

A novel use of virtual reality in the treatment of cognitive and motor deficit in spinal cord injury

A case report

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Abstract

Rationale: Aim of this study is to evaluate the cognitive and motor outcomes after a combined rehabilitative training using a standard cognitive approach and virtual reality (VR), in a patient with spinal cord injury (SCI).

Patient's concerns: A 60-year-old right-handed man, affected by incomplete cervical SCI, came to our observation for a moderate tetraparesis, mainly involving the left side, after about 6-months from the acute event. The neurological examination showed imbalance with upper limb incoordination, besides the paresis mainly involving the left side. At a neuropsychological evaluation, he presented important impairment in cognitive and behavioural status, with temporal and spatial disorientation, a reduction of attention and memory process, deficit of executive function and a severe depression of mood, which was not detected during the previous recovery.

Diagnosis: Motor and cognitive deficits in SCI.

Interventions: The patient was 1st submitted to standard cognitive training and traditional physiotherapy, and then to a combined therapeutic approach, in which virtual reality training was provided by means of the virtual reality rehabilitation system (VRRS, Khymeia, Italy).

Outcomes: After the combined therapeutic approach with the VRRS training, we observed a significant improvement in different cognitive domains, a notable reduction of anxiety and depressive symptoms, as well as motor performance, and balance improvement.

Lessons: Virtual reality can be considered a promising tool for the rehabilitation of different neurological disorders, including patients with both motor and cognitive deficits following SCI.

Abbreviations: ATP = attention process training, BBS = Berg balance scale, CAM = attentive matrices test, FIM = functional independence measure, HRS-A = Hamilton rating scale for anxiety, HRS-D = Hamilton rating scale for depression, MoCA = Montreal cognitive assessment, MSCIS = the model spinal cord injury system, PT = physiotherapy, RAVLI = Rey auditory verbal learning immediate, RAVLR = Rey auditory verbal learning recall, RCI = reliable change index, ROT = reality orientation therapy, SCI = spinal cord injury, SCT = standard cognitive training, SD = standard deviation, SFT = semantic fluency test, TMT = trail making test, VFT = verbal fluency test, VR = virtual reality, VRRS = virtual reality rehabilitation system.

Keywords: neurorehabilitation, spinal cord injury, virtual reality, VRRS

1. Introduction

Spinal cord injury (SCI) consists of temporary or permanently loss of motor, sensory, or autonomic functions after either traumatic or non-traumatic spinal cord damage. Every year, spinal trauma, affects about an individual in a thousand. An

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Italian epidemiologic survey^[1] has found 1014 new cases of spinal cord injury (SCI) in 2 years, most trauma (67.5%). Among these, almost the 57% showed a SCI close to the neck, which can cause total or partial quadriplegia and an alteration of the muscle tone, depending on the specific position, and the seriousness of the trauma.^[2] The location and type of spinal cord damage determine the different clinical pictures (ranging from various levels of incomplete forms up to a complete SCI), and the functional and rehabilitation outcomes.^[3]

The SCI can cause important disability, mainly involving the motor function. Sensory-motor as well as genito-urinary, neuro-vegetative or breathing alterations may also be present. Cognitive dysfunctions sometimes may be detected, but they are not related to the injury. The model spinal cord injury system (MSCIS)^[4] observed that 28% of the patients affected by acute SCI tend to have minor brain injuries, and among these, only 12% presents cognitive or behavioral alterations. Kreutzer et al^[5] have observed a chronic deficit in visual verbal learning, in the visual organization and attention in 30 patients affected by SCI, even if they did not reveal evident traumatic brain injuries. Moreover, patients affected by SCI shows high levels of depression and

anxiety, which tend to decrease during their rehabilitative period even if their prevalence remains unexpectedly high.^[6] In literature, some studies^[7,8] highlighted that cognitive and emotional-behavioral symptoms in SCI (concentration, attention and memory deficits) can be a consequence of the loss of consciousness or of a post-traumatic amnesia. Nonetheless, these symptoms can also be a consequence of predisposing risk factors connected to some aspects of the patients' everyday life,^[9,10] to their level of education,^[6] to their stress and other socio-demographic factors, or to prolonged anesthesia. Many traditional and innovative techniques can be useful for the rehabilitation of motor and cognitive deficits,^[11,12] however; in the last decade, virtual reality (VR) has had a growing role in the treatment of different neurological disorders.^[13,14]

The VR is the term used to indicate a simulated reality: it consists in the use of computer technologies to create artificial environments, similar to the real ones with which the patient can interact. The "virtual rehabilitation" puts together the advantages of a cognitive and motor stimulation with a recreational and highly ecologic role, so that the patients' motivation and pleasure grows during the rehabilitative session, with a simulation of everyday life activities. These aspects have relevant consequences on both motor and cognitive abilities, with regard to attention, memory and executive processes,^[15] supporting higher awareness and knowledge of results and performance. Indeed, thanks to these virtual scenarios, the central nervous system receives an increased sensory feedback, which is able to produce changes in the synaptic plasticity, to reinforce motor learning.^[16]

Among the various tools using VR, the virtual reality rehabilitation system (VRRS) is a promising device for the rehabilitation of a wide range of neurological disorders, thanks to its modularity. The VRSS has 3 main rehabilitative modules: Neurologic (including motor, cognitive; and logopedic activities; Cardiorespiratory, and Orthopedic, whose use is giving promising results.^[17-19]

The aim of this study is to evaluate the cognitive and motor outcomes after combined rehabilitative training using a standard cognitive approach and virtual reality, in a patient with SCI.

2. Case description

A 60-year-old right-handed man, affected by incomplete cervical vertebro-spinal trauma, presented with a moderate tetraparesis, mainly involving the left side. The patient, an oncologist living in Messina (Sicily, Italy), was married and has 2 children (a 27-year-old male and 23-year-old female). His parents were both dead: the father for natural causes and mother from breast cancer, while he and her older sisters were healthy. The psychomotor development of the patient was normal and he practiced sport regularly; at a young age, he was a soccer player, and he liked cycling. The patient also liked reading, swimming and travelling, and he had a very intense social life. He was a moderate coffee drinker; he did not drink alcohol and was a non-smoker.

In November 2016, following a severe car accident resulting in SCI, he was admitted to a neurosurgical ward for a total decompressive laminectomy at C3-4 level. He attended the rehabilitation center for about 4 months, with moderate motor improvements. At discharge, an assessment of cognitive status was not performed. The patient was then admitted to the (blinded), to undergo a specific neurorehabilitation cycle (i.e. around 6 months after the SCI).

At our observation, the neurological examination showed a moderate left-hemiparesis and imbalance with upper limb

incoordination (that was present only in the eye-closed condition) and reduced sensitivity (hypoesthesia). At a neuropsychological evaluation, he presented several alterations in the cognitive and behavioral status, with temporal, spatial and autobiographic disorientation, reduction of attention and memory processes, deficit of the executive function and severe anxious-depressive symptoms. No other medical comorbidities were detected, and hematological tests, as well as cardiac evaluation, and cerebral magnetic resonance, were normal.

Patient gave informed consent for the diagnostic procedures, treatment, and publication of the case.

2.1. Procedures

As the patient was in a post-traumatic chronic phase, to manage his cognitive, motor and emotional status, we decided to treat him by using a specific rehabilitation protocol, including 2 different types of training. The patient was adequately informed about the study and offered his collaboration and written consent. In the 1st phase, the patient was submitted to a conventional treatment, including psychological counselling, standard cognitive training (SCT) and physiotherapy (PT). After the 1st phase, 4 weeks of latency have elapsed before the next phase, in which the patient was only treated with physiotherapy (to avoid a cumulative effect). Then, the patient was submitted to the experimental protocol (second phase; i.e. a combined therapeutic approach, cognitive and sensory-motor training was provided by means of the virtual reality rehabilitation system (VRRS, by Khymeia, Italy), besides the standard Bobath physical therapy).

However, the patient was provided with the same amount of treatment both in phase 1 and 2; in particular, in the 1st phase the patient underwent 72 sessions of PT and 72 of SCT, whereas in the 2nd phase the patient was submitted to 36 PT sessions and 36 SCT sessions, besides 72 VRRS sessions (both cognitive and motor). The entire rehabilitation treatment lasted about 6 months: the patient was hospitalized for 3 months, then, he stayed at home for 1 month, and came back as inpatient for other 3 months (for more details see Table 1).

2.2. Functional assessment

The patient was evaluated by a skilled neuropsychologist through the administration of specific neuropsychological battery, including Montreal cognitive assessment (MoCA) to evaluate general cognitive status, attentive matrices test (CAM); trail making test (TMT), digit span and the Rey auditory verbal learning immediate and recall (RAVLI, RAVLR), Weigl's sorting test, Raven's coloured matrices; verbal fluency test (VFT) and semantic fluency test (SFT) to assess spontaneous speech, comprehension and communication skills, Hamilton rating scale for depression (HRS-D) and Hamilton rating scale for anxiety (HRS-A).

A physiotherapist administered the functional independence measure (FIM) (after discussion with the rehabilitation team), and the Berg balance scale (BBS) to assess functional recovery and balance (Table 2). Both the neuropsychologist and physiotherapist were blinded to the patient's treatment. We evaluated the patient's cognitive and motor profile in 2 separate phases, before and after the 2 different trainings (T0: baseline; T1: at the end of the traditional neurorehabilitation training; T2: at the beginning of the combined experimental approach; and T3: after the combined approach). Reliable change index (RCI) was used to

Table 1**Standard and experimental training performed by the patient.**

Rehabilitation program	Rehabilitative approach	Session duration	Types of treatment
Phase 1 3 months Nov-Jan (2016–2017) conventional neurorehabilitation	Psychological counseling	2 weekly sessions of 60 minutes (24 total treatments)	60 minutes of psychological counseling
	Standard cognitive training	6 weekly sessions of 60 minutes (72 total treatments)	15 minutes of reality orientation therapy 15 minutes of attention process training 15 memory training 15 problem solving
	Traditional physiotherapy	6 weekly sessions of 60 minutes (72 total treatments)	10 minutes: stretching and mobilization in supine position 10 minutes: assisted exercises, exercises against resistance, and free exercises 15 minutes: exercises for trunk control, and balance in sitting position 10 minutes: balance exercises with weight shift 15 minutes: cycling/gait training
PHASE 2 3 months Apr-June (2017) combined rehabilitative approach	Psychological counseling	2 weekly sessions of 60 minutes (24 total treatments)	60 minutes of psychological counseling
	Standard cognitive training	3 weekly sessions of 60 minutes (36 total treatments)	15 minutes reality orientation therapy 15 minutes attention process training 15 memory training 15 problem solving
	Traditional physiotherapy	3 weekly sessions of 60 minutes (36 total treatments)	10 minutes: stretching and mobilization in supine position 10 minutes: assisted exercises, exercises against resistance, and free exercises 15 minutes: exercises for trunk control, and balance in sitting position 10 minutes: balance exercises with weight shift 15 minutes: cycling/gait training
	Virtual reality rehabilitation system (VRRS)—cognitive Module	3 weekly sessions of 60 minutes (36 total treatments)	15 minutes reality orientation therapy 15 minutes attention process training 15 memory training 15 Problem Solving
	Virtual reality rehabilitation system (VRRS)— sensory-motor module	3 weekly sessions of 60 minutes (36 total treatments)	30 minutes: trunk control training, static and dynamic balance. 30 minutes: symmetrical load and weight shifting

evaluate whether a change in an individual's score (i.e., between T0 and T1, and T2 and T3) was significant or not (based on how reliable the measure is). The RCI allows to define if the change observed in a patient is clinically and practically significant, based on the amount of change that a patient has to show on a specific psychometric instrument between the measurement occasions in such a way that a difference is more significant than reasonably expected for any measurement errors. The RCI is a statistic used to determine if a change occurring in the score of an individual (or group) is statistically significant based on the test-retest reliability of the measurement.^[20] This provides information about the likelihood that a change in test scores "results from" true or reliable change or results from the case. To calculate RCI as suggested by Bauer et al^[21] we used a specific formula. In this study, we added other scores. We administered same criteria to a half-treatment evaluation, to monitor the changes, and in the end the post-treatment scores. We used the standard deviation (SD) from the functional normative sample, and coefficient alpha from the normative sample for the scale to obtain the minimum change in a scale score calculation. The standard error of the difference will be dependent on the measure's standard error, which involves the standard deviation of the normative sample of the

instrument and the test reliability. The result represents a standard score. Values ≥ 1.96 or ≤ -1.96 are representative of a true change at a 95% confidence level (P -value = .05), unlikely to be explained by measurement error. Given that it has been demonstrated that RCI could be useful in assessing changes in the neuropsychological field,^[22] we used this index also for motor functional outcomes.

2.3. Conventional rehabilitation training

The conventional treatment consisted of psychological counseling, standard cognitive training (SCT) and physiotherapy (PT). Counselling was focused to reduce anxiety and depression symptoms, using a narrative and introspective training to help both the patient and his family. The SCT was based on a face-to-face approach between the therapist and the patient using paper and pencil tools. It was mainly focused on strengthening orientation with a specific cognitive program based on the reality orientation therapy (ROT); autobiographic memory, temporal and spatial orientation, and simple relationships and logic associations were also trained. To improve attention, we used the attention process training (ATP) that includes task

Table 2
shows the patient's neuropsychological and motor assessment.

Test/scale	Domain	Description
Montreal cognitive assessment (MoCA)	Cognition	The Montreal cognitive assessment is a brief cognitive screening assessing: short-term memory, visuo-spatial abilities, executive functions, attention, concentration and working memory, language and orientation to time and place
Hamilton anxiety rating scale (HARS-A)	Anxiety	The Hamilton anxiety rating scale is a rating scale developed to measure the severity of anxiety symptoms; the scale consists of 14 items, each defined by a series of symptoms, and measures both psychic and somatic anxiety
Hamilton depression rating scale (HRS-D)	Depression	The Hamilton depression rating scale is a multiple item questionnaire used to provide an indication of depression; it is designed for adults and is used to rate the severity of their depression by feelings of guilt, suicidal ideation, insomnia, apprehension or retardation, anxiety, weight loss and somatic symptoms
Attentive matrix test	Attention	It is used to evaluate the selective visual attention. There are 3 matrices that are shown to the subject. Each of them consists of 13 lines of 10 numbers from 0 to 9 each, arranged in a random sequence. The subject must block all numbers equal to those printed at the top of the matrix. Matrices should be presented from the simplest to the most difficult
Trail making test	Attention and visuo-spatial function	TMT assesses spatial planning capability in a visuo-motor task. TMT is composed of two parts, A and B. The trail A evaluates the sustained attention, the trail B measures split and alternate attention, and the difference in time between the 2 tests (B-A) is a factor of cognitive flexibility and shifting ability
Digit span	Memory	This test evaluate the verbal memory span (digit memory). It consists of 2 different tests: 1. Forward digits (repeat digits forwards); 2. Back digits (repeating digits in reverse)
Rey auditory verbal learning immediate and recall (RAVLI, RAVLR)	Memory	This test measures the immediate memory span and provides an analysis of learning. The test consists of 5 presentations, with re-enactment, a list of 15 words
Verbal fluency test (VFT)	Fluency	It evaluates the amplitude of the lexical stock, the ability to access the lexicon and the lexical organization. It consists in 2 parts: Verbal fluency for phonemic categories and Verbal fluency for semantic categories
Raven's coloured matrices	Executive functions	The test measures the fluid Intelligence. They are used with adults of low intellect or old age
Weigl's sorting test	Executive functions	This test measures the ability of categorical thinking and it is composed by 12 wood stimuli classifiable for form, colour, suit thickness and dimensions. The test can be done in 2 ways (active and passive)
Berg balance scale (BBS)	Balance	The Berg balance scale (BBS), consisting in 14 item and built on 4-points Likert Scale. It is a widely used clinical test for the evaluation of the effectiveness of interventions and for the quantitative descriptions of the motor functions of the older adult
Functional independence measure (FIM)	Disability	The functional independence measure is an assessment tool that allows to measure the disability, it also inspects 18 activities of everyday life (13 motor sphincters, 5 cognitive). Each activity can receive a variable score of 1 (complete dependence on others) and 7 (full self-sufficiency)

targeting for the sustained, selective, split and alternating attention. The memory enhancement goal was achieved by working on recognition and remembrance tasks with verbal and nonverbal material, reminiscence and validation therapy, mnemonic techniques and strategic skills. The training of the executive function was reached by working on categorization, planning, association and analogical reasoning (Table 3). The PT was provided according to Bobath approach, aimed at improving balance, reducing spasticity and increasing left side muscle force.

2.4. Combined neurorehabilitation approach

The combined neurorehabilitation approach consisted of the virtual reality (VR) treatments, in addition to the conventional rehabilitation approach. This kind of approach was provided by the virtual reality rehabilitation system (VRRS), one of the most advanced comprehensive and clinically proven VR system for rehabilitation^[19,23] and telerehabilitation.^[24] Extremely easy to use, high customization capacity, complete automated reporting, functional telerehabilitation, are some of the guiding principles of continuous system development. The VRRS, in fact, is conceived as a "central HUB" to which you can connect via USB a series of specialized peripherals, fully synchronized and integrated with the system. The VRRS can be used in many neurological disorders, thanks to the different modules for cognitive, language, postural, and motor rehabilitation.

During the cognitive training, the patient was sitting in front of the device, actively interacting with the platform. The VRRS cognitive module consists in a large set of activities for

rehabilitation, with more than 50 exercises already available and many others under development. All activities are organized by cognitive function: memory, attention, language, spatial-temporal orientation, planning, reasoning and other executive function, calculation, and praxis. Cognitive exercises provided through the VRRS can be classified in 2 main categories. The 1st category includes 2D exercises where the patient interacts with objects and scenarios through the touch screen or through a particular magnetic tracking sensor coupled with a squeezable object, thus emulating mouse-like interaction capabilities. The 2nd category consists of 3D exercises, where the patients interacts with 3D on immersive virtual scenarios and objects through a magnetic tracking sensor generally placed over the hand (that permits a 3D position tracking of the end effector). Furthermore, cognitive tasks are generally coded as pick and place activities, ordering activities, selection activities, and sequential selection activities (Table 3).

The VRRS motor program includes specific tasks of the virtual sensory motor to stimulate muscle strengthening, strengthen leg tendons and ligaments, improve posture, pelvis movements, and balance reactions. All virtual exercises have been planned and organized by the therapist (after consultation with the neurologist), with increasing difficulty in relation to the time of execution and the category of activity. In fact, in the 1st training phase, the therapist used the stabilometric platform to increase the static balance. Supine mobilization and assisted and free exercises for trunk control and balance in a sitting position, along with exercises with weight shift and walking, were carried out. At a later stage, the therapist used a proprioceptive/dynamic platform,

Table 3**Cognitive rehabilitative program, including the standard and the experimental (VRRS) one.**

COGNITIVE domain	VRRS cognitive training	STANDARD cognitive training
Orientation	To select and sort in the right sequence the days of the week and the months of the year. To indicate the position of the objects on the screen (right, left, up, down). To recognize the rotation type of animals and objects (clockwise and anti-clockwise) and to position the items according to the type of rotation indicated. <i>The level of difficulty increases with the increase of the numbers of elements</i>	To stimulate temporal and spatial orientation through the recall of days, months, years, festivities, events or personal data, personal stories, places, itineraries and spatial locations. The informations are repeatedly transmitted in visual, verbal, written or auditory mode. <i>Cognitive therapist uses tasks with increasing difficulty, enhancing the specificity of the requests. The patient was gradually requested to give more temporal, spatial and autobiographical details</i>
Attention	To select, with an immediate and recall feedback (audio and video), some various elements (colors; musical strings; geometric or not form; animals . . .) observed in the virtual environment. These elements remain visible to the observer for a variable time, established by the interaction between the virtual system, therapist and patient. The patient touches the virtual target element, in a specific time; this action causes a visual change with a specific audio feedback (positive reinforce); otherwise the element disappear (negative reinforce) <i>The level of difficulty increases with the increase of the numbers of distracters and reducing the usable time of execution.</i>	To indicate and touch the specific target-stimuli in relation to specific characteristics (color; image; animal, function . . .), neglecting the distracters, which consist in other picture, different for number and complexity of criteria. The therapist gives the verbal commands to the patient, which combines the different selected images. <i>Cognitive therapist uses tasks with increase difficulty, according to specific parameters, such as number and type of the target, number and type of distracters; complexity of the consign.</i>
Memory	To observe at 1st particular elements, and then (in the immediate and recall time) to remember these (egg; season; colors, boll; numbers; environments, animals; geometric form or not; fruit; job . . .) with a dynamic interaction in semi-immersive virtual environment (<i>sprites task</i>). The patient remembers the place (the position; visuo-spatial memory) and the name (verbal information) of the element/s observed. <i>The level of difficulty increases with the increase of the number of elements to remember and with the reduction of the time to execution.</i>	Memory training tasks are conducted on paper and pencil approach in a face to face rehabilitative setting with an interaction only between therapist and patient. The forms of these tasks include recalling a series of locations of items on a specific rehabilitative table (in a cognitive room), recalling digits or letters in either the order presented or reverse order, or recalling specifically where a particular number or name, digit was in a sequence. <i>The memory training is articulated in 3 levels of complexity (easy; medium and high difficulty) in relation to time and number of verbal and not stimuli to remember.</i>
Executive and visuospatial functions	To program some movements finalized to virtual touch, to move or manipulate specific objects, in different directions (i.e. balls; flowers; butterfly.); or to realize specific associations (i.e. number- color) with a dynamic interaction in virtual environment. When the patient touches virtual objects, he/she obtains a video and audio feedback (<i>using sprites task</i>). In particular, the subject realizes ideo-motor sequences (from simple to complex series of actions), after the verbal consign by therapist. <i>The level of difficulty increases (from first to third level) with the increase of the complexity of virtual ideo-motor serious to realize.</i>	To program some movements finalized to direct touch and to move the specific objects (i.e. pencil; pen) in different directions (i.e. left; right; according to therapist's indication) in a specific space (i.e. rehabilitative table); or to realize specific associations (i.e. letter- color), using a pen and pencil approach, organized in a face to face rehabilitative session. <i>Each training is articulated in three different levels of difficulty in relation to the complexity of the ideo-motor sequences and executive increased tasks to administer.</i>

characterized by greater instability and greater executive difficulty, with training of the trunk control, in static and dynamic equilibrium and weight displacement (Figure 1).

At the end of the traditional treatment (T1) using standard techniques, the patient presented a mild improvement only in orientation and mood, with a reduction of negative thoughts, besides a better postural control. Only at the end of combined approach using VRRS, we observed a significant improvement in different cognitive domains such as executive process, selective attention, memory abilities, and spatial cognition; moreover, we have seen a substantial reduction in anxiety's level and depressive symptoms (Table 4), with the optimization of global motor performance and balance improvement, in both static and dynamic control, as per Berg balance scale (BBS) score (Table 5).

3. Discussion

Spinal cord injury is a condition that causes total or partial tetra or paraplegia and alteration of the muscle tone^[2] with possible sensory deficit, genito-urinary, neurovegetative, and respiratory symptoms. Generally speaking, no cognitive impairment is found^[2] although, as described by Hartmann et al,^[2,5] our case shows that the evaluation and treatment of neuropsychological

and motor deficits may eventually contribute to a better functional outcome. We are not completely able to state if cognitive deficit pre-existed the accident or total anaesthesia; however, the impairment appeared after this event, and it was neglected during the 1st rehabilitative intervention. The accurate neuropsychological evaluation we carried out led us to the detection of the cognitive decline for which allowed us proper management of the disorder. Therefore, the rehabilitative team should consider applied neuropsychology as an integral part of the rehabilitation process, even when no cognitive deficits are referred^[2,6] in patients including those with spinal cord injury (SCI).

In this report, we want to underline the important role of innovative devices using virtual reality (VR) in improving both motor and cognitive performances.

In the last decades, in the field of rehabilitation, we have witnessed the development of innovative tools that make use of VR. This consists of a set of computing technologies that can create interactive environments involving the user in simulating real world activities. Several clinical and experimental applications demonstrated the effectiveness of these technologies on people of all ages, affected by neurological and motor disorders and spasticity of different etiologies.^[11,14] In addition, VR may promote psychological wellbeing, participation and autonomy of



Figure 1. A: the patient is located on a dynamic platform shifting the weight thought right, left, forward, and back and following the indicated path so to reach different points in the football field. The score is calculated according to the symmetry between the required trajectory and the trajectory performed. B: (Virtual labyrinth) The patient, situated on a static footboard, is trained by moving a ball inside the labyrinth to reach a specific destination; scoring is calculated in relation to the time of execution and the number of errors.

a person with a disability, including SCI, avoiding monotone activities, to have a positive effect on the self-esteem, the motivation and mood.

Shin et al^[26] has shown that VR has a positive impact on cognitive functions, and literature confirms that the use of new technologies in cognitive rehabilitation is an important resource.

The VR is an efficient approach to neurological rehabilitation that creates more stimulating environments, is more effective in improving problem solving skills and performing functional tasks.^[27] In fact, VR allows the calibrating of the difficulty of proposed activities based on the actual capabilities and the potential of the patient which therapist is dealing with. In

Table 4

Cognitive outcome evaluated at baseline (T0), after the standard training (T1), at the beginning of the combined experimental approach (T2), and after such approach (T3).

Psychological evaluation	T0	T1	T2	T3 (RCI)	Cut-off
Montreal cognitive assessment	19	21	23	26 (3.1)	≥26
Attentive Matrices Test	29	32	33	45 (2.5)	≥30
Trail Making Test A	91	88	88	50 (3.1)	< 93
Trial Making Test B	221	185	186	105 (3.1)	< 282
Trial Making Test B-A	130	97	98	55	< 187
Digit Span	3.50	4.50	4.50	6.50	≥ 3.75
Rey Auditory Verbal Learning Test – Immediate recall	28	31	31	38	≥ 28.53
Rey Auditory Verbal Learning Test – Delayed recall	3	5	5	6	≥ 4.69
Weigl's Sorting Test	9	9	10	15 (2.1)	≥ 4.50
Raven's Colored Progressive Matrices	20	21	21	26	≥ 24
Phonemic Verbal Fluency (PVF) Test	15	17	19	30 (2.5)	≥ 17
Semantic Verbal Fluency	18	21	23	31	≥ 25
Hamilton Depression Rating Scale	26	18	17	8 (3.1)	< 7 (no depression)
Hamilton Anxiety Rating Scale	20	17	15	7 (3.1)	< 17 (no anxiety)

Score is provided as raw data, and the RCI was calculated to evaluate whether a change over time of an individual score (i.e., the difference score between two measurements in time) is considered significant (RCI > 1.9). The cut-off column shows the minimum number of score that someone must have on a neuropsychological test in order to be considered normal.

Table 5

Motor outcome evaluated at baseline (T0), after the standard training (T1), at the beginning of the combined experimental approach (T2), and after such approach (T3).

Physiotherapy evaluation	T0	T1	T2	T3 (RCI)	Potential range of normality
Functional independence Measure (FIM) total score	48	73	78	119 (2.8)	18–126
FIM (Cognitive subtotal score)	28	30	30	35 (2.0)	5–35
FIM (Motor subtotal score)	20	43	48	84 (3.1)	13–91
Berg balance scale	13	28	38 (1.9)	51 (2.7)	0–56

Score is provided as raw data, and the RCI was calculated to evaluate whether a change over time of an individual score (i.e., the difference score between two measurements in time) is considered significant (RCI > 1.9).

addition, it is possible to constantly measure and monitor performance by providing a wide range of responses. It has been demonstrated that VR technology, providing a higher feedback on the characteristics of motion, can improve motor learning and performance in both healthy and post-stroke subjects compared to traditional training.^[27]

The VR can also be a “afe” tool to simulate everyday life activities that are not always accessible to a person with disability (i.e. simulating alpine skiing or playing musical instruments). One last advantage is the possibility that some VR systems pursue home-based rehabilitation^[15] by prolonging the time spent to perform the exercises in terms of cost and effectiveness of the intervention itself. Among the several existing tools, virtual reality rehabilitation system (VRRS) allows the creation of different simulated scenarios so that the therapist can prepare a patient tailored rehabilitation. Indeed, VRRS is designed to put the patient in a situation that generates increased feedback to his central nervous system (augmented feedback) through exercises performed in a virtual environment helping to develop the knowledge of the results of movements (knowledge of the results) and the knowledge of the quality of movements (knowledge of performance), leading to a training-specific motor learning. In this way, the central nervous system can activate a physiological learning mechanism called “reinforcement learning” which implies an increase in the specific information of a movement to produce an effective improvement in performance quality. Indeed, the patient treated with the VRRS device was submitted to an intensive stimulation as visual and auditory feedbacks given by both the therapist and the device may have boosted neuroplasticity and thus functional recovery.^[19,28–29] This can partly explain the reason why our patient had clearly better outcomes after the experimental training with VR, as demonstrated both by the scales administered to the patient and by the patient himself, who rated his improvement in quality of life as 7 in a 0 to 10 Likert scale. Our case-report suggests that VRRS may be a valuable tool in promoting better functional outcomes, also in patients with SCI, when coupled to traditional rehabilitation. However, our conclusions need confirmation as our findings comes from a single case report, which represents the main limitation of this study. Further studies are needed to confirm what extent cognitive deficits in SCI individuals are underestimated.

4. Conclusions

With this case-report we want underline the possibility that our combined standard cognitive training-virtual reality rehabilitation system (SCT-VRRS) approach could be effective in improving motor and cognitive recovery in patients with spinal cord injury (SCI). However, a complete neuropsychological evaluation should be performed in all the patients attending a

neurorehabilitation ward, in order to treat properly possible and underestimated cognitive deficits with better functional outcomes.

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