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EXAMINATION VERSION

Virtual reality-based therapy for people with spinal cord injuries - A scoping review

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Abstract

Introduction: Virtual Reality (VR)-based therapy may improve motor and executive functions for people with various medical conditions, including stroke. However, VR-based therapy in complex rehabilitation of people with spinal cord injury (SCI) remains underexplored from an occupational perspective. **Aim:** This scoping review aimed to map and synthesise the literature on VR-based interventions in rehabilitation of people with SCI from an occupational perspective. **Method:** A literature search of quantitative studies was performed in four databases, in addition to grey literature and a manual search. Data were analysed using basic qualitative content analysis. **Results:** Twelve studies were included. The findings showed that VR-based therapy may decrease neuropathic pain and enhance walking function, balance and sitting balance. Less is known about VR-based therapy relating to mental wellbeing and there were mixed results on performance in activities of daily living (ADL). **Conclusions:** The findings suggest that VR-based therapy has potential to complement existing occupational therapy and may address various rehabilitation goals. Overall, the use of VR is reportedly safe within a therapeutic context. **Significance:** VR-based therapy may support rehabilitation of people with SCI. However, to promote an occupational perspective, future research is needed to explore VR-based therapy using ADLs and occupation-related outcome measures.

Keywords

Occupational therapy; Paraplegia; Tetraplegia; Virtual Reality; Rehabilitation; Physical functional performance; Activities of daily living; Neuropathic pain

List of abbreviations

10MWT	10 Meter Walking Test
ABC Scale	Activities-Specific Balance Confidence Scale
ADL	Activities of Daily Living
AIS	The American Spinal Injury Association Impairment Scale
BBS	Berg Balance Scale
BI	Barthel Index
BQCA	Basic qualitative content analysis
CG	Control Group
DB	Database
E.g.	Exempli gratia (“for example”)
EG	Experimental Group
FFRT	Forward Functional Reach Test
FIM	Functional Independence Measure
HMD	Head Mounted Display
IG	Intervention Group
JBI	Joanna Briggs Institute
LFRT	Lateral Functional Reach Test
LOS	Limit of Stability

mFRT	Modified Functional Reach Test
MFRT	Modified Functional Reach Test
MMT	Manual Muscle Test
NLI	Neurological Level of Injury
NPS	Neuropathic Pain Scale
NRS	Numeric Rating Scale
OP	Occupational Perspective
OT	Occupational Therapy/Occupational Therapists
PGIC	The Patient Global Impression of Change
PHQ-9	Patient Health Questionnaire-9
QOL	Quality of Life
QUEST	Quebec User Evaluation of Satisfaction with Assistive Technology 2.0
RAND SF-36	36-Item Short Form Survey Instrument
RCT	Randomized Controlled Trial
SCI	Spinal Cord Injury/Injuries
SCI QL-23	Spinal Cord Injury Quality of Life Questionnaire
SCIM III	The Spinal Cord Independence Measure
SD	Standard Deviation
TEI	The Treatment Evaluation Inventory

TSD	Three Screen Display
TUG	Timed Up and Go Test
UEMS	Upper Extremity Motor Scores
VR	Virtual Reality
WISCI II	Walking Index for Spinal Cord Injury II

Virtual reality-based therapy for people with spinal cord injuries - A scoping review

Introduction

Globally, over 15 million people live with a spinal cord injury (SCI) which represents a severe trauma to the body functions and mental wellbeing of the individuals affected (1). Rehabilitation usually involves training of the sensorimotor functions in the upper and lower extremities and the trunk (2). However, symptoms occurring due to SCI are far more diverse and may include neuropathic pain. Neuropathic pain is caused by a lesion of the somatosensory system following a SCI, characterised by burning or electric shock-like pain (3). Other symptoms following SCI comprise muscle spasticity and psychological concerns impacting the rehabilitation process and mental wellbeing of the affected (4, 5). From an occupational perspective (OP), defined as ”a way of looking at or thinking about human doing” (6) as well as the holistic perspective of occupational therapy (OT), regaining the ability to perform activities of daily living (ADLs) as independently as possible and based on the individual’s needs and desires, can facilitate mental wellbeing and a high quality of life, which are some of the most important rehabilitation goals (7).

The therapeutic application of virtual reality (VR)-based training has been used among people with different medical conditions including stroke (8) and dementia (9), with varying objectives, such as improvement of upper extremity functions or executive functions. Briefly defined, VR-based therapy offers digitally and specially designed environments in which patients take in an active role in certain scenarios related to their healthcare issues. Virtual environments and their requirements can be tailored to meet the needs and functional and/or

cognitive skills of individuals (10). The technological hardware may differ between simple computer setups and novel systems (e.g. using VR headsets and glasses).

Earlier studies indicate that VR has potential to support existing interventions in conventional occupational and physiotherapy (11) which include task-specific training, high repetitive exercise, and practicing ADLs like getting dressed or cooking (12). Functional recovery and neuroplastic developments (the rewiring of neural circuitries for neurological adaptations within the central nervous system (13)) after SCI depend on intense therapy including a high amount of movement repetitions (11). However, due to practical and economic factors, conventional therapy may not be delivered sufficiently (14). Moreover, advantages of VR-based interventions include the precise adjustment of levels of difficulty and measurement of performance (11). VR has also been shown to increase motivation and compliance in individuals during therapy (15).

Internationally, SCI are evaluated in accordance with The American Spinal Injury Association International Standards for Neurological Classification of Spinal Cord Injury (16) to determine the exact neurological level of injury (NLI),. This may be simplified as either tetra- or paraplegia. The American Spinal Injury Association Impairment Scale (AIS) is used to classify the severity (complete or incomplete) of a SCI (17) (see Table 1 for an overview of the AIS). AIS grades should be considered when comparing studies on therapeutic interventions in SCI population, since functional recovery is strongly determined by the completeness of injury. For instance, people classified with an impairment of grade “A” on the AIS present with a low possibility to recover walking function, whereas people classified with grade “D” have a high prognosis of regaining walking function (18).

[Insert Table 1]

More recently, a systematic review and meta-analysis of randomized controlled trials (RCT) in people with SCI was conducted from a physical therapy perspective focused on the effects of VR on functional performance. Overall, the results suggested that VR did not achieve better effects in functional performance compared to conventional physiotherapy although other outcomes were inconclusive (19). To the author's knowledge there exist no systematic or scoping reviews about the utilisation of VR-based therapy for the SCI population from an occupational perspective. From an OP, considerations about functional aspects as well as mental well-being and pain management, are integral to enable a person to perform and participate in their chosen occupations (20, 21).

Aim

This scoping review aimed to map and synthesise the literature on VR-based therapy in rehabilitation of people with SCI from an OP. Furthermore, this study aimed to identify and address research gaps in this field.

Methods

A scoping review was conducted to provide an overview of the current state of the literature on the usage of VR-based therapy among people with SCI from an OP. This scoping review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist, to describe the salient aspects of the review process as transparently as possible (22). As a theoretical foundation, this scoping review is based on the framework from Arksey and O'Malley (2005) (23) and further developments by

Levac et al. (2010) (24). The five stages of the scoping review are described below. Furthermore, the Joanna Briggs Institute (JBI) coping review guidance was taken into account for data extraction, analysis and presentation (25). A basic qualitative content analysis (BQCA) was used and is detailed in the data analysis section (25, 26).

Stage 1: Identifying the research question

The PCC (Population (or participants)/Concept/Context) framework (27) was applied to formulate a research question for this scoping review. For the purposes of this scoping review, population/participants included people with SCI, the concept explored was VR-based therapy, and the context referred to the rehabilitation process from an OP.

Thus, the overall research question was formulated as "What does the literature reveal about VR-based therapy in the rehabilitation of people with SCI from an occupational perspective?".

To help guide the scoping review, two specific secondary research questions were developed, as follows:

1. In what ways can VR-based therapy support people with SCI in improving their body functions and performance in ADLs?
2. How can VR-based therapy be applied to promote mental wellbeing and for pain management among people with SCI?

Stage 2: Identifying relevant studies

Literature was searched in four databases: Medline, CINAHL, the occupational therapy (OT) related database - OT Seeker, and the engineering and technology-related database - IEEE. The choice of databases reflects the interdisciplinary focus of this review, encompassing OT

but also rehabilitation, engineering and technology. The eligibility criteria for identifying relevant studies are presented as follows:

Inclusion criteria

- Quantitative intervention studies with quantitative outcome measures
- At least one outcome measure relevant from an occupational perspective
- People aged 18 years or over, with a diagnosis of traumatic or non-traumatic SCI (including acute and chronic state of disease, and all neurological levels of injuries and severeness of SCI)
- VR specifically applied as an intervention in the study protocol
- Studies conducted in acute care or community-based settings
- Studies conducted between 2009 and 2024 (as VR is a novel and fast-developing technology)
- Studies with full texts available and accessible in English language

Exclusion criteria

- Qualitative studies, reviews and meta-analyses
- People with physical impairments or mental health issues due to other diagnoses (e.g. stroke, Parkinson's Disease, etc.)
- Patients with severe comorbidities (e.g. schizophrenia, peripheral nerve injuries, etc.)

Initially, both quantitative and qualitative study designs were considered. However, following initial test searches and consultations with the scientific librarian the search focus was refined to quantitative studies only. Due to ethical considerations and for more consistent comparisons between studies, exclusively studies involving adults who were expected to evaluate risks and benefits of study participation and who could legally provide informed

consent were considered. To promote an OP and differentiate this scoping review from earlier research (19), studies needed to include at least one outcome measure relevant from the OP Therefore, also assessments focusing on body functions including walking were considered in the present scoping review.

Before the literature was searched in the databases, search terms were defined in accordance with the PCC framework as suggested for scoping reviews (27). With support from a scientific librarian, the search strategy was developed and tested, and search terms were connected by Boolean operators OR and AND (Table 2). Additionally, a manual literature search was conducted by checking reference lists of relevant included articles, and grey literature was explored on *clinicaltrials.gov* to potentially find the latest studies on the topic.

[Insert Table 2]

Stage 3: Study selection

The selection of suitable articles to address the research questions was performed in a structured way and filters in databases were applied in accordance with the eligibility criteria. The retrieved articles were screened by title, and then by abstract. Full texts were retrieved for relevant studies. The database search and article selection were performed by the author of this review (the master's student), together with ongoing critical discussions and reflections with her supervisor and peer group consisting of fellow students via meetings throughout the review process. After the databases were searched for relevant literature, the identification process of literature was conducted and presented in accordance with the PRISMA-ScR flowchart which included searches of databases, registers and other sources (28) (Figure 1). Furthermore, an overview of the database search process is displayed in Table 3.

[Insert Figure 1 and Table 3]

Stage 4: Charting the data

The data were charted to descriptively summarise the most essential information about each included article for addressing the research questions (Table 4). Here, the focus was on describing the participants/population in as much detail as possible (e.g. number of participants, country the study took place, age distributions, severity of SCI, para- or tetraplegia). Furthermore, the methods used in each study were described, for instance which study design was used as well as the duration of intervention. Additionally, ethical considerations in each study were reported for transparency, such as if the study protocols were approved by an ethics committee and were conducted in accordance with the Declaration of Helsinki (29). For this review, the exact VR-systems used in the studies were listed as there are various VR systems on the market. Outcome measures relevant to the research questions were listed, since this may be important to elucidate research gaps. Finally, the most relevant outcomes of the VR-based therapy on the rehabilitation process of people with SCI from an OP were recorded.

[Insert Table 4]

Stage 5: Collating, summarising and reporting the results

Information on the included articles is described narratively and is intended to be understandable to the reader. In this stage, the purpose was to broadly present the characteristics of the included studies that were considered important to address the research questions. According to Arksey and O'Malley (2005) (23), this might include geographic information and detailed information about the range of different interventions and

procedures conducted in the studies. By describing the current state of the literature, gaps in this field might be detectable by the end of Stage 5. To extract and present data relevant for answering both research questions, a basic qualitative content analysis (BQCA) was conducted as recommended by the JBI scoping review guidance (25, 30).

Data analysis

This thesis used one of various approaches to undertake the BQCA, namely an approach developed by Elo and Kyngäs (26) and described by Pollock et al. (2023) (25). Initially, in the "Preparation phase" the decision must be made to follow an inductive or deductive approach. As VR-based therapy in the SCI population represents a rather novel intervention, the chances are high that an inductive approach will be applied as there is no established conceptual framework within the existing literature. Next, in the "Organising phase" open coding of the relevant data is performed according to the inductive approach. The purpose is to develop a coding framework by building categories and taking notes to group information and organise the extracted data. The coding framework may be adapted during this process to help address the research questions as precisely as possible; hence categories and subcategories were merged and refined during this process. Finally, in the "reporting phase" data can be presented and visualised in multiple ways – including tabulated and narrative presentations of the results in this scoping review.

Ethical considerations

This study represents a scoping review of literature, and it did not involve any interventions with participants, therefore it did not require ethical approval. The methods and steps

undertaken were described in detail to enhance transparency (31). This scoping review might contribute to further research in the field of VR-based therapy in people with SCI. Therefore, the selection process and interpretation of the included studies was carried out carefully and transparently by following recommended guidelines (22-26). Furthermore, this study was not funded, and the author declared no conflicts of interest.

Positionality

As a statement of positionality, the author of this review is an experienced OT working in acute care with SCI patients, but has had limited experience with the application of VR-based therapy in general. As the interest of VR-based therapy has increased steadily within the field of neurological rehabilitation, the author was motivated to become familiar with the current literature, also with reference to evidence-based practice in SCI rehabilitation. To increase the trustworthiness, the author engaged in ongoing critical and reflective discussions with her supervisor and peer group to unpack and mitigate any potential biases regarding the advantages or disadvantages of VR technology used in SCI rehabilitation. The author included all suitable studies in this review regardless of whether they reported negative or positive results. The *Form for Self-Assessment of Ethical Issues in Degree Projects at the School of Health and Welfare* was completed (Supplementary file).

Results

Search results

Altogether, 12 studies focusing on VR-based therapy in the SCI population were included in this scoping review. Congruent with the defined eligibility criteria, all studies followed a quantitative study design and comprised at least one outcome measure relevant to the OP. The

included studies were published between 2014 and 2023 and were performed internationally; the majority occurred in European countries (32-36), followed by studies from the United States of America (37-40). Two studies were performed in India (41, 42) and one in South Korea (43).

Characteristics of participants

All included studies considered participants either within a subacute or a chronic stage of SCI. Some studies concentrated on VR-based therapy exclusively in participants with cervical SCI (tetraplegia) in which upper extremity motorsensory function is impacted (33, 34). Other studies solely focused on people with paraplegia (35, 39, 41, 42). One study did not clearly state the NLI of participants (32) meanwhile the others included both tetra- and paraplegic participants (36, 37, 40, 43). A few studies only included people with incomplete SCIs (AIS grades C-D) (32, 36), and moreover, two studies required participants capable of walking (40, 43). Three studies included motor complete (AIS grades A-B) people with SCI (34, 41, 42), only two studies included motorsensory complete (AIS grade A) participants (38, 39), and the rest of the studies involved a wide range of AIS grades (AIS grades A-D) (33, 35, 37). Overall, the age range of participants was wide, from 18 (37) to 70 years (39).

Types of VR-systems

Different VR technologies were utilised, including non-immersive VR systems such as the Wii® Fit (Nintendo™) (32, 40) and Sony PlayStation® 2 (41, 42). Most of the studies used semi-immersive VR-systems providing an interactive virtual environment (33-38, 43). Fully immersive VR-systems using head-mounted displays and conveying the impression to be within the virtual space were only used in two studies (37, 39).

Review findings

The BQCA resulted in four overarching categories: “The utilisation of VR-based therapy concerning the physical rehabilitation and the coping of ADLs in people with SCI”, “The utilisation of VR-based therapy concerning aspects related to the quality of life”, “Professionals involved in study implementation”, and “Adverse events during VR-utilisation”. Some of those comprise further sub-categories. See Table 4 for study details.

The utilisation of VR-based therapy concerning the physical rehabilitation and the coping of ADLs in people with SCI

Some of the findings represented positive outcomes of VR-based therapy on different body functions such as the sitting balance. ADL performance was predominantly evaluated by applying The Spinal Cord Independence Measure (SCIM III). Most studies reported no statistically significant changes in the SCIM III following the VR-based therapy.

Body functions

Positive outcomes were reported in lower extremity and core functions using VR-based training as walking speed (36, 40, 43), balance (32, 36, 43) and muscle strength (36) improved significantly. The sitting balance for non-ambulatory participants in wheelchairs was shown to be improved by VR-based therapy (41, 42), however, another study did not report significant improvements (35). Concerning the effects on upper extremity functions, study results suggest that training shoulder muscles in participants with paraplegia using VR has a similar or slightly more positive effect than training without VR (38).

Performance in ADLs

Overall, the included studies comprised a wide range of specific interventions addressing ADLs. One of those studies compared two different VR-simulators aiming to enhance driving performance in SCI participants. Finally, the results suggested that both VR-simulators were applicable in the daily practice. However, the experience of simulator sickness was slightly higher in the fully immersive VR system using a Head Mounted Display (HMD) compared to the semi-immersive system using a Three Screen Display (TSD) (37). To evaluate independence in everyday activities, The Spinal Cord Independence Measure (SCIM III) (44) was frequently applied among the included studies. Three studies reported no significant changes in SCIM III-scores after VR-based therapy (34, 35, 41). One study revealed a significant change in the SCIM III selfcare component for time, nonetheless there was no group difference between the VR and non-VR training group (42). The same study recorded an improved walking speed and balance as well as significant improvement in the SCIM III mobility component post VR-based therapy (36). One study reported a significant change for group effect in the T-shirt Test following the VR-based therapy (42). This assessment evaluates the sitting balance while putting on a t-shirt (45).

The utilisation of VR-based therapy concerning aspects related to the quality of life

The findings suggest that VR-based therapy may contribute to enhance the quality of life and mental well-being in people with SCI. The data regarding neuropathic pain management is very limited within the included studies. However, positive outcomes were generated following VR-based therapy. Most importantly, the findings did not reveal an increase of neuropathic pain post VR-based therapy.

Mental wellbeing and quality of life

Altogether, the focus on mental wellbeing and the quality of life (QOL) in the included studies was rather low. Post intervention, one study assessing the QOL recorded higher scores in global QOL in the EG (VR)-group compared to the CG (35). Furthermore, symptoms of depression were evaluated and showed a decline in symptomatology in the VR as well as in the CG after intervention (39). When rating the VR-therapy experience, participants were highly satisfied (34). In contrast, one study showed no significant changes in QOL after the VR-based therapy (40).

Management of neuropathic pain

One study concentrating on neuropathic pain (NP) management in the SCI population determined a decline in the current NP post gaming in the VR group and CG. Nevertheless, a significant decline in NP in the follow-up analysis was detected in the VR group (39). Another pre-posttest study assessed a decrease in the intensity and unpleasantness of NP post intervention and in the follow-up assessment (36).

Professionals involved in study implementation

Most of the studies were conducted by multi-professional teams consisting of doctors, OTs and physiotherapists and engineers (32-34, 36, 38). A few studies were primarily conducted involving mainly physiotherapists (40-43). The participation of OTs was mentioned in two studies (33, 34). In three studies the professions of the research team members remained unrevealed (35, 37, 39).

Adverse events during VR-utilisation

As already stated above, simulator sickness was mentioned in one study evaluating VR-driving simulators. Altogether in this study, five participants using the HMD and two using the TSD were affected (37). Otherwise, no study reported any adverse events, such as motion sickness or vertigo. In accordance with the eligibility criteria of this scoping review, all included studies obtained ethical approval from an Ethics committee except for one where this was not explicitly mentioned (43). Furthermore, all included studies received informed consent from the participants.

Discussion

The aim of this scoping review was to map and synthesise literature on VR-based therapy in the rehabilitation process of people with SCI. Overall, the findings from the studies included indicate that VR-based therapy has potential to support the rehabilitation of the SCI population. From an OP, the included studies addressed various relevant aspects, such as walking training, pain management or even specific ADLs such as car driving within a virtual environment (37). The diverse options to integrate VR-based interventions enable various professionals to use it when working with the SCI population, including OTs, physiotherapists as well as psychotherapists. Moreover, OT-related outcome measures were applied frequently, such as the SCIM III (44). In SCI rehabilitation, the training of lower extremity and core functions and balance plays an important role. In this regard, the studies showed statistically significant improvements. One point to discuss is the external validity of the included studies as they focused on reporting statistically significant improvements. Though, the clinical significance of VR-based therapy in people with SCI was not observed. This raises the question about the ecological validity which describes to what extend the study findings can be transferred to real-life contexts (46). Especially for evaluating ADL performance, more research is necessary to evaluate the clinical significance of VR-based

therapy for people with SCI. From an OP, it would be interesting to know in which way participants could transfer those improvements achieved through VR-based therapy into their daily life, e.g. when conducting ADLs or participating in everyday life activities, outside of laboratory settings. These conclusions may support the development of future research questions and/or projects.

Overall, most studies applied outcome measures concentrating on functional outcome measures (e.g. the TUG, LOS, WISCI II, etc.) which are more related to physiotherapy. Nonetheless, highlighting these functional components is also relevant from the OP. Improvements in functional performance may further enhance independence and performance in ADLs. This may be better understood when considering the International Classification of Functioning, Disability and Health (ICF) (47). The OP should view a person holistically and consider all domains of the ICF model as they may all influence one's health condition. Regarding the "Body Functions and Structures" domain, notably upper limb functions are considered relevant when evaluating occupational performance. Thus, more research is needed where ADL-specific and task-oriented interventions and outcome measures are applied.

Most studies were from a physiotherapy perspective and the intention is not to attempt to contest this knowledge or argue for OTs to perform functional tests by physiotherapist. Instead, the scoping review sought to better understand the potential role of VR-based therapy for people with SCI from an OP since OTs work in interdisciplinary teams. Specifically, this scoping review identified a discrepancy between the relevance of outcome measures and the environment, with only one study showing a clear link between driving and the outcome of driving proficiency (37). From an OP, this suggests there is a potential opportunity to utilise occupation-based theories and assessments e.g., the Canadian Occupational Performance

Measure (48) to enhance alignment between VR-based therapy, the environment and the intended goals of individuals with SCI.

The positive outcomes on walking speed in the included studies (36, 40, 43) correspond with the results of a meta-analysis including participants with chronic stroke who achieved increased walking speed in the VR-based therapy groups compared to non-VR-based therapy groups (49). Nonetheless, gait training is exclusively feasible with a limited number of people with incomplete SCI (AIS grades C-D) (18). In contrast, participants with tetraplegia and severely impaired upper extremity functions were underrepresented in the included studies. Especially for this population, ADL training in all areas such as personal hygiene or cooking using VR may be highly beneficial. An earlier meta-analysis focusing on stroke patients with impacted upper extremity functions concluded that VR-based training positively affected the recovery of upper limb function and ADL performance compared to conventional treatment (50). From an OP, people with SCI might profit from task-specific VR-based training in preparation for real-life training. Generally, VR-based ADL-specific training has not been extensively explored yet in any patient group, or for any diagnosis, and this represents a notable research gap. Regarding this, one feasibility study including healthy participants demonstrated that fully immersive VR-based ADL training in which tea was prepared, was possible from a technological point of view (51). For other populations, VR-based therapy is also increasingly relevant from an OP. For instance, VR-based therapy was successfully employed in people with phantom limb pain during therapy sessions (52) which concurs with the findings of the included studies addressing neuropathic pain in people with SCI (36, 39). Another example demonstrated that the use of fully-immersive VR-based therapy in the treatment of anxiety disorders for exposure therapy had positive outcomes (53). Taken together, these results and the absence of adverse events suggest that VR may provide a safe

environment, especially concerning vulnerable populations. However, further research is needed to determine how adverse events were defined, and indeed whether they included not only physical injury but also broader psychological, sensory, and behavioural aspects.

Conclusions

The results of the included studies suggest that from an OP, VR-based therapy can improve motor functions, such as walking in participants with incomplete SCI. Moreover, sitting balance which is essential for wheelchair users to conduct ADLs could be enhanced. VR-based interventions also showed potential in decreasing neuropathic pain. However, little research was conducted on the influence of VR-based therapy on the mental wellbeing and QOL in the SCI population. This scoping review revealed that most studies focused on functional outcome measures related to physiotherapy, however, these are also important from an OP for enhancing independence in performing ADLs. Future research should investigate ADL-specific and task-oriented interventions and outcome measures. Importantly, VR-based procedures were reportedly safe to use in a therapeutic context. In summary, VR-based therapy is a potentially useful addition to conventional rehabilitation, including OT.

Significance

From an occupational perspective, providing people with SCI with a virtual training environment may increase their motivation as shown in earlier research (15). The ability to select games and levels appropriate to a person's skills allows the execution of high-repetitive movements which are important for sensorimotor rehabilitation after SCI (11). Additionally, when using VR within the clinic setting, it might enable OTs to convey a different and more joyful environment to facilitate the person with SCI's mental wellbeing (54). VR could potentially enable people with tetraplegia to train upper extremities, and particularly hand

functions after reconstructive hand surgery where intense training guided by OTs is required afterwards (55). Another important point to address is that the included studies incorporated a diverse range of VR technologies, from non- to semi- and fully-immersive VR systems. Most studies used complex equipment, (e.g. with special sensors), and yet none of the studies discussed the price point of the VR systems used. Within clinical practice this is essential information when considering whether to purchase a VR device and future research should report this to enhance transparency, reproducibility, and potential implementation in practice settings. To the author's knowledge, the results contribute novel insights as this is among the first scoping reviews on VR-based therapy for the SCI population from an OP.

Methodological considerations

Although this scoping review followed recommended guidelines and approaches (23-28, 30, 56) there are some methodological aspects to critically reflect. Firstly, due to practical reasons there was no second reviewer to independently screen the literature retrieved from search in databases and grey literature. Therefore, the selection of included studies may have been influenced by the potential biases and positionality of the author. To help minimise bias and promote trustworthiness, the author critically reflected and discussed the review process with her supervisor and peer group, particularly regarding any studies where there was uncertainty about inclusion or not. Secondly, regarding the included studies, there was heterogeneity in the quality of studies according to the OCEBM Levels of Evidence published by the Oxford Centre of Evidence-Based Medicine (57). Some studies conducted higher-level research (e.g. RCTs) whereas others applied pre-posttest designs. Altogether, the smaller size and heterogeneity of samples (especially heterogeneity regarding NLI, AIS grades and age range) are potential limitations to the interpretation of findings. However, since this is a scoping and not a systematic review, appraising the quality of studies was not the intention. The inclusion

period for this scoping review as set as 2009-2024 but only studies from 2014 were included which may suggest that not all relevant literature was found, and other databases may need to be searched in future reviews. A 15-year period was chosen in consultation with the academic librarian in part due to the rapid rate of change in technological developments, but the author acknowledges that VR has potentially been used before that date for rehabilitation purposes (although it is unclear if such technology would be still available or relevant). Despite the limited time and scope for this thesis, attempts were made to search for grey literature in clinicaltrials.gov. It is recommended that this search process is expanded to other sources such as Google Scholar, BASE, Dart Europe, and OAIster according to guidance from Karolinska Institutet (58).

Finally, it is important to reflect on the analysis process. On the one hand, an inductive approach was chosen to analyse the data due to the lack of pre-existing theory on VR-based therapy which is a relatively new technology, especially in occupational science and OT. On the other hand, the OP is a well-established in the field of occupational science and OT, notably described by Ann Wilcock (59) and more recently by Njelesani et al. in 2012 (6). Hence, a deductive approach could have been used alternatively. Thus, to balance these considerations, the author chose to analyse the data inductively but to discuss the interpretation of the findings, including the significance and identification of future research opportunities, through an OP lens.

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*** = included in the results of the review**

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Tables and Figures

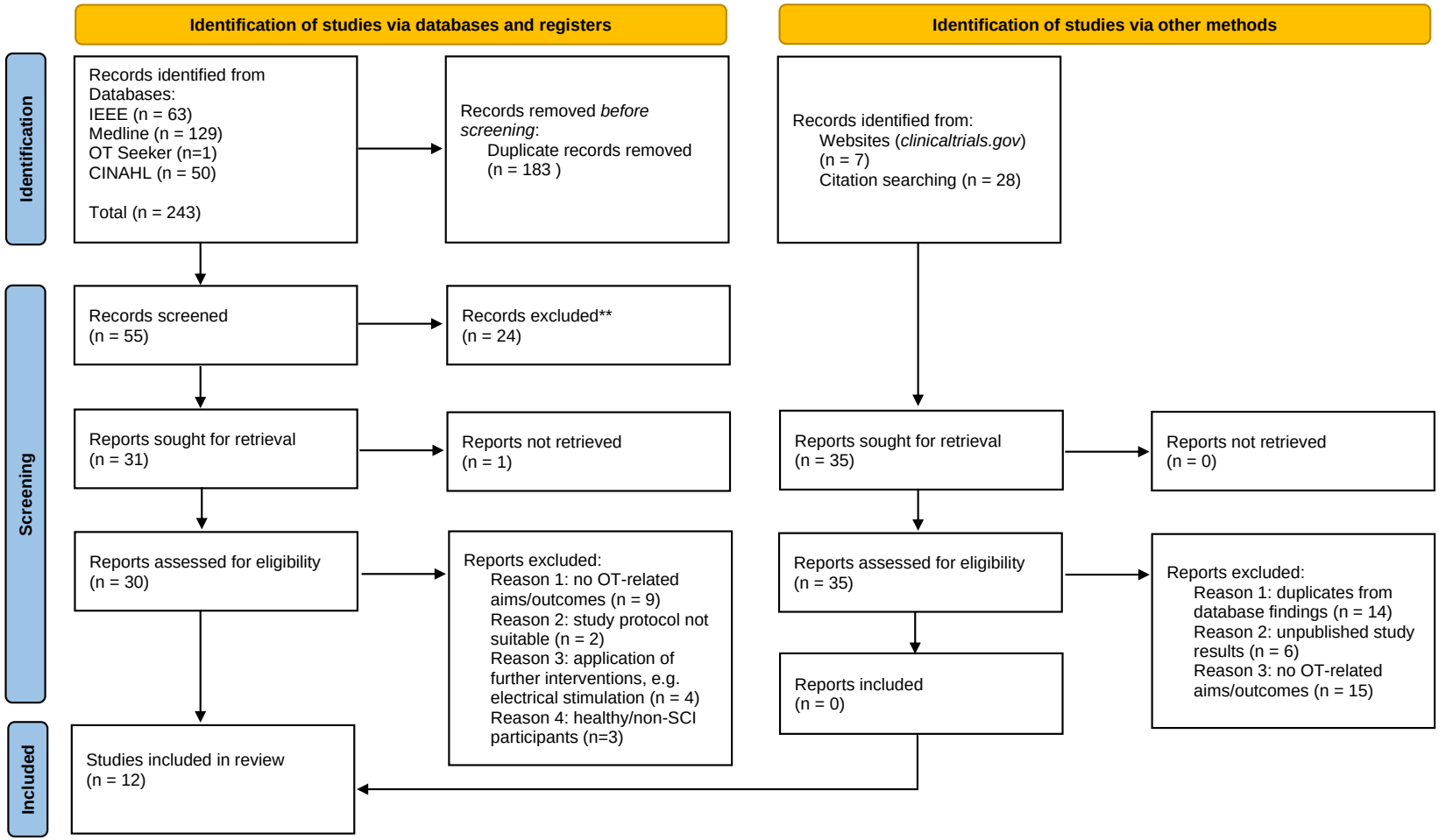
Table 1. The American Spinal Injury Association Impairment Scale (AIS)

AIS Grade	Clinical State
A	**Complete**: No motor or sensory function is preserved in the sacral segments S4-S5
B	**Incomplete**: Sensory but NOT motor function is preserved below the NLI and includes the sacral segments S4-S5
C	**Incomplete**: Motor function is preserved below the NLI, and more than half of the key muscles below the NLI have a muscle grade less than 3
D	**Incomplete**: Motor function is preserved below the NLI, and at least half of the key muscles below the NLI have a muscle grade of 3 or more
E	**Normal**: Motor and sensory function is normal

Note. NLI: Neurological Level of Injury; S: Sacral (e.g. sacral segments 4 and 5).

Table 2. PCC framework – search terms

PCC element	Definition	Synonyms & search terms
Population/Participants	People with spinal cord injuries (SCI)	Tetraplegia OR quadriplegia OR cervical spinal cord injury OR paralysis OR paraplegia
Concept	Virtual reality (VR)- based therapy interventions	Virtual reality OR VR OR augmented reality OR exergaming
Context	Rehabilitation, occupational therapy, occupational performance in the activities of daily living (ADL) AND/OR sensorimotor performance of the upper and lower extremities, neuropathic pain management, spasticity management	Rehabilitation AND/OR occupational therapy AND/OR activities of daily living OR ADL AND/OR physical functional performance AND/OR neuralgia OR neuropathic pain AND/OR chronic pain AND/OR muscle spasticity



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Figure 1. PRISMA flow chart of the study selection process

Table 3. Overview of data base search

Data base, search terms, inclusion-/exclusion criteria	No. of hits	Left to review (Duplicates)	Chosen by title	Chosen by abstract	Chosen articles
IEEE					
Search terms incl. boolean operators: Tetraplegia OR quadriplegia OR cervical spinal cord injury OR paralysis OR paraplegia AND Virtual reality OR VR OR augmented reality OR exergaming	69				
Chosen limitations: year of publication from 2009-2024	63	60	12	5	2
Medline					
Search terms incl. boolean operators: Tetraplegia OR quadriplegia OR cervical spinal cord injury OR paralysis OR paraplegia AND Virtual reality OR VR OR augmented reality OR exergaming	199				
Chosen limitations: year of publication from 2009-2024, Human species	129	89	24	12	5
OT Seeker					
Search terms incl. boolean operators: Tetraplegia OR quadriplegia OR cervical spinal cord injury OR paralysis OR paraplegia AND Virtual reality OR VR OR augmented reality OR exergaming	1				
Chosen limitations: year of publication from 2009-2024	1	0	0	0	0
CINAHL					
Search terms incl. boolean operators:	64				

Tetraplegia OR quadriplegia OR cervical spinal cord injury OR paralysis OR paraplegia AND Virtual reality OR VR OR augmented reality OR exergaming					
Chosen limitations: year of publication from 2009-2024	50	34	19	14	5
Total no. databases only:	243	183	55	31	12
Manual Search (reference lists)	28	16	13	6	0
Grey Literature (clinicaltrials.gov)	7	5	3	3	0
Total no. altogether:	278	204	71	40	12

Table 4. Data extraction table of included articles

Title & Database	Authors	Participants	Purpose	Methods and ethical considerations	VR-based therapy	Outcome measures relevant to research question	Results relevant to research question 1: Improvement of body functions and ADL performance	Results relevant to research question 2: Improvement of mental wellbeing and pain management
The effects of semi-immersive virtual reality therapy on standing balance and upright mobility function in individuals with chronic incomplete spinal cord injury: A preliminary study DB: Medline	An et al., 2018 (43)	Participants with chronic SCI (AIS grade C or D) and walking function (N=10), mean age 44.20 ± 8.66 years (range 29–54 years) Country: South Korea Setting: neurological rehabilitation center	Investigation of effects of semi-immersive VR therapy on standing balance and upright mobility function in individuals with chronic incomplete SCI.	Pre-posttest 30 min./day, 3x/week over 6 weeks. Informed consent was obtained from participants. No ethical approval from an Ethics Committee obtained.	VR-system: IREX; Gesture Tek; Toronto, Canada, Semi-immersive VR	Limit of Stability (LOS), BBS, Timed Up and Go (TUG), Activities-Specific Balance Confidence (ABC) scale, and Walking Index for Spinal Cord Injury II (WISCI II)	Overall LOS score: 32.00 to 46.40, respectively; P < 0.01, Directional LOS score: 28.80 to 42.40 and 34.60 to 48.40, respectively; P < 0.01, BBS: 35.70 to 40.10, respectively; P < 0.01, ABC scale: 67.90 to 76.85, respectively; P < 0.05, WISCI-II: P < 0.05	
Using virtual reality driving simulators in persons with spinal cord injury: three screen display versus head mounted display DB: Medline	Carlozzi et al., 2023 (37)	N=54 HMD condition N=26, TSD condition N=26, Age range 18-65 (mean age 37.9) Country: USA	To examine methods for improving driver retraining protocols for persons with SCI (para- and tetraplegia;	Controlled, randomized, non-blinded. Participants randomized into two groups to use two different VR-driving	VR-devices: specially designed VR-simulators that incorporated hand controls and adaptive equipment (e.g.	Simulator Sickness Questionnaire and software driving simulator variables / driving performance	Driving performance: several group differences; HMD had more “offroad collisions” and higher duration at stop signs	Simulator sickness: five participants in HMD condition & two in TSD with acute simulator sickness, Fisher’s exact

		Setting: Community /outpatient	complete and incomplete SCI)	simulators: 1.) a three screen display (TSD) or 2.) a head mounted display (HMD) Informed consent was obtained from participants. Data collection in accordance with of local Institutional Review Boards.	spinner knob, tri-pin): - TSD - HMD			test did not indicate significant group differences ($p = 0.23$), no significant group differences in reported simulator sickness prior and subsequent to VR exposure, $t(20) = -1.27$, $p = 0.22$ for HMD; $t(23) = -1.02$, $p = 0.32$ for TSD
Comparison between clinical and instrumental assessing using Wii Fit System on balance control DB: IEEE	D'addio et al., 2014 (32)	Participants with SCI (AIS grade C&D) Study group (SG) with SCI patients N=15, CG with healthy participants N=15 Country: Italy Setting: not described	Comparing benefits on balance control of Wii Fit use with traditional rehabilitation therapy in patients (study group) with SCI and in normal subjects (control group)	RCT, non-blinded. Informed consent was obtained from participants.	VR-system: Wii® Fit (Nintendo™), Study group: 3 sessions/week over 12 weeks	Berg Balance Scale (BBS), The Spinal Cord Independence Measure (SCIM-III)	Study group: BBS: First visit 2,5, discharge 66,5 ($p<0.0001$), SCIM-III: First visit 44,3, discharge 96,5 ($p<0.0001$), Group comparison at discharge: BBS: SG 66.5, CG 60.4 ($p<0.02$), SCIM III: SG 96,5, CG 84,1 ($p<0.02$)	
RehabHand: Oriented-tasks serious games for upper limb rehabilitation by	de los Reyes-Guzmán et al., 2021 (33)	Participants with cervical SCI ranging from AIS grade A-D (N=20, aged 30.70 (+-	Presenting the virtual applications based RehabHand	Single experimental session. For intervention, the hand static	VR-device: RehabHand prototype LMC device SDK (version 2.3.1)	Upper Extremity Motor Scores (UEMS), Hand	Significant statistical differences were found between both groups for the static pose ($p <0.01$), the	

using Leap Motion Controller and target population in spinal cord injury. DB: CINAHL		10.29)), and neurologically healthy participants (N=20, aged 27.25 (+-6.60)). Country: Spain Setting: Laboratory/clinical setting	prototype for rehabilitation of manipulative skills of the upper limbs in patients with SCI	pose was captured, all movements were then performed with dominant hand. Pinching and grasping were analysed in SCI and healthy participants. No information about ethical consideration nor approvement given.		movements: static pose, pinch, grasping, wrist flexion-extension, forearm pronation-supination	effect size of this difference is small (d =0.15). Although the fitting rate is statistically greater in healthy subjects (0.953 ± 0.080) than in patients (0.799 ± 0.290), the difference is small. The effect size of the difference for each variable measured is small.	
Effectiveness of the Virtual Reality System Toyra on Upper Limb Function in People with Tetraplegia: A Pilot Randomized Clinical Trial DB: CINAHL	Dimbwadyo-Terrer et al., 2016 (34)	Participants with subacute complete cervical SCI (AIS grade A-B) Intervention group: N=16, aged 34,53 (+-13,71) Control group: N=15, aged 40,27 (+-13,61) Country: Spain Setting: Hospital	Investigation of effectiveness of VR-system Toyra to improve upper extremity function in SCI population	RCT, VR-intervention conducted by on OT, Standard OT and PT (for both groups) combined with 15 sessions with VR system (IG) for 5 weeks (30 min/day & 3 days/week), Assessments before and after intervention	VR-system: Toyra Focus on ADL tasks (e.g. reproducing movements necessary to eat or comb hair)	Manual Muscle Test (MMT) of upper extremities, Functional Independence Measure (FIM), The Spinal Cord Independence Measure (SCIM III) → self-care subscore, The Barthel Index (BI), Quebec	No group showed statistically significant improvements between pre- and posttest in the clinical and functional variables assessed. No significant differences were found between pre-evaluation and follow-up evaluation.	QUEST questionnaire: VR system scored an overall average value of 33.20+-2.177 over 35 points. The satisfaction survey: overall average value of 84.80+-8.80 over 100 points

				and 3 months follow-up Study protocol was approved by the Local Ethics Committee. Informed consent was obtained from participants		User Evaluation of Satisfaction with Assistive Technology 2.0 (QUEST) → IG	
Effectiveness of immersive virtual reality training to improve sitting balance control among individuals with acute and sub-acute paraplegia: A randomized clinical trial DB: CINAHL	Goel et al., 2023 (41)	Participants with traumatic SCI (paraplegia, AIS grade A-B) (N=30) IG: N=15 CG: N=15 Country: India Setting: Hospital	Determination of whether there is a difference in functional performance in VR-based balance training or real-world balance training in people with SCI (paraplegia)	Randomized trial, IG: VR-based balance training, CG: real-world task-specific balance training, both groups 45 min/day, 5 times/week for 4 weeks	VR-system: Sony PlayStation 2 and EyeToy (Sony Computer Entertainment Inc., Beijing, China) were used with 3 virtual environments (birds and balls, soccer, and snowboard games)	Modified Functional Reach Test (mFRT), Spinal Cord Independence Measure–III (SCIM-III) → self-care	Effect size: largest change was observed in mFRT scores for time and then for Time x Group: "Forward" 1.67, "Left": 1.89, "Right": 1.58. (when effect size is >0.7, the change in the measured value is considered large)
Study on the Effectiveness of Virtual Reality Game-Based Training on Balance and Functional Performance in Individuals with Paraplegia DB: CINAHL	Khurana et al., 2017 (42)	Participants with paraplegia (N=30), VR-group N=15, reality-based training group N=15 Country: India Setting: Hospital	Determination whether there is any difference between virtual reality game–based balance training and real-	Pretest-posttest experimental design 4 weeks, 5 sessions/week each 45 min. Ethical approval for the study was	VR-system: Sony PlayStation 2 and EyeToy (Sony Computer Entertainment Inc., Beijing, China)	Functional Reach Test (mFRT), T-shirt test, SCIM-III (self-care component)	mFRT: significant difference for time (p = .001) and Time x Group effect (p = .001), T-shirt test: group effect (p = .05), SCIM-III (self-care component): time effect (p = .001)

			world task-specific balance training in improving sitting balance and functional performance in individuals with paraplegia	obtained by the Ethical Research Committee of Tertiary Care teaching Hospital. Informed consent was obtained from participants. Study protocol was approved by a research and ethics committee.				
Effect of a semi-immersive virtual reality navigation therapy on quality of life in persons with spinal cord injury DB: CINAHL	Manzanares et al., 2023 (35)	Participants with paraplegia (N=11), EG: N=6, CG: N=5, Age range 20–56 years (mean age 42.36) Country: Spain Setting: Hospital	Aiming to develop a sailing simulation-based therapeutic rehabilitation program for individuals with SCI during subacute phase of injury	Pre-test/post-test quasi-experimental design, participants randomly assigned into groups, 30–40 min/day, three times/week for six weeks Ethical approval for the study was obtained by an Ethics Committee. Informed consent was	VR-system: vSail-AccessVR , Virtual Sailing Pty Ltd, Semi-immersive VR	SCIM-III, Spinal cord injury quality of life questionnaire (SCI QL-23), Modified functional reach test (mFRT)	SCIM-III, MFRT: no statistically significant differences found on post-tests between experEG and CG imental and control group on any of the dependent variables. Significant multivariate effect in mFRT functional reach variable	EG: significantly higher value for the global QOL variable in the post-test compared to the pre-test

				obtained from participants.				
Intensity of shoulder muscle activation during resistive exercises performed with and without virtual reality games DB: IEEE	Mazzone et al., 2023 (38)	Participants with SCI (paraplegia) N=5, age range 22-49, mean age 35.4 years Country: USA Setting: Rehabilitation center	To determine if performance of shoulder exercises integrated Into VR-Gaming (VRG) results in similar muscle activation as non-VRG exercise	One single session lasting for 4 hours. Ethical approval for the study was obtained by the Institutional Review Board. Informed consent was obtained from participants.	VR-system: video game prototype with GameTrak® sensor	Kinematics and EMG data (Electrodes were inserted into the muscle bellies of four muscles in the right shoulder: sternal pectoralis major, supraspinatus, infraspinatus and rhomboideus major)	Key shoulder muscle activity was similar overall during exercise with two VRG prototypes, compared to exercising without VRG, No clinically significant differences were found in kinematics between conditions. Muscle activation was similar or greater during VRG than non-VRG exercise	
Immersive interactive virtual walking reduces neuropathic pain in spinal cord injury: findings from a preliminary investigation of feasibility and clinical efficacy DB: Medline	Trost et al., 2022 (39)	Participants with paraplegia (N=27), Interactive condition (IG) N=17, Passive condition (CG) N=10 Aged 23-70 Country: USA Setting: individual's homes/residences	Comparing interactive, virtual walking intervention to a passive, noninteractive virtual walking Condition in participants with SCI and neuropathic pain (NP)	Non-randomized design, Intervention over 2 weeks, 2 sessions/day, 20 sessions in total. Ethical approval for the study was obtained by an Ethics Committee.	VR-system: head-mounted display (HMD) wired to a laptop PC	NRS (11-point numeric rating scale) before and after each 5-minute gaming session, Patient Health Questionnaire-9 (PHQ-9), The Patient Global Impression of Change (PGIC), The Treatment Evaluation		Decline in current NP from pregaming to postgaming F(1,25) 5 10.58, P , 0.01, with no significant interaction between groups. Follow-up analyses: participants in interactive condition showed

						Inventory (TEI), Appraisal of virtual walking		significant decline in NP ratings from pre- to post-intervention, F(1,16) 5 11.71, P , 0.01. Appraisal of virtual walking: IG agreed to the statement "I was not aware of the wheelchair while playing the game," 4.63(1.96) compared to CG 3.60(2.12). Significant decline in depressive symptomatology regardless of group, F(1,25) 5 7.44, P , 0.05.
Virtual reality-augmented neurorehabilitation improves motor function and reduces neuropathic pain in patients with incomplete spinal cord injury DB: Medline	Villiger et al., 2023 (36)	People with incomplete SCI (N=14), (AIS grade C-D), aged 52.7 +-14.9 years Setting: outpatient Country: Switzerland Setting: Hospital	Examination of VR-training on improvement of lower limb function and neuropathic pain in people with SCI	Pre-posttest design, VR intervention for 4 weeks, 16-20 sessions/week each 45 min. Ethical approval for the study was obtained by the	VR-system: PC and a large-screen display showing virtual representations of legs and feet	10 Meter Walking Test (10MWT), Berg Balance Scale (BBS), Lower extremity motor score from 0 (complete paralysis) to 50 (normal strength),	Increase of walking speed in post- and follow-up test (post P ≤ .001, follow-up P ≤ .003) BBS score: P ≤ .001 Muscle strength: P ≤ .001 Mobility (SCIM mobility, P ≤ .001; WISCI II, P ≤ .004)	Neuropathic pain: decreases were found in intensity (P ≤ .004, P ≤ .031) and unpleasantness (P ≤ .004, P ≤ .016) post- and follow-up assessments

				local Ethics Committee. Informed consent was obtained from participants.		SCIM III → mobility, Neuropathic Pain Scale (NPS)	→ Significant changes in all participants at post- and follow-up assessments	
The effects of the Nintendo™ Wii Fit on gait, balance, and quality of life in individuals with incomplete spinal cord injury DB: Medline	Wall et al., 2015 (40)	Participants with chronic, incomplete SCI (AIS grade D) and walking function (N=5), age range from 50-64, mean age 58.6 years Country: USA Setting: rehabilitation hospital	Assessing effects of VR using the Nintendo™ Wii Fit on balance, gait, and quality of life in ambulatory people with incomplete SCI	Interrupted time series design with three pre-tests over three weeks, post-test within one week of the intervention, and four-week follow up. 1-hour sessions, 2x/week over 7 weeks. Ethical approval for the study was obtained by the Institutional Review Board.	VR-system: Wii® Fit (Nintendo™)	Gait speed, timed up and go (TUG), forward functional reach test (FFRT) and lateral functional reach test (LFRT), RAND SF-36	Gait speed: significant increase from pre-intervention to post-intervention ($P = 0.001$, $d = 0.35$), FFRT: ($P < 0.001$, $d = 1.12$, LFRT: ($P = 0.001$, $d = 0.88$, No other statistically significant changes.	RAND SF-36: no statistically significant changes.

Note. 10MWT: 10 Meter Walking Test; ABC Scale: Activities-Specific Balance Confidence Scale; AIS: The American Spinal Injury Association Impairment Scale; BBS: Berg Balance Scale; BI: Barthel Index; CG: Control Group; DB: Database; E.g.: for example; EG: Experimental Group; FFRT: Forward Functional Reach Test; FIM: Functional Independence Measure; HMD: head mounted display IG: Intervention Group; LFRT: Lateral Functional Reach Test; LOS: Limit of Stability; mFRT/MFRT: Modified Functional Reach Test; MMT: Manual Muscle Test; NP: Neuropathic Pain; NRS: Numeric Rating Scale; PGIC: The Patient Global Impression of Change; PHQ-9: Patient Health Questionnaire-9; QOL: Quality of Life; RAND SF-36: 36-Item Short Form Survey-Instrument; RCT: Randomized Controlled Trial; SCI: Spinal Cord Injury/Injuries; SCI QL-23: Spinal Cord Injury Quality of Life Questionnaire; SCIM III: The Spinal Cord Independence Measure; SD: Standard Deviation; TEI: The Treatment Evaluation Inventory; TUG: Times Up and Go Test; TSD: Three Screen Display; UEMS: Upper Extremity Motor Scores; VR: Virtual Reality; WISCI II: Walking Index for Spinal Cord Injury II.