REVIEW ARTICLE

Virtual reality in spinal cord injury rehabilitation: a systematic review of its effectiveness for balance performance and functional mobility

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Abstract:

Post-traumatic Spinal Cord Injury (SCI) leads to poor balance performance and functional mobility, and effective rehabilitation is crucial in improving these impairments, thus improving quality of life. However, there are some barriers to effective rehabilitation, which include time-constraint, availability of therapists, and patient's motivational level. In order to overcome these barriers, Virtual Reality (VR) was introduced in the rehabilitation setting. This review aimed to determine the effects of VR on balance performance and functional mobility in the SCI population. Four search engines were selected to search online databases, with inclusion criteria ; (i) VR as a primary intervention towards the SCI individuals and (ii) published in the English language. After screening and eligibility checks, six studies with a total of 97 participants with PEDro score (Median: 3.5) were included in this review. The results showed that the application of VR in rehabilitation is beneficial since it may induce motor relearning in retraining motor control. We proposed that dosage for the intervention of 30 to 60 minutes per session, two to five sessions per week within at least 3 weeks to 7 weeks of VR training, may have a positive impact on balance and functional mobility in the SCI population.

Keywords: Balance, functional mobility, spinal cord injury, rehabilitation, virtual reality

1. INTRODUCTION

Spinal Cord Injury (SCI) is a worldwide incident that mostly resulted in life-long incapability. Individuals with SCI may face physical and mental challenges in addition to financial loss after the incidence [1]. According to Ning, Wu, Li, & Feng (2012), rates of SCI incidence ranged from 12.06 to 61.6 per million population in Asia [2]. SCI is most common in a motor vehicle accident (MVA), followed by fall accidents, sports or recreation activity and acts of violence [2]. It is relatively low-incidence as compared to other upper motor neuron injuries, but can be a high-cost fatality leading to a devastating change in the life of a person. SCI lead to reduced mobility, self-care and the ability to engage in certain social activities. Besides, it also affects other systems, which are cardiopulmonary, integumentary, gastrointestinal, genitourinary, and sensory systems. ASIA Impairment Scale (AIS) provides a particular approach to assess the severity of the SCI. The following criteria determine the degree of impairment following SCI. A=complete, B=sensory incomplete, C=motor incomplete have fewer than three muscle grade, D=motor incomplete have more than three muscle grade and E=normal or anyone without SCI [3, 4].

One of the common issues in patients with SCI is balance disorder [5]. The leading causes of balance disorder in SCI are partial or complete loss of somatosensory perception and/or voluntary motor control [6]. From a clinical perspective, balance performance is an essential component in the rehabilitation of SCI; however, it may vary from those with partial or complete voluntary control of the trunk, hip, knee, and ankle joints to those with a complete motor lesion [6]. While the former group may be able to stand and walk, the latter is usually dependent on a mobility wheelchair. Other than that, static and dynamic balance in SCI patients tend to be affected by impaired somatosensory afferents, reduced voluntary motor control resulting in increased postural sway during quiet standing, decreased precision during bodyweight shift, and delayed external disturbance responses [7].

Besides, individuals with SCI may present with poor functional mobility because of muscle weakness [7]. However, exercise following SCI has been shown to enhance functional mobility and to promote the recombination of the cerebral cortex in the somatic region [8]. Some studies have found that early exercise after corticospinal motor system injury may restore corticospinal tract contact and primary motor cortex movement projection, thereby raising the number of intermediate cholinergic neurons in the ipsilateral and contralateral spinal cord and decreasing the physical control disorder [8].

Rehabilitation following SCI, which includes ADL re-learning, for example, maintaining body postures under different conditions, is guided by principles of motor learning and is one of the core pillars of subacute learning [4,7]. However, it requires a lengthy rehabilitation period and put a financial burden on the SCI patients [3]. Geographic, temporal, social, transportation restriction and financial are known as barriers for them to get access to a supervised rehabilitation center [9]. The virtual reality (VR), defined as an approach to the user-computer interface, was widely accepted intervention in SCI rehabilitation. It provides a stimulating atmosphere, scenario, or behavior in real-time, which allows user interaction via multiple sensory channels and increasing the focus and motivation of the participants through input and graduated stimuli in real-time [10, 11].

Several systematic review studies have shown that VR is an effective intervention tool and has positive effects on functional mobility and gait in Stroke and Parkinson's Disease populations [11, 12, 14]. In the SCI population, a number of studies have explored the effects of VR on balance performance [15, 16, 17, 18, 19, 20] and functional mobility [15, 16, 17, 18, 19]. However, there is yet systematic review to be conducted to date. Therefore, this systematic review will review studies from the year 2015 until 2019 that explored the effects of VR on balance and functional mobility in the SCI population. In addition, the dosage and types of VR will be analyzed in order to determine its effectiveness during SCI rehabilitation.

2. METHODOLOGY

2.1 Search strategy and search term

A Preferred Reporting Items (PRISMA), a compliant systematic review was performed to evaluate the studies pertaining to the effects of VR on balance and functional mobility in the SCI population and the dosage of VR training needed for effective rehabilitation. In search strategy, an extensive systematic search of published sources was conducted from electronic databases such as Scopus, PubMed, Science Direct and Web of Science from 2015 until 2019.

2.2 Eligibility criteria

Studies were included if the inclusion criteria were met: (1) a randomized, quasi-randomized, or non-randomized controlled trial (RCT) (prospective or retrospective); (2) full-text article; (3) English language; (4) virtual reality as an intervention; (5) participants with Spinal Cord Injury. Studies were excluded if (1) conference abstract, book chapters, letters patient; (2) other than English language articles were excluded; (3) not include virtual reality as intervention; (4) populations with neurological conditions other than spinal cord injuries. Titles and abstracts of the eligible studies were reviewed by two reviewers independently and full-texts were retrieved for all potentially suitable papers.

2.3 Data extraction

Data were extracted using a pre-designed data extraction form for each selected study. Data extracted included citation details, trial setting, inclusion and exclusion criteria, study population, participant flow, intervention details, outcome measures and results, and methodological quality. Following the selection process for review, the following data were extracted from each selected article: (1) author, (2) study design, (3) sample size, (4) sample description, (5) experimental intervention, (6) control intervention, (7) sessions details and (8) number of sessions, duration and frequency.

2.4 Outcomes Measure

The primary outcome measures for balance performance were the Berg Balance Scale (BBS), Activities-specific Balance Confidence (ABS), and Functional Reach Test (FRT). In addition, Timed Up and Go (TUG), the Walking Index for Spinal Cord Injury-II (WISCI-II), and Spinal Cord Independence Measure mobility (SCIM) were used to measure functional mobility [15, 16, 17, 18, 19, 20].

The secondary outcomes measures were (i) adapted Self-Reported Changes questionnaires, with scoring 0 is worsened, 1 stand for no change, 2 to 3 for minimal improved, and 4 to 5 for much improved [5] and (ii) RAND SF-36 Health measure for the quality of life and wellbeing of a person [6].

2.5 Methodology Quality Assessment

The methodological quality of assessment was assessed using the Physiotherapy Evidence Database (PEDro) Scale (REF).

3. RESULTS

3.1 Search Result

Figure 1 shows the sequences of the research process, starting from the identification of studies until the inclusion of the potential studies into the review.

3.2 Methodological Quality

Table 1 shows the PEDro scores for all reviewed studies with the range of the total score is between 2 to 5 out of 10. The highest score is 5 out of 10, while the lowest score is 2 out of 10.

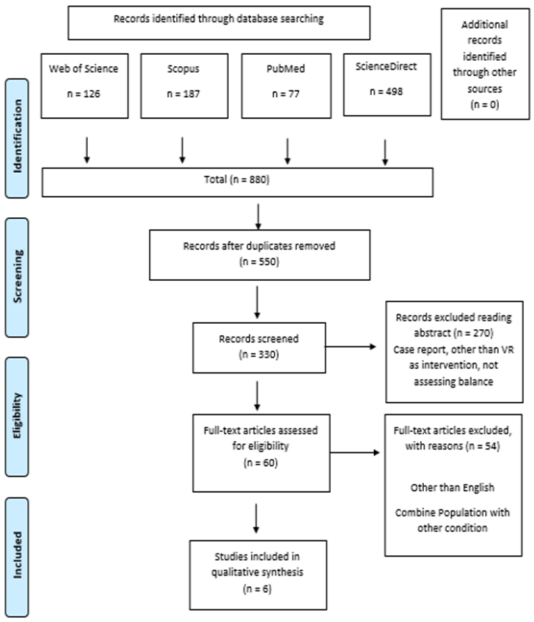

Figure 1: Research flow diagram

3.3 Characteristic of Included Studies

The summary of studies' authors, study design, types of Virtual Reality tool, frequency, participants and results were presented in Table 2. A total 6 studies were included; six studies explored the effects of virtual reality on balance and functional mobility and five studies explored the effects of virtual reality on functional mobility only. All studies selected in this review were quasi-experimental designs.

3.3.1 Participants

A total of 97 SCI subjects were included in this systematic review. Out of the total, 40 subjects were traumatic or non-traumatic SCI for more than six months [21], 27 subjects were more than one-year post-injury [17, 18], and 30 subjects were categorized as either group A or B in the American Spinal Injury Association Impairment (ASIA) Scale with underlying SCI for less than six months [16]. In terms of injury level, 12 subjects had lesion below C4, and 30 participants have levels of injury between T6 and T12 [16, 18], and other studies not mention the levels of injury [19,20].

3.3.2 Outcome Measure

As outcome measures for balance, a number of studies had used the Berg Balance Scale (BBS) to measure balance [16, 19, 25], 1 study had used Functional Reach Score (FRS) [21], another had used balance confidence [22], Limit of stability (LOS), Functional Reach Test (FRT), Forward Functional Reach Test (FFRT), Lateral Functional Reach Test (LFRT), Timed Up and Go (TUG) [19], and 2 studies had used Activity Specific Balance Confidence (ASBC) [22]. As for functional mobility, 2 studies had used Walking Index for Spinal Cord Injury-II (WISCI-II) and walking speed [17, 18], one study used stride length, stride frequency and step width and 2-min walking test (2MWT) [22]. In addition, one study used a 10 meter walking test (10MWT) and a 6-min walking test (6MWT) [18].

Table 1: PEDro score for all articles

Author	PEDro Criteria Score										Total
	1	2	3	4	5	6	7	8	9	10	
Madhusree Sengupta et al. (2019)	1	0	0	1	0	0	0	1	1	1	5/10
Van Dijssendonk et al. (2018)	1	0	0	1	0	0	0	0	0	0	2/10
An et al. (2017)	1	0	0	1	0	0	0	1	0	0	3/10
Khurana et al. (2017)	1	1	0	1	0	0	1	1	0	0	5/10
Villiger et al. (2017)	1	0	0	1	0	0	0	0	0	0	2/10
Wall et al. (2015)	1	0	0	1	0	0	0	0	0	0	2/10

1= Yes, 0= No. Criteria score: 1=eligibility criteria; 2=random allocation; 3=concealed allocation; 4=baseline comparability; 5= blind subject; 6=blind therapist; 7=blind assessors; 8=adequate follow-up; 9=intention to treat; 10= between group comparison

3.4 Training Parameters

Table 2 summarizes the training parameters used in the included studies. All studies used different types of VR as their intervention, which were Xbox Kinect [8], GRAIL training [9], semi-immersive VR therapy [10], Sony PlayStation 2 and EyeToy [11], VR-augmented Training [5] and Nintendo TM WiiFit [6]. Most of the intervention in the studies lasted from 30 to 60 minutes per session, two to five sessions per week of at least 3 weeks to 7 weeks.

Table 2: Summary of training parameters

Author	Subjects	Types of VR	Intervention Details	Duration
Madhusree Sengupta et al. (2019)	25 (not mention age and gender)	Xbox Kinect (Rhetoric)	Routine, conventional therapy consisted of an individualized exercise program as per patient's needs prepared for all subjects	30 minutes/ session 5 days/week Duration: 3 weeks
Van Dijssendonk et al. (2018)	15 (chronic iSCI)	GRAIL training	Perform a 2-minute walking test on the GRAIL in a self-paced mode.	1hour / session 12 sessions Duration: 6 weeks

An et al. (2017)	10 (chronic iSCI)	Semi-immersive VR therapy	The system consisted of Interactive Rehabilitation Exercise (IREX). 6 out of 20 programs were included, which are soccer, conveyor, volleyball, formula racer, airborne and snow-board. Each of the activities performed 4 minutes with 1-minute rest in between.	VR therapy was performed: 30 minutes /day 3 days/week Duration: 6 weeks
Khurana et al. (2017)	30	Sony PlayStation 2	Group A (VR): consists of birds and ball games, soccer games and snowboard simulation. The first and second games have three levels of difficulty, whereas the third game only one level used. Group B (real-world): Specific tasks for upper limbs and out of base of support. The level of difficulty increased by instructing subjects to move during activities.	45 minutes /day 5 days /week Duration: 4 weeks
Villiger et al. (2017)	12	VR-augmented training	Five sceneries for feet and legs selected which are; ankle dorsal flexion, knee extension, leg abduction and adduction.	30-45 minutes /sessions 16–20 sessions Duration: 4 weeks
Wall et al. (2015)	5 (male subjects)	Nintendo TM WiiFit	Multiple games in Nintendo to promote weight shifting, stability, balance and coordination. Subjects play games that focus on gait components.	One-hour/ sessions Nintendo Wii Fit 2 times/week

4.0 DISCUSSION

4.1 Introduction

This systematic review has found pieces of evidence supporting the use of virtual reality as a useful treatment tool in SCI rehabilitation. These are consistent with other systematic reviews on the effectiveness of virtual reality in neurological conditions such as stroke [23] and Parkinson's Disease [24] that showed improvement in balance and functional mobility. Within our knowledge, few studies demonstrated the effectiveness of VR regardless of the types used in the SCI population, evidenced by improvement in short-term and long-term balance and functional mobility.

4.2 Outcome measure

Half of the included studies used BBS as a primary outcome measure in order to evaluate balance performance [16, 19, 25]. In addition, another two studies used ASBC as a primary outcome measure in their studies [22] and FRT as their primary outcome measure [19]. Meanwhile, for functional mobility, three studies used TUG as their primary outcome measure [16, 18, 19]. One of the studies used walking speed, stride length, stride frequency, and step width as their primary outcomes [22]. Besides, there is one study used SCIM as their primary outcomes for functional mobility parameters [16]. Lastly, one study did not discuss functional mobility as an outcome measure [21].

4.3 Types of VR and Intensity of Intervention

Although the types of VR tools selected varied between studies, the tools, in general, provided programmed exercise and games with the goals of balance and functional mobility aspects such as soccer games, snowboard simulation [15, 16], weight shifting, stability, balance and coordination [19]. The goals were in line with a study by Nas (2015), in which the aim of the recovery period should be to concentrate on sitting and transportation balance and strength education [3].

The intensity of intervention was frequently recognized as a crucial element in enhancing outcomes in varieties of population, and likely the key of elements of balance training in virtual reality [16]. Based on the selected studies, most studies conducted 30 to 45 minutes every session [15, 19, 25]. Only two studies conducted one-hour in a session [17, 18], and both showed significant results. In terms of functional mobility, five studies showed significant results in both TUG and gait speed. In another study, TUG is not significant, but gait speed is significant [19]. Besides, another four studies using TUG as parameters showed the same result.

All studies in this review had conducted the VR intervention in SCI rehabilitation from two to five sessions per week for at least 3 weeks to 7 weeks. Based on the studies, VR training showed a positive impact on improving balance and functional mobility among individuals with SCI for more than 6 months [15, 17, 19, 25]. Nonetheless, it was recommended that extended training periods might produce a more significant result in this population [27].

4.4 Balance Performance

Significant improvement in BBS and ASBC scores following VR intervention had shown that it helps in enhancements of standing stability and confidence in balance in the SCI population. This is consistent with a result showed in the study on stroke individuals, which compared the VR therapy group with the control group [12]. It may be postulated that the improvement in BBS and ABC scores might be due to the nature of VR-therapy training conducts. A recent study revealed that VR therapy increases motivation by giving beneficial effects on psychological and motivational aspects of individuals with SCI [15] hence, encourage them to do rehabilitation exercises.

However, balance measured with FRT following VR intervention had produced inconclusive results. VR intervention 2 times per week in 7 weeks, and 5 days per week in 4 weeks for a period of time had produced a significant improvement in FRT scores [15, 18], whereas 30 minutes session with 5 times per week in seven-week showed no significant improvement [21]. Nonetheless, it can be deduced that time range from 840 to 900 minutes of VR intervention session will produce significant positive effects on balance in the SCI population.

4.5 Functional Mobility

In this review, the functional mobility of the SCI population following VR intervention was measured with TUG, WISCI, and SCIM [14, 16, 18, 19], and the results are inconclusive. In one experimental study, the TUG scores did not significantly improve following Nintendo WiiFit training with an intensity of 2 times a session per week for seven weeks. The result may be due to the limitation of the Nintendo Wii Fit design. The tool may have a limited range of specific functional activities that can be used to enhance mobility, thus suggest a need for further research with more extended intervention training and different VR gaming [19]. On the contrary, the TUG scores were significantly improved in two studies using semi-immersive VR therapy and VR-augmented training. Both studies had conducted three to five sessions of VR gaming per week [16, 18]. Nonetheless, the inconclusive results in this review were consistent with a study on Parkinson's disease population [14]. This could be because functional mobility was a complex task involving multiple functions such as lower limb strength, spatiotemporal parameters such as step length, step width, and the use of aids such as a walker, cane, or crutches.

4.6 Limitation of Study

The main limitation of this review is the insufficient published sources of study, especially randomized control trial design study included as it produces the most reliable empirical evidence of treatment's efficacy. The included studies were either quasi-experimental studies with a moderate methodological quality or pilot study with a small sample size that may affect the statistical power of the results. In addition, this review included studies in English only and might be a potential limitation that restricts the results of this review. Finally, all the studies used different types of VR as their intervention, and it was necessary to highlight that all the subjects in selected studies were C and D on the ASIA scale with numerous injury levels. These could hinder the generalizability of the results among all SCI population.

5. CONCLUSION

In conclusion, VR may promote neural plasticity on multiple central nervous system levels and induce motor relearning in retraining motor control leading to improved balance and functional mobility in the SCI population. We suggested that dosage for the intervention of 30 to 60 minutes per session, two to five sessions per week within at least 3 weeks to 7 weeks of VR training to have a positive effect on balance and functional mobility. Finally, the result of this review study can be used as a guideline in order to design intervention for the SCI population with barriers to access rehabilitation center regularly.

Future studies should include standardizing criteria of participants, including types of VR modes with specific periods used to avoid bias. Other than that, outcome measures selected must be considered in VR therapy nature as it might be a potential bias to the results. Lastly, systematic review RCTs studies should be done for more extensive benefits in neurological worldwide.

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