therapists related to acute upper limb rehabilitation and to co-design immersive virtual reality-based upper limb activities.

Methods: Seven focus groups were conducted online using Microsoft Teams: four with people with tetraplegia ($n = 15$, age range 36-65 years) and three with occupational therapists and physiotherapists specialising in SCI rehabilitation ($n = 11$). Participants were asked to discuss their experiences and expertise about acute SCI upper limb rehabilitation and their opinions and ideas on the use of VR for upper limb rehabilitation. The transcripts were analysed using content analysis enabling the proposition of design characteristics of a VR-based intervention for upper limb exercise.

Results: The study identified five major themes describing the clinical features, treatment, and recovery of spinal cord injured people during the acute stage of SCI, their motivations for participating in therapy, and suggestions for the design of a VR intervention in treating the upper limbs following SCI. The results highlighted what motivates people with SCI to participate in therapy and how these motivators could be encouraged and maintained using VR. These findings were used to design accessible VR applications for use by people with SCI and their therapists.

Conclusions:

The themes identified in this study allow the elicitation of software requirements for a bespoke immersive VR platform for upper limb rehabilitation following SCI. They can also contribute to the better understanding of the advantages of using VR as an adjunct to upper limb rehabilitation, as well as features of VR-based interventions to avoid. Additionally, participants used their expertise to suggest factors that would enable the development of a usable and effective intervention as well as identifying potential pitfalls and software features to avoid during the intervention development.

Ethical Approval: Ethical approval granted by the Psychology, Social Work, and Allied Health Sciences (PSWAHS) Research Ethics Committee of Glasgow Caledonian University (reference: HLS/PSWAHS/21/247).

Keywords: Virtual Reality; Spinal Cord Injury; Upper Limb Rehabilitation; Co-Design; Focus Groups; Acute Tetraplegia; Secondary Care.

Introduction

A spinal cord injury (SCI) results from an insult to the spinal cord and impacts nearly every aspect of a person's life. People with SCI usually have a degree of permanent neurological disability, including muscular paralysis and loss of sensory and autonomic function below the level of their injury [2]. The global incidence of SCI is between 10 and 80 new cases per million people each year [1], with 4400 new cases per year in the UK [3]. The lifetime costs of SCI are estimated to total £1.43 billion for 1270 cases per year in the UK [4].

The level of SCI is a major factor determining the degree of independence a person will achieve following injury [5]. Typically, the higher the level of injury, the lower the level of independence [6]. Damage to the cervical spinal cord results in tetraplegia, where function of all 4 limbs is impaired [7]. As well as physical and sensory issues, people with SCI are at risk of pressure ulcers, urinary tract infections, spasticity, autonomic dysreflexia, depression, neuropathic pain, difficulty breathing, and circulatory problems [8]. This multitude of impairments following SCI is associated with lower quality of life [9].

Immediately following injury, SCI patients require acute medical management. This is followed by a period of rehabilitation as an inpatient. The aim of rehabilitation post SCI is to optimise recovery, restore and maximise function by leveraging activity-dependent plasticity for neurological recovery, learn compensatory techniques for lost function, and prevent secondary complications [10]. Central nervous system plasticity, where neural pathways can be altered in response to an injury and promote recovery, can occur spontaneously or as a result of rehabilitation [11]. In the last thirty years, the primary aim of physical rehabilitation of SCIs has moved away from compensatory strategies to neurological recovery, particularly in people with incomplete SCI [12]. Incomplete SCI refers to the preservation of sensory and/or motor function below the level of injury, as opposed to complete injuries, which do not have preservation of movement [7]. Rehabilitation is life-long, but it is recommended that rehabilitation starts early after injury to maximise functional status and clinical outcomes [10].

Reducing reliance on care and achieving higher levels of independence with respect to activities of daily living (ADLs) is a major goal for SCI patients and therapists [13]. Improving motor function, especially of the upper limbs, through rehabilitation [14] enables SCI patients to carry out tasks, such as dressing, bladder and bowel care, transferring in and out of a wheelchair, and feeding which may otherwise require a carer [15–17]. Even small improvements in upper limb function can have large effects on a patient's independence [18,19]. It is understandable therefore that improving upper limb function is a high priority for people with tetraplegia [13,20–22].

Improvements in upper limb function can be achieved through Activity-Based Therapy (ABT) [23]. ABT, a rehabilitation approach, refers to any intervention that involves high intensity, repetitive exercises which target activity-dependent plasticity in spinal circuits [24]. The improvements in upper limb function from ABT have greater effects on quality of life when compared to traditional physical interventions targeted above the level of injury [19].

Virtual Reality (VR) technology has the potential to deliver upper limb therapy by providing engaging interventions for SCI patients as part of their rehabilitation [25,26]. Immersive VR delivers to the user a real-time digital environment that incorporates multimodal sensory paradigms including proprioception, kinaesthesia, stereopsis (the perception of depth via a stereoscopic display) and spatial audio, and the ability to interact within the digital environment via head and hand tracking

[27]. In these environments repetitive upper limb movements, similar to ABT, can be performed. VR-based therapy can facilitate greater adherence to therapy [28], and increase access to the most effective rehabilitation strategies for people with neurological disorders [27]. However, currently there are few studies that have investigated the use of VR in SCI rehabilitation of the upper limbs with most focussing on the chronic stage after injury.

Six systematic reviews published between 2019 and 2024 have evaluated the evidence for VR for upper limb rehabilitation following SCI. These reviews included between three and seven studies involving the upper limb. The overall findings from these reviews suggested that the evidence base is limited and that immersive VR appears to be more beneficial than non or low immersive VR [28–32]. However, these studies also suggested that exercises delivered in immersive VR could be used as an adjunct to conventional rehabilitation, although further investigation would be needed.

The VR devices and software used for upper limb therapy vary widely in terms of fidelity, cost, and the design and production of the software have rarely incorporated the lived experiences of SCI experts (SCI patients and healthcare professionals). The input of end-users into the development of software, particularly in healthcare, is important in delivering successful products [32–34]. This process allows highly customised and bespoke projects to be developed, ensuring that the service or intervention is targeted towards the needs of SCI patients [33]. This study forms the first part of a co-creation process for the design of a suite of VR-based exercises for upper limb rehabilitation in the acute SCI rehabilitation context .

The aim of this study was to explore the lived experiences of people with tetraplegia and specialist SCI therapists related to acute upper limb rehabilitation and to co-design immersive virtual reality-based upper limb activities. Methods

Design

In this qualitative study, seven focus groups were conducted online from August to October 2022 to gather opinions and insights from the lived experiences of people with SCI and, separately, SCI specialist therapists with experience of upper limb rehabilitation.

Participants

A convenience sample of people with (a) tetraplegia and (b) therapists specialising in spinal cord injury rehabilitation were recruited. Although the VR intervention was to be developed for inpatient SCI rehabilitation, in order to fully explore lived experiences of people with SCI, the study recruited people who had been discharged from hospital having completed rehabilitation.

a) People with SCI were recruited through the third sector organisation, Spinal Injuries Scotland (SIS). Recruitment material was also shared on social media channels (Twitter and LinkedIn). Inclusion criteria for participants with SCI were a diagnosis of non-progressive tetraplegia, discharged from a spinal injuries unit having received upper limb therapy, over 18 years of age, able to attend focus groups and contribute in spoken English, and have been discharged from hospital having received upper limb rehabilitation as part of their treatment. Exclusion criteria were any co-morbidities that could preclude participants from attending and contributing to focus groups.

b) Therapists (occupational therapists (OTs) and physiotherapists (PTs)) were recruited via similar social media channels and a WhatsApp group of UK and Ireland-based SCI rehabilitation specialists. Inclusion criteria for therapists were being over the age of 18 years, and able to attend and contribute to focus groups in spoken English.

Respondents to recruitment material emailed AG to register interest in participating in the study. Participant information sheets were provided to these interested parties by email. Participants provided informed consent prior to taking part in the study by either printing and physically signing a digital consent form, or completing the form digitally. Participants without the physical ability to sign consent forms provided consent by designating a witness to sign on their behalf [36].

After providing informed consent, participants were asked to complete a demographic information form; for people with tetraplegia this included their age, sex, Spinal Cord Independence Measure (SCIM) self-reported score [37], and for therapists this included sex, occupation, and years of professional experience.

Focus Groups

Participants with SCI were asked to recall their experiences of the acute stage of in-patient SCI rehabilitation. They were also asked to discuss upper limb impairments caused by SCI and how these relate to prehension, strength, and range of motion. Therapists were asked about the current practise surrounding delivery of upper limb therapy. Both cohorts were asked to discuss their opinions on VR as an adjunct to usual upper limb rehabilitation, and the potential facilitators and barriers to its use in the acute rehabilitation setting. Participants were introduced to the concept of VR as a commercial product for immersive entertainment. They were shown a portion of video promoting a high-immersion head-mounted display being used by able-bodied people to play interactive games [38]. Additionally, specifications for the design of a VR system to promote upper limb exercise were gathered from both groups.

Question schedules were created in order to facilitate discussion. The questions were devised to enable future software design and software requirements specification. Each focus group had two facilitators, AG (male) and LP (female). Three focus groups of therapists and four focus groups of people with SCI were conducted. The duration of focus groups ranged between 45 and 75 minutes.

Analysis of Transcripts

Focus groups were audio-recorded and recordings were transcribed verbatim following pseudonymisation of participants. Transcriptions were generated manually in order to enable familiarisation with the data. Inductive content analysis was used to count the responses and determine the meaning of participants' discussions [39]. Data were managed using NVivo 20 [40]. Therapist and SCI focus groups were analysed separately. After codes were generated by AG, they were independently reviewed by LP, MPo, and MPu. AG, LP, MPo, and MPu discussed codes to come to a consensus on identification of codes and naming of themes in the theme hierarchy. Quotes are presented with participant identifiers and focus group (FG) number.

Codes (units of meaning) were typically sentences, phrases, or longer portions of text. Shorter phrases and sometimes single words were coded if they related specifically to recommendations for the design of the VR games. Initially, codes were first organised under categories deduced from the schedule of questions. Sub-themes were abstractions of groups of similar codes and were created during coding. Major themes were then generated from groups of sub-themes and replaced the organisational categories. Transcripts were not returned to participants for comments or corrections.

Reflexivity

Relationships with study participants were not established prior to the study commencement. LP had previous experience facilitating focus groups and interviewing research participants, but AG did not. Neither facilitator worked in SCI rehabilitation and as such reduced the likelihood of inhibiting frank

discussion about patient care with participants [41].

Results

Recruitment

Eighteen people with SCI and fourteen therapists expressed interest in the study. Three therapists and three people with SCI did not attend the focus groups thus 15 people with tetraplegia and 11 therapists took part (Table 1). Three focus groups with therapists and four focus groups with people with SCI were conducted. Seven SCI participants did not complete the demographic information forms. Reasons for not completing the information form included technical difficulty completing the form (only reported by participants with SCI). Three therapists did not report their years of professional experience. Therapists reported not having enough time, or opted out of form completion with no reason given. Half of SCI participants had experienced immersive VR at least once, but none had extensively used VR.

SCI participants had a range of SCIM scores demonstrating a variety of levels of independence.

Table 1. Summary demographic information for participants with tetraplegia and therapist participants.

Spinal Cord-Injured Participants (n=15)		
Mean SCIM score* (SD) (n=8)		17.9 (SD 6.4)
Mean age (SD) (Years) (n=8)		54.5 (SD 8.6)
Sex M/F (n=13)		10/5
Experience with VR None/Some (n=8)		4/4
Therapist Participants (n=11)		
Professional	Background	(n=11)
Occupational Therapists		7
Physiotherapists		4
Mean years of professional experience** (n=8)		14.8 (SD 8.6)
Sex M/F (n=11)		2/9

**Only 8 out of 15 SCI participants completed the SCIM and age information. 13 participants recorded their sex. Lower SCIM score values indicate lower independence out of a total of 75 points. Only 15 subscales out of a total of 19 were included, including six items related to self-care, and nine items related to mobility.. **Three therapists did not report their years of professional experience.*

Themes

Analysis of the focus group transcripts identified five major themes shared by the therapists (TPs) and SCI participants (SCIPs); Descriptions of SCI impairment, descriptions of acute rehabilitation, factors affecting participation in therapy, perspectives on VR, and suggestions for VR design. A total of 35 sub-themes were generated from 660 and 600 individual codes from the SCI and therapist groups transcripts respectively (Figure 1).

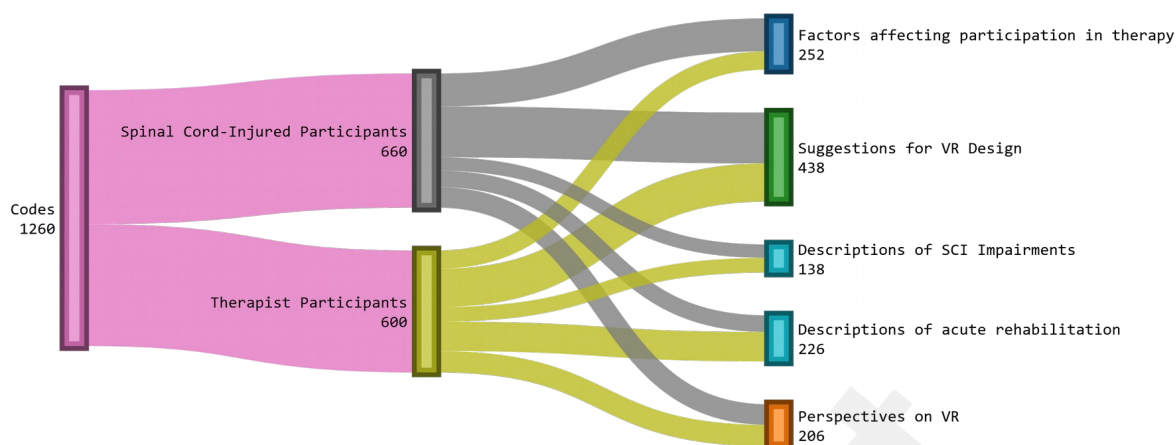


Figure 1. Visual summary of the number of Major Themes (listed in the right column) identified from the 1290 codes (shown on the left column) generated by content analysis of focus groups with SCI participants and therapists.

Presentation of Major themes and their Sub-themes

Major Theme 1: Descriptions of SCI Impairments

Five sub-themes were identified that described impairments resulting from spinal cord injury immediately after injury and during the acute stage of rehabilitation (Error: Reference source not found).

Descriptions of SCI impairments			
Sub-Theme	Number of TP Codes	Number of SCIP Codes	Total
Impairment of upper limb movement	17	28	45
Other impairments	27	8	35
Impairment of function including ADL *	9	19	28
Heterogeneous presentations and demographics	16	2	18
Impairment of upper limb strength	3	9	12

Table 2. Summary of sub-themes for the major theme 'description of SCI impairments'. *ADL = Activities of Daily Living

Both groups described impairments related to upper limb movement and strength and impairment of function as a result.

My arms, I wasn't able to move them at all after I had my accident. (SCIP27, FG 3)

Similarly both groups described a highly variable presentation of upper limb impairments, depending on e.g. the level and severity of injury.

I suppose [the degree of upper limb impairment] depends on the severity of your tetraplegic-ness, you know. Some people might, might be really bad and some people might still have a bit of movement. (SCIP27, FG 3)

Both groups, but especially therapists, discussed 'Other impairments'. These included spasms, pain, and mental health issues with therapists also raising age related comorbidities and complications.

Therapists specifically raised the concept of 'heterogeneous presentations and demographics' in acute SCI patients, with a growing prevalence of central-cord syndrome, in older adults presenting as greater weakness in the upper limbs (than lower limbs) and greater involvement of distal muscles

[7].

You could have somebody who's got, you know, full shoulder movement, full elbow movement, but they've got some weakness in the hands. Or the opposite, you know you could have someone who has got good hands but reduced movement at the shoulder. (TP03, FG 1)

Major Theme 2: Descriptions of Acute (inpatient) Rehabilitation

Seven sub-themes described the rehabilitation SCIPs received and therapist deliver during the acute inpatient stage (Table 3Error: Reference source not found).

Table 3. Summary of sub-themes for the major theme 'descriptions of acute rehabilitation'.

Descriptions of acute rehabilitation			
Sub-Theme	Number of Therapist Codes	Number of SCI Codes	Total
Upper limb therapy	92	51	143
Patient-centered care	31	0	31
Assistive devices, orthotics, and neck stabilisation	0	16	16
Barriers to effective therapy	12	0	12
Psychological adjustment and treatment	4	9	13
Bed rest and ventilation	0	5	5
Symptom management	6	0	6

Both groups described a large variety of upper limb activities ('Upper Limb Therapy') people receive as inpatients after SCI including functional tasks and remedial activities targeted to their individual requirements. TPs specifically described therapy to maintain and improve range of movement, muscle strengthening, and activities of daily living-type activities.

[...] we do work on range of movement, you know shoulder, elbow, wrist, fingers. (TP7, FG 2)

There were various things that we used—we had these games where we had little pegs that we had to move around the board, or also another one with a bucket full of the marbles. (SCIP16, FG 4)

TPs also discussed upper limb functional improvement, particularly where SCI patients have incomplete injuries:

If they're an incomplete injury we might be looking for more of a normal movement. [...] Whereas if they're more of a complete, it's obviously looking at function and how we can use what they've got—what muscles they've got working to functionally achieve the task. (TP09, FG 2)

Both groups highlighted the common use of 'Assistive devices' during rehabilitation, which included arm and hand stabilisation using orthotics and neck stabilisation, which hindered their movement.

I had to use the Active Hand, which are the Velcro gloves so I could hold things. (SCIP16, FG 4)

I was 12 weeks in a neck brace, so I ended up with a very, very weak neck. (SCIP13, FG 3)

There were some sub-themes that were only raised by the therapists. In terms of ‘Patient-centered care’, therapists described working in collaboration with SCI patients by choosing activities based upon a patient’s goals.

We would set those goals collaboratively with the patient based on a little bit of, kind of advice and guidance from us as to what we anticipate their outcomes might be. (TP05, FG

1)

Under ‘Barriers to effective therapy’, TPs stated that limited resources and long wait times for treatment could exacerbate impairments and affect recovery.

Unfortunately the later we get someone sometimes the more issues we can have with contractures and upper limb pain and things, which then makes it harder for us then to, to rehab them. (TP09, FG 2)

Both groups identified that in acute SCI there was a process of ‘Psychological adjustment and treatment’. SCIPs referred to this in terms of how SCI patients perceived treatment, finding it difficult to psychologically adjust, whereas TPs discussed how an understanding of the psychological impact of SCI was needed to manage expectations of patients about recovery.

Trying to deal with everything and I found it really hard to be having to rely on other people for your personal care just day in, day out for everything. (SCIP21, FG4)

In their mind they want [a goal] to be achievable. So it, again comes down to communication and managing those expectations of patients and their families. (TH9, FG2)

‘Bed rest and ventilation’ and ‘Symptom management’ were less commonly raised in either groups.

Major Theme 3: Factors Affecting Participation in Therapy

Ten sub-themes were identified that described the factors that affect SCI patients’ participation in therapy during the acute stage. Sub-themes were then classified as ‘Motivational’ or ‘Demotivational’ (Table 3Error: Reference source not found).

Table 4. Summary of sub-themes for the major theme ‘factors affecting participation in therapy’. Sub-themes are categorised as either promoting motivation, or reducing motivation.

Factors affecting participation in therapy				
Sub-Theme	Motivational or Demotivational	Number of Therapist Codes	Number of SCI Codes	Total
Useful or enjoyable rehabilitation	Motivational	1	39	40
Goal setting and therapist support	Motivational	6	31	37
Understanding tasks and prognosis	Motivational	30	0	30
Peer support and competition	Motivational	5	11	16
Seeing improvement	Motivational	0	10	10
Boring, repetitive or difficult rehabilitation	Demotivational	5	41	46
Limiting symptoms	Demotivational	22	6	28
Low mood	Demotivational	11	6	17
Downtime	Demotivational	0	15	15
Limited resources and lack of supervision	Demotivational	10	3	13

SCIPs commonly stated that therapy should be useful and/or enjoyable and that game-based therapies and functional tasks were more motivational when compared to simpler remedial activities

We had some games to play, which is quite good fun. Like maybe like playing dominoes. Uh, so fiddling about with them things and also trying to build things with Lego was quite motivational and we had a tower of blocks that was probably my favourite thing. (SCIP26, FG 4)

In contrast, 'Boring, repetitive, or difficult rehabilitation', which included pointless, tedious and humiliating activities was demotivational.

You know what it's like sometimes you go and do a bit of exercise, you know you're pulling on a TheraBand and [imitates snoring] 'boring!'. (SCIP01, FG 1)

Sometimes strategies that were intended to make therapy more enjoyable, such as creative activities using putty or interactive cycling, were frustrating for SCI patients.

[...] most days doing the exercises with the putty and so on, it felt like a really kind of childish, I don't know. Like, 'what's this doing?'. (SCIP21, FG 4)

And [patients] found that really—you know they were cycling [FES cycling] away, cycling away along this road but they never went anywhere. And they got really frustrated by that. (TP09, FG 2)

Some activities were too difficult or too easy for SCIPs, which resulted in them disengaging with therapy.

I also had a board with different sizes of bolts and nuts that are had to screw and I hated that because I thought, you know, 'I can't do this! Why are they making me do this when I cannot do it? This is so humiliating'. (SCIP16, FG 4)

SCIPs described that collaboratively setting rehabilitation goals such as improving independence or taking part in hobbies was motivational ('Goal setting and therapist support'). This also related to 'Seeing improvement' which was a key motivating factor.

[...] my goal was actually to, to get back up. Yeah, to be to be at least 100% OK. [...] I had the zeal. I had the zeal to be—to, to carry on with it. (SCIP19, FG 3)

TP discussions described SCI patients were more motivated if they understood about injury, prognosis, and purpose of therapy ('Understanding tasks and prognosis').

[Patients need] to have a good understanding of their injury and what the task is working towards. If they don't then often they're: "What's the point?" or "I don't really know why I'm just rolling this putty out". Umm "I'm not gonna get any better" or "How's this gonna strengthen?". So how much they understand about their injury is really important in their engagement. (TP05, FG 1)

Both groups also raised that 'Peer support and competition' could be motivational

Some of our patients.... a kind of element of challenge or competition almost with themselves in some of the more repetitive remedial tasks, um, can be really beneficial—like if they get 10 pegs one day - the next time they want them to get 15. (TP04, FG 1)
I think being in the group as well gave you a bit more, you know, just a bit more reason

to sort of get on with it and people would be chatting and you had that, you know, nice social aspect as well. (SCIP27, FG3)

Conversely comparing progress with other SCI patients could be demotivational.

Other people were whizzing through and you just sat there doing like one at a time. And it was just demoralizing. (SCIP21 FG 4)

Symptoms such as fatigue, pain, bladder and bowel problems and 'Low mood' negatively affected engagement in therapy..

[...] a lot of the time I was just knackered, it turned out that I had an underlying infection due to the metalwork in the back of my neck. (SCIP01, FG1)

A lot of pain can be difficult for them to kind of adhere to upper limb therapy (or any therapy). (TP04, FG 1)

I mean, some people in the unit—when I was there for 12 months didn't do anything. And they just lay in bed. They gave up. (SCIP4, FG 2)

Disengagement could occur if therapists could not be present at all times during therapy ('Limited resources and lack of supervision):

[...] you know people who never do what's asked of them unless someone's standing over them making them do it (TP12, FG 3)

You know, they did their best to keep things fresh and, and try introduce, but obviously they had a limited amount of resources available to them, but equally limited staff time (SCIP13, FG 3)

Finally, SCIPs identified 'Downtime' especially at the weekend meant there was nothing to do, and as such was demotivational.

The weekends at the spinal unit are, are very long and you just you know everything finishes on a Friday and you do nothing till Monday and you just feel I could I could be doing [something]. (SCIP27, FG 3)

Major Theme 4: Perspectives on VR

Nine sub-themes were identified that described the participants' perspectives (positive or negative) on VR (Table 5).

Table 5. Summary of sub-themes for the major theme 'perspectives on VR'. Sub-themes are categorised as having a positive or negative sentiment.

Perspectives on VR				
Sub-Theme	Positive or Negative Sentiment	Number of Therapist Codes	Number of SCI Codes	Total
VR could/should be engaging & meaningful	Positive	14	31	45
VR could/should be used for rehabilitation	Positive	9	18	27
Younger SCI patients will like VR	Positive	9	0	9
VR could alleviate symptoms	Positive	5	4	9
Consumer equipment is not suitable	Negative	29	15	44
VR could cause adverse effects/be inappropriate	Negative	17	33	50

Resources are limited	Negative	15	0	15
Training is required	Negative	7	0	7

Both SCIPs and TPs were enthusiastic about using VR ('VR could/should be used for rehabilitation').

So I think VR would have a very big use in a spinal injury centre there's a whole range of things it could cover. It's exciting it would be fun to use with people. (TP8, FG 3)

SCIPs suggested VR could be motivational especially for SCI patients who disengage from typical therapy.

I think [VR] is great because as I said earlier, there are other people [in hospital] who, you know, their mindset is totally negative. [...] they need that stimulation, that encouragement, and VR might be the way. (SCIP04, FG 2)

[VR could] make any training or rehab more, more interesting, more exciting, more varied. Yes, I think... huge potential. (SCIP13, FG 3)

So [VR scenarios] don't have to be, you know, your everyday mundane activities that we have to do in terms of getting up, getting dressed, getting washed, but you know, activities that are you know, leisure activities, occupations that are meaningful to the patient. (TP7, FG 2)

Both groups said that VR could encourage engagement in therapy by reducing symptoms such as pain and improve mood ('VR could alleviate symptoms').

And [VR is] good, actually help people to get involved in activities without even imagining the pain they are in. (SCIP19, FG 3)

I do quite like that element of escapism for them, I think. It could psychologically really help them as well. (TP3 FG 3)

Conversely both groups identified negative perspectives on the use of VR as a rehabilitation tool.

TPs warned that their 'Resources are limited' and that also 'Training is Required' to use new equipment. Resource limitations which included low staffing, physical space, equipment, could negatively impact the implementation of VR.

If [devices] are too labour intensive or take a while to set up or need someone there then when we're short-staffed as we have unfortunately been for quite a long time, um, you tend to go for things that are quicker and easier to use if you've only got quite a short treatment session. (TH9, FG2)

TPs and SCIPs identified problems from their previous experience with 'off the shelf' hardware and software ('Consumer equipment is not suitable). For example, VR head-mounted displays, which are not specified for use by people with SCI, may be too heavy, bulky or lead to unwanted neck movement.

The other thing as well is our very high injury levels, [who are] struggling just holding their head up—or that kind of movement with the head [TP8 demonstrates neck rotation] a lot—it can tire them. (TP8, FG 3)

TPs speculated that their younger SCI patients would be more suited to VR games ('Younger patients will like VR').

So I think the younger people will probably get [VR], you know they'll understand a lot better how it works. (TP4 FG 1)

Both groups warned that 'VR could cause adverse effects' such as nausea, or that the specific activities in VR that could remind them of their SCI

I think when you're already feeling self-conscious about yourself as an individual and how you move... em VR might have a bit of a negative effect on people as well. (TP05, FG 1)

When you take [the VR headset] off and you go 'Oh shit. It's true, this is where I am'. (SCIP21, FG 4)

Major Theme 5: Suggestions for VR Design

Five sub-themes were identified that described the participants' suggestions for the design of the VR system Error: Reference source not found (Table 6).

Table 6. Summary of sub-themes for the major theme 'suggestions for VR design'.

Suggestions for VR design			
Sub-Theme	Number of Therapist Codes	Number of SCI Codes	Total
Activities and scenarios	86	150	236
Usability and training	32	33	65
Measuring performance and achievement	38	27	65
Movements	21	23	44
Immersion, presence, and engagement	11	17	28

All participants suggested 'Activities and scenarios' which could be deployed in VR. SCIP suggestions included sporting activities and everyday skills, such as gardening and cooking. TPs suggested vocational and functional skills such as driving.

[...] it's down to the individual what interests they have and you know what would benefit them the most and... I mean, metalwork is obviously not gonna be the same as scuba diving and, you know, skiing, or playing the piano. One's having loads of fun, one's more sort of creative and you're constructing something in VR. Yeah. So yeah, just depends. (SCIP04, FG 2)

TPs also discussed providing a range of different activities for their patients. Both groups recommended incorporating concepts such as relaxation and escapism into the design ('Immersion, presence, and engagement').

So we are really trying to provide a variety of different type of games that we offer but obviously when you've got a patient who's had a long (and all of our spinal injury patients have quite a long) admission with us, it's like the variety that's key. (TP14 FG 3)

What about making really realistic sound, [...] soaring noises, painting noises of the paint going on to the wall and those kind of things where it actually feeds back extra reality to the experience? (SCIP16, FG 4)

Additionally, SCIPs and TPs suggested outdoor spaces such as hills, glens, mountains underwater

spaces, outer-space, jungles would be good environments for VR activities.

[I have] a static bicycle at home. I get a bit bored because I'm always in the same place, while if you could have the feeling that you're actually outside and going places that might make it more interesting. (SCIP16, FG 4)

Both groups said that VR games should enable a range of movements, from fine to gross ('Movements') including reaching, grasping, and wrist flexion and extension.

[VR] could be something that could be really useful for larger gross movements but also for really drilling down to repetition of very fine motor movements. (TP12, FG 3)

TPs also recommended the quality of movements in VR was of high importance.

Sometimes it's not the number of movements, it's quality as well. So, you know, we'd be looking at the quality of someone's reach, not just that they are able to reach, but maybe not recruiting the right muscle groups to perform that task. (TP09, FG 2)

Both groups gave recommendations for 'Measuring performance and achievement' of users. These included giving encouragement and providing feedback to increase engagement. TPs discussed providing incremental levels of difficulty to accommodate progression and achievement.

[...] like you get a big tick or a big thumbs up or something. Not something annoying but something that shows you've reached the level of the activity that's actually doing something. (SCIP27, FG 4)

TPs recommended incorporating easily comprehensible progress reports and feedback to users to help with motivation.

[...] and patients love seeing kind of that—we can put it—display it on a graph for them to kind of say like this is what you did like a month ago and this is what you're doing now. (TP08, FG 3)

TPs and SCIPs recommended that the movements should be configurable for users, and that training should be provided to SCI patients and therapists ('Usability and training').

So there's gonna have to be sort of that adjustability with the system to make it relevant to that patient's rehab and what muscles you want to work on and that, yeah. (TP07, FG 2)

Also under this sub-theme it was highlighted that adding straps to the controllers might be required and for those with limited hand function, SCIPs also requested interaction mechanisms using head-movement, gaze, hand tracking, and voice input.

I think you'd have to be really aware of even things like how people could grip any hand controls, you know, just the simple things like holding them, putting headsets on, how much assistance was needed to make it as practical as possible. (SCIP21, FG 4)

Discussion

Principal Results

The aim of this qualitative study was to explore the lived experiences of people with SCI and SCI specialist therapists in terms of upper limb rehabilitation in order to inform the design of a VR-based intervention. Five major themes and their associated sub-themes were identified that enabled the

specification of software requirements which have subsequently been implemented in a prototype VR intervention. The focus groups indicated that VR has the potential to help improve function and build strength, as well as learning skills, by adapting to loss of function.

The findings indicate the need for the VR intervention to account for the variation in the upper limb impairment people might have following SCI. To account for diverse user profiles and needs, the software has to adapt to the personal rehabilitation needs of the user. Therapists discussed that VR activities would be suited for younger SCI patients. However, developing the intervention to only target this demographic would be contrary to the needs established by TPs and SCIPs. This reiterates the importance of designing VR activities with broad appeal among different demographics as well as keeping usability a development priority, particularly since most participants had little to no experience with using VR.

This study provides insight into factors which motivate inpatients with SCI to participate in rehabilitation and also factors which cause disengagement. Typical barriers to participation reported by people with SCI and SCI therapists in the literature were corroborated by the results. Barriers included comorbidities such as urinary tract infections, pressure sores, fatigue, pain, and low mood, as well as the resource limitations of healthcare providers, 'downtime', the difficulty accommodating the large variation in rehabilitation needs of each SCI patient, and patients' need for more control over their therapy combined with the effects of lowered independence [42–45]. In addition to these factors, all participants provided details about the barriers and facilitators to participating specifically in upper limb activities. SCI patients were described to have a high level of motivation that is driven by the will to improve and become more independent. This feature could have been influenced by the characteristics of the participants with SCI, who would be more likely to attend research studies. Motivation driven by 'seeing improvement' or 'competition' could be capitalised upon by using VR to provide feedback about task progress and performance concurrently and post-task to users. This motivation could also be conducive to participation in VR therapy, as in a willingness to try a novel therapy, or participate in VR in addition to the usual treatment.

SCIPs saw VR as an assistive technology to enhance function and therefore improve independence, a factor previously shown to be of high importance to people with SCI [46]. In addition, VR was perceived as a tool to give SCIPs independence during their rehabilitation. This could be important for acceptability of VR interventions, as SCIPs wanted to minimise extended periods of 'downtime' while in hospital. The findings also indicate that people with SCI are motivated by choice, having control over their therapy, and establishing a good relationship with their therapists. This could also enable therapists in administering or prescribing therapy, by facilitating movements that are typically difficult to achieve in usual treatment or that are more appealing to SCI patients.

Barriers to rehabilitation included the repetitive nature of upper limb exercise. VR could maintain motivation by using repetitive input to drive engaging game mechanics such as firing a bow and arrow, hitting boxing targets, or completing puzzles. Improving scores over time and stimulating 'interpersonal' and 'intrapersonal' competition could also encourage users to adhere to repetitive therapy for longer periods. Users can be engaged in gameplay and rewarded in immersive scenarios for repeating movements. This concept relies on the immersive capabilities of VR to provide positive distraction from typical therapy while still enabling prescribed movement. A key perspective to consider for the development of VR interventions for SCI patients during this phase of recovery is the proximity in time to initial injury and the subsequent effects this has on day-to-day life. Because of this, SCIPs and TPs required that the intervention alleviate the effect of spending long durations in hospital. This included the addition of 'escapism' and 'relaxation' to the design to provide positive distraction to users, which are concepts known to be provided by VR interventions [47].

An additional barrier to participation in upper limb therapy was resource limitation. Yet, both groups saw the potential of VR-based therapy, if designed and implemented effectively, to alleviate some of these limitations. In particular, the ability of VR to automate therapy would allow SCI patients to perform repetitions with minimal assistance and supervision and therefore enable therapists to use their time more effectively.

TPs and SCIPs reported that upper limb rehabilitation was delivered to groups of SCI patients more often than individual sessions. Group-based therapy had some advantages in terms of building relationships and between SCI patients and therapists and peer support between SCI patients.

Both therapists and people with SCI made many suggestions about what type of activities and upper limb movements they would like to see implemented in VR. There was no consensus on particular types of VR scenarios to which SCIP patients would engage with, which was probably due to the heterogeneous demographics, presentations, and needs of the acute spinal cord-injured population. This again supports an implementation of the VR intervention that provides a range of different upper limb activities and VR environments for a diverse population of people with SCI.

VR may be most beneficial in situations where repetitive activities can be gamified and can adapt to an individual's needs. The results of this study align with previously published research investigating the rehabilitation of people with acute SCI, descriptions of therapy received for these injuries, and the factors that affect motivation to attend therapy within the inpatient setting [46,48–51]. The study identified that SCIPs desired to enhance functional independence, were optimistic and motivated about rehabilitation, and benefitted from shared decision making, which are key components of the patient-centered care described by TPs. This study recognises the complexity and diversity of SCI rehabilitation as an important factor for the development of new interventions for upper limb rehabilitation.

These findings add to the growing body of research concerning the recommendations for implementing VR for people with upper limb impairments and their rehabilitation [52–55]. VR interventions must be designed to take advantage of their attributes which include real-time feedback and ability to provide motivating environments in which to participate in therapy. These designs must be informed by the specific populations who are intended to use these systems [56–59]. No previous studies have explored the views of SCI patients and therapists in terms of VR and their suggestions for the development of VR games for upper limb exercise in those with acute SCI rehabilitation.

Specifications for the design of a VR upper limb rehabilitation intervention

From each major theme and its subthemes, specifications for the design of software applications targeting acute upper limb rehabilitation for people with tetraplegia have been sorted into VR application development domains and presented below. These specifications can be used as guidance for the development of virtual reality applications for upper limb rehabilitation for people with SCI. Themes generated from the focus group discussions can also be used to justify the specification of software requirements for a more systematic approach to intervention development.

Domain 1: Accessibility and Interfaces

As many SCI patients as possible should be able to use VR applications. Using VR, SCI patients can take ownership over their activities, engage in a range of exercises, and receive encouragement and feedback enabling them to understand their progress. Thus, the user's interaction with the software must allow the user to take ownership of their own therapy where possible, yet still facilitate the

therapist-patient relationship.

Applications must accommodate the wide variation in upper limb abilities of users and be usable to the same degree for all users, irrespective of upper limb ability. Applications must also account for the variation in demographics of the acute SCI population and be usable by people with comorbidities associated with acute SCI. Applications must allow all prescribed movements to be specified and configured by the user and must be comfortable to use.

Domain 2: Implementation

Applications must be feasible, fit into existing treatment plans and aim to provide some alleviation to resource-limited practise. They must fit into patient-centered care approaches and align with goal setting between SCI patients and therapists. Furthermore applications must minimise physical and psychological adverse effects. Applications must consider the correct dosage and minimise overexertion while in use. Applications should be usable especially in settings where resources including time, space, and staff are limited. Finally, therapists must be able to monitor the use of applications in real time and therefore require to be trained to a suitable level in order to effectively administer applications.

Domain 3: Engagement and Motivation

Applications must increase and maintain engagement and encourage repetitions of prescribed movements through meaningful virtual activities and environments. Therefore, applications must appeal to the broad range of interests held by acute SCI patients and subsequently encourage repetitions of movement without getting boring. More specifically, applications must avoid factors that cause disengagement from therapy and to achieve this provide an optimal degree of challenge for each user by not being frustrating, too difficult, or too easy. Applications must also provide motivational feedback for the user (e.g. scores and progress).

Domain 4: Effectiveness and Efficacy

Applications must be effective in real practise (as an adjunct to usual treatment). Applications must target as many movement domains as possible, and support movement/activity that is difficult to achieve in standard upper limb treatment

Domain 5: Understanding Limitations of VR applications

Applications will have limitations. Some of these limitations can be predicted and mitigated against, but others will be unknown until an application's feasibility is tested. Device deficiencies will occur, so applications will need troubleshooting, fixing, and update support while in use. SCI patients may not be able to use applications if they are too fatigued or experiencing very low mood, so applications must be designed in the knowledge that adherence could be intermittent.

Limitations

SCIPs sometimes had difficulty recalling their time as inpatients, typically when years or decades had passed following discharge. However, it was important to prioritise the perspective of individuals with a full retrospective view of inpatient care.

Separate focus groups were conducted for TPs and SCIPs in order to remove the effect of the relationships/perceived power differences between SCI patients and clinicians. For example, when discussing opinions about particular types of upper limb therapy, SCIPs may have been reluctant to express negative opinions about care if TPs were present. Interaction between SCIPs and TPs may however have been beneficial in terms of ideating about suggestions for the design of VR scenarios.

Data saturation was not achieved as the final focus groups in both groups yielded additional insights, though at a lower frequency compared to earlier groups. However, the information power of the focus groups was improved by revising the question schedules after each focus group. In particular, follow-up questions and prompts were added in order to explore new areas of discussion that had not been covered by previous groups. The inclusion of different rehabilitation disciplines with experience of working in different specialist Centres across the UK ensure diverse groups were assembled was a strength of this study and allowed for more varied discussion.

Conclusions

This study reported the perspectives and suggestions of people with SCI and SCI therapists about the use of VR for upper limb rehabilitation in the acute setting. Five themes were generated that designers and developers of immersive applications for rehabilitation can use to create their applications. SCI patients have a large variation in upper limb impairments for which many different movements are prescribed by therapists. This variation must be accommodated by applications in a usable and accessible way. Applications must also implement features that motivate patients to attend and adhere to therapy, such as providing useful feedback and appealing to the broad range of patients' interests, and also avoid factors that can cause disengagement from therapy. This study's findings facilitated the co-design of a novel immersive VR intervention for upper limb rehabilitation for people with tetraplegia while they are inpatients.

Future Work

The next part on this project is to use the results from this study to produce software requirements and a software architecture for a suite of VR games for upper limb therapy. This enabled the development and deployment of the proposed software and its continued improvement.

Acknowledgments

The authors would like to thank all the participants (co-designers) who took part in this study, Spinal Injuries Scotland for helping recruit participants, and finally Stoke Mandeville Spinal Research (SMSR) for funding this PhD through their Assistive Technology for Upper Limb Rehabilitation PhD Studentship.

Authors' Contributions

AG, LP, MPo, and MPu designed and conceptualized this study. AG and LP facilitated the focus groups. AG and LC were responsible for project administration, including recruitment of focus group participants. AG, LP, MPo, and MPu performed the analysis. AG and LP wrote and prepared the original draft of the manuscript. AG, LP, MPu, MPo, and LC reviewed and edited the manuscript.

Conflicts of Interest

None declared.

Abbreviations

GCU: Glasgow Caledonian University

PSWAHS: Psychology, social work, and allied health sciences

SMSR: Stoke Mandeville Spinal Research

SCIP: Spinal cord-injured participant

TP: Therapist participant

QENSIU: Queen Elizabeth national spinal injuries unit

VR: Virtual reality

ADL: Activities of Daily Living

Multimedia Appendix 1

Tables of all codes

Transcripts

References

1. Thompson C, Mutch J, Parent S, Mac-Thiong J-M. The changing demographics of traumatic spinal cord injury: An 11-year study of 831 patients. *The Journal of Spinal Cord Medicine* 2015 Mar;38(2):214–223. doi: 10.1179/2045772314Y.00000000233
2. Hutson TH, Di Giovanni S. The translational landscape in spinal cord injury: focus on neuroplasticity and regeneration. *Nat Rev Neurol* 2019 Dec;15(12):732–745. doi: 10.1038/s41582-019-0280-3
3. Andrew Coxon, Shajia Shahid. Estimating the UK population of People living with SCI. South Tees Hospitals NHS Foundation Trust; 2024.
4. McDaid D, Park A-L, Gall A, Purcell M, Bacon M. Understanding and modelling the economic impact of spinal cord injuries in the United Kingdom. *Spinal Cord* 2019 Sep;57(9):778–788. doi: 10.1038/s41393-019-0285-1
5. Ditunno JF, Cohen ME, Hauck WW, Jackson AB, Sipski ML. Recovery of upper-extremity strength in complete and incomplete tetraplegia: A multicenter study. *Archives of Physical Medicine and Rehabilitation* 2000 Apr;81(4):389–393. doi: 10.1053/mr.2000.3779
6. Mateo S, Di Marco J, Cucherat M, Gueyffier F, Rode G. Inconclusive efficacy of intervention on upper-limb function after tetraplegia: A systematic review and meta-analysis. *Annals of Physical and Rehabilitation Medicine* 2020 May;63(3):230–240. doi: 10.1016/j.rehab.2019.05.008
7. Rupp R, Biering-Sørensen F, Burns SP, Graves DE, Guest J, Jones L, Read MS, Rodriguez GM, Schuld C, Tansey-MD KE, Walden K, Kirshblum S. International Standards for Neurological Classification of Spinal Cord Injury. *Topics in Spinal Cord Injury Rehabilitation* 2021 Mar 1;27(2):1–22. doi: 10.46292/sci2702-1
8. Bickenbach J, Officer A, Shakespeare T, von Groote P, World Health Organization, The International Spinal Cord Society. International perspectives on spinal cord injury / edited by Jerome Bickenbach. Geneva: World Health Organization; 2013. ISBN:978-92-4-156466-3
9. Adriaansen J, Ruijs L, Koppenhagen C, Asbeck F, Snoek G, Kuppevelt D, Visser-Meily J, Post M. Secondary health conditions and quality of life in persons living with spinal cord injury for at least ten years. *J Rehabil Med* 2016;48(10):853–860. doi: 10.2340/16501977-2166
10. Burns AS, Marino RJ, Kalsi-Ryan S, Middleton JW, Tetreault LA, Dettori JR, Mihalovich KE, Fehlings MG. Type and Timing of Rehabilitation Following Acute and Subacute Spinal Cord Injury: A Systematic Review. *Global Spine J* 2017 Sep;7(3 Suppl):175S-194S. PMID:29164023
11. Lynskey JV. Activity-dependent plasticity in spinal cord injury. *JRRD* 2008 Dec 1;45(2):229–

240. doi: 10.1682/JRRD.2007.03.0047

12. Musselman KE, Shah M, Zariffa J. Rehabilitation technologies and interventions for individuals with spinal cord injury: translational potential of current trends. *J NeuroEngineering Rehabil* 2018 Dec;15(1):40. doi: 10.1186/s12984-018-0386-7
13. Anderson KD. Targeting Recovery: Priorities of the Spinal Cord-Injured Population. *Journal of Neurotrauma* 2004 Oct;21(10):1371–1383. doi: 10.1089/neu.2004.21.1371
14. Roy RR, Harkema SJ, Edgerton VR. Basic Concepts of Activity-Based Interventions for Improved Recovery of Motor Function After Spinal Cord Injury. *Archives of Physical Medicine and Rehabilitation* 2012 Sep;93(9):1487–1497. doi: 10.1016/j.apmr.2012.04.034
15. Savic G, Frankel HL, Jamous MA, Soni BM, Charlifue S. Participation restriction and assistance needs in people with spinal cord injuries of more than 40 year duration. *Spinal Cord Ser Cases* 2018 Dec;4(1):28. doi: 10.1038/s41394-018-0056-9
16. Lu X, Battistuzzo CR, Zoghi M, Galea MP. Effects of training on upper limb function after cervical spinal cord injury: a systematic review. *Clin Rehabil* 2015 Jan;29(1):3–13. doi: 10.1177/0269215514536411
17. Kramer JLK, Lammertse DP, Schubert M, Curt A, Steeves JD. Relationship Between Motor Recovery and Independence After Sensorimotor-Complete Cervical Spinal Cord Injury. *Neurorehabil Neural Repair* 2012 Nov;26(9):1064–1071. doi: 10.1177/1545968312447306
18. Kalsi-Ryan S, Beaton D, Curt A, Popovic MR, Verrier MC, Fehlings MG. Outcome of the upper limb in cervical spinal cord injury: Profiles of recovery and insights for clinical studies. *The Journal of Spinal Cord Medicine* 2014 Sep;37(5):503–510. doi: 10.1179/2045772314Y.00000000252
19. Quel de Oliveira C, Refshauge K, Middleton J, de Jong L, Davis GM. Effects of Activity-Based Therapy Interventions on Mobility, Independence, and Quality of Life for People with Spinal Cord Injuries: A Systematic Review and Meta-Analysis. *Journal of Neurotrauma* 2017 May;34(9):1726–1743. doi: 10.1089/neu.2016.4558
20. Huh S, Ko H-Y. Recovery target priorities of people with spinal cord injuries in Korea compared with other countries: a survey. *Spinal Cord* 2020 Sep;58(9):998–1003. doi: 10.1038/s41393-020-0457-z
21. Simpson LA, Eng JJ, Hsieh JTC, Wolfe and the Spinal Cord Injury Re DL. The Health and Life Priorities of Individuals with Spinal Cord Injury: A Systematic Review. *Journal of Neurotrauma* 2012 May 20;29(8):1548–1555. doi: 10.1089/neu.2011.2226
22. Namrata Y. Priorities of Spinal Cord Injured Population – A Survey. *AJAP* 2017;6(6):183. doi: 10.11648/j.ajap.20170606.17
23. Behrman AL, Ardolino EM, Harkema SJ. Activity-Based Therapy: From Basic Science to Clinical Application for Recovery After Spinal Cord Injury. *Journal of Neurologic Physical Therapy* 2017 Jul;41:S39–S45. doi: 10.1097/NPT.0000000000000184
24. Kazim SF, Bowers CA, Cole CD, Varela S, Karimov Z, Martinez E, Ogulnick JV, Schmidt MH.

- Corticospinal Motor Circuit Plasticity After Spinal Cord Injury: Harnessing Neuroplasticity to Improve Functional Outcomes. *Mol Neurobiol* 2021 Nov;58(11):5494–5516. doi: 10.1007/s12035-021-02484-w
25. Scalise M, Bora TS, Zancanella C, Safa A, Stefini R, Cannizzaro D. Virtual Reality as a Therapeutic Tool in Spinal Cord Injury Rehabilitation: A Comprehensive Evaluation and Systematic Review. *JCM* 2024 Sep 13;13(18):5429. doi: 10.3390/jcm13185429
 26. Vinciguerra C, Federico A. Virtual Rehabilitation in Spinal Cord Injury Patients: Realities and Future Perspectives. A Systematic Review. *Curr Phys Med Rehabil Rep* 2024 Oct 8;12(4):425–434. doi: 10.1007/s40141-024-00470-6
 27. Schiza E, Matsangidou M, Neokleous K, Pattichis CS. Virtual Reality Applications for Neurological Disease: A Review. *Front Robot AI* 2019;6:100. PMID:33501115
 28. Leemhuis E, Esposito RM, De Gennaro L, Pazzaglia M. Go Virtual to Get Real: Virtual Reality as a Resource for Spinal Cord Treatment. *IJERPH* 2021 Feb 13;18(4):1819. doi: 10.3390/ijerph18041819
 29. De Miguel-Rubio A, Rubio MD, Alba-Rueda A, Salazar A, Moral-Munoz JA, Lucena-Anton D. Virtual Reality Systems for Upper Limb Motor Function Recovery in Patients With Spinal Cord Injury: Systematic Review and Meta-Analysis. *JMIR mHealth and uHealth Canada: JMIR Publications*; 2020;8(12):e22537. doi: 10.2196/22537
 30. Orsatti Sánchez BA, Diaz Hernandez O. Efficacy of Virtual Reality in Neurorehabilitation of Spinal Cord Injury Patients: A Systematic Review. *Rev Mex Ing Biom* 2022 25; /03;42(2):90–103.
 31. de Araújo AVL, Neiva JF de O, Monteiro CB de M, Magalhães FH. Efficacy of Virtual Reality Rehabilitation after Spinal Cord Injury: A Systematic Review. *BioMed Research International* 2019 Nov 13;2019:1–15. doi: 10.1155/2019/7106951
 32. Bird M, McGillion M, Chambers EM, Dix J, Fajardo CJ, Gilmour M, Levesque K, Lim A, Mierdel S, Ouellette C, Polanski AN, Reaume SV, Whitmore C, Carter N. A generative co-design framework for healthcare innovation: development and application of an end-user engagement framework. *Res Involv Engagem* 2021 Dec;7(1):12. doi: 10.1186/s40900-021-00252-7
 33. Bourke JA, Bragge P, River J, Sinnott Jerram KA, Arora M, Middleton JW. Shining a light on the road towards conducting principle-based co-production research in rehabilitation. *Front Rehabil Sci* 2024 Apr 10;5:1386746. doi: 10.3389/fresc.2024.1386746
 34. Bate P, Robert G. Experience-based design: from redesigning the system around the patient to co-designing services with the patient. *Quality and Safety in Health Care* 2006 Oct 1;15(5):307–310. doi: 10.1136/qshc.2005.016527
 35. Elwyn G, Nelson E, Hager A, Price A. Coproduction: when users define quality. *BMJ Qual Saf* 2020 Sep;29(9):711–716. doi: 10.1136/bmjqs-2019-009830
 36. The Medicines and Healthcare products Regulatory Agency (MHRA). Joint Statement of Seeking Consent by Electronic Methods. 2018;

37. Fekete C, Eriks-Hoogland I, Baumberger M, Catz A, Itzkovich M, Lüthi H, Post MWM, von Elm E, Wyss A, Brinkhof MWG. Development and validation of a self-report version of the Spinal Cord Independence Measure (SCIM III). *Spinal Cord* 2013 Jan;51(1):40–47. doi: 10.1038/sc.2012.87
38. Valve Corporation. SteamVR featuring the HTC Vive. 2016. Available from: <https://youtu.be/qYfNzhLXYGc>
39. Elo S, Kyngäs H. The qualitative content analysis process. *J Adv Nurs* 2008 Apr;62(1):107–115. doi: 10.1111/j.1365-2648.2007.04569.x
40. QSR International Pty Ltd. NVivo Qualitative Data Analysis Software. Denver; 2018.
41. Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care* 2007 Sep 16;19(6):349–357. doi: 10.1093/intqhc/mzm042
42. Vissers M, Van Den Berg-Emons R, Sluis T, Bergen M, Stam H, Bussmann H. Barriers to and facilitators of everyday physical activity in persons with a spinal cord injury after discharge from the rehabilitation centre. *J Rehabil Med* 2008;40(6):461–467. doi: 10.2340/16501977-0191
43. Tallqvist S, Eskola K, Täckman A, Kauppila A-M, Koskinen E, Anttila H, Rajavaara M, Arokoski J, Hiekkala S. Facilitators and barriers in the rehabilitation process described by persons with spinal cord injury: a deductive-inductive analysis from the Finnish spinal cord injury study. *Annals of Medicine* 2023 Dec 12;55(2):2303398. doi: 10.1080/07853890.2024.2303398
44. Whalley Hammell K. Experience of rehabilitation following spinal cord injury: a meta-synthesis of qualitative findings. *Spinal Cord* 2007 Apr;45(4):260–274. doi: 10.1038/sj.sc.3102034
45. Lindberg J, Kreuter M, Taft C, Person L-O. Patient participation in care and rehabilitation from the perspective of patients with spinal cord injury. *Spinal Cord* 2013 Nov;51(11):834–837. doi: 10.1038/sc.2013.97
46. Sousa SS, Andrade MJ, Fernandes CS, Barbeiro SR, Teixeira VT, Pereira RS, Martins MM. Healthcare Experience of People with Acute Spinal Cord Injury: A Phenomenological Study. *Nursing Reports* 2023 Dec 4;13(4):1671–1683. doi: 10.3390/nursrep13040138
47. Williamson SD, Aaby AO, Ravn SL. Psychological outcomes of extended reality interventions in spinal cord injury rehabilitation: a systematic scoping review. *Spinal Cord* 2025 Jan 9; doi: 10.1038/s41393-024-01057-7
48. Kirchberger I, Sinnott A, Charlifue S, Kovindha A, Lüthi H, Campbell R, Zwecker M, Scheuringer M, Cieza A. Functioning and disability in spinal cord injury from the consumer perspective: an international qualitative study using focus groups and the ICF. *Spinal Cord* 2010 Aug;48(8):603–613. doi: 10.1038/sc.2009.184
49. Krysa JA, Gregorio MP, Pohar Manhas K, MacIsaac R, Papathanassoglou E, Ho CH. Empowerment, Communication, and Navigating Care: The Experience of Persons With Spinal Cord Injury From Acute Hospitalization to Inpatient Rehabilitation. *Front Rehabil Sci* 2022 May 31;3:904716. doi: 10.3389/fresc.2022.904716

50. Hearn JH, Finlay KA, Fine PA, Cotter I. Neuropathic pain in a rehabilitation setting after spinal cord injury: an interpretative phenomenological analysis of inpatients' experiences. *Spinal Cord Ser Cases* 2017 Nov 30;3(1):17083. doi: 10.1038/s41394-017-0032-9
51. Kerstin W, Gabriele B, Richard L. What promotes physical activity after spinal cord injury? An interview study from a patient perspective. *Disability and Rehabilitation* 2006 Jan;28(8):481–488. doi: 10.1080/09638280500211932
52. Glegg SMN, Levac DE. Barriers, Facilitators and Interventions to Support Virtual Reality Implementation in Rehabilitation: A Scoping Review. *PM&R* 2018 Nov;10(11):1237. doi: 10.1016/j.pmrj.2018.07.004
53. Herrera V, Albusac J, Schez-Sobrinho S, Reyes-Guzmán A, Glez-Morcillo C. Dynamic Adjustment of Interactive Objects in Virtual Environments for Upper Limb Rehabilitation: A Patient-Centred Solution. *Spanish Computer Graphics Conference (CEIG)* 1142nd ed The Eurographics Association; 2024; doi: 10.2312/CEIG.20241142
54. Herrera V, Albusac J, Castro-Schez JJ, González-Morcillo C, Monekosso DN, Pacheco S, Perales R, De Los Reyes-Guzmán A. Creating adapted environments: enhancing accessibility in virtual reality for upper limb rehabilitation through automated element adjustment. *Virtual Reality* 2025 Jan 25;29(1):28. doi: 10.1007/s10055-024-01078-w
55. Lewis GN, Rosie JA. Virtual reality games for movement rehabilitation in neurological conditions: how do we meet the needs and expectations of the users? *Disability and Rehabilitation* 2012 Nov;34(22):1880–1886. doi: 10.3109/09638288.2012.670036
56. Creed C, Al-Kalbani M, Theil A, Sarcar S, Williams I. Inclusive AR/VR: accessibility barriers for immersive technologies. *Univ Access Inf Soc* 2024 Mar;23(1):59–73. doi: 10.1007/s10209-023-00969-0
57. Mott M, Cutrell E, Gonzalez Franco M, Holz C, Ofek E, Stoakley R, Ringel Morris M. Accessible by Design: An Opportunity for Virtual Reality. *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)* Beijing, China: IEEE; 2019. p. 451–454. doi: 10.1109/ISMAR-Adjunct.2019.00122
58. Dudley J, Yin L, Garaj V, Kristensson PO. Inclusive Immersion: a review of efforts to improve accessibility in virtual reality, augmented reality and the metaverse. *Virtual Reality* 2023 Dec;27(4):2989–3020. doi: 10.1007/s10055-023-00850-8
59. Vlahovic S, Suznjevic M, Skorin-Kapov L. A Framework for the Classification and Evaluation of Game Mechanics for Virtual Reality Games. *Electronics* 2022 Sep 17;11(18):2946. doi: 10.3390/electronics11182946

Supplementary Files

Untitled.

URL: <http://asset.jmir.pub/assets/a275030d1fda58bb1644f5c2ed11fa64.xlsx>

Figures

Visual summary of the number of Major Themes (listed in the right column) identified from the 1260 codes (shown on the left column) generated by content analysis of focus groups with SCI participants and therapists.

