Table 9. Virtual Reality (VR) and/or Biofeedback for Standing Balance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Virtual Reality/Biofeedback		
An & Park (2022); Republic of Korea RCT PEDro=7 Level 1 N=40	**Population:** 40 participants with tetraplegia and incomplete SCI; 23 males and 17 females; mean age 42.6 years; level of injury C5-7 (n=40); AIS C (n=17) and AIS D (n=23); and time since injury > 1 year. **Treatment:** Participants were randomly divided into two groups and received 12 sessions of a 30 min therapy three days/week for four weeks in their homes: • Participants in the experimental group (n=20) underwent rehabilitation while sitting in a wheelchair, performing a virtual soccer game. • Participants in the control group (n=20) underwent a similar rehabilitation intervention but without the VR content. **Outcome Measures:** Stability and balance control during a pattern of FTSTS movements (by the chair stand test); the risk of falls (by the TUG test); and walking speed (by 10MWT) were assessed before and after the intervention protocol.	1. Within-group improvements were significant in both groups (p<0.02). a. Chair stand test times had an effect size (Cohen's d=0.71), classified as large. b. 10MWT had an effect size (Cohen's d=0.61), classified as medium. c. TUG test time had an effect size (Cohen's d= 0.42), classified as medium. 2. There were significant differences between groups at the end of the intervention, favouring the experimental group for chair stand test time (p=0.03), for 10MWT (p=0.03), and for TUG test (p=0.04).
Sengupta et al. (2020); India Prospective control trial Level 2 N=33	**Population:** 33 patients with SCI, neurological level of injury C5 or below and ability to abduct both shoulder at >90°; 27 males and 6 females; mean age 29.25 years; level of injury cervical (n=11), upper dorsal (n=10) and lower dorsal (n=12); AIS A (n=10), AIS B (n=8), AIS C (n=8), and AIS D (n=7); and mean time since injury < 6 months. **Treatment:** Routine conventional therapy, consisting of individualized exercise program, was provided to all participants.	1. No major AEs were reported by participants in either group. 2. No statistically significant difference between groups in the scores of all the outcome measures at pre- and post-therapy (the main effect in both groups) was observed.

	Additionally, participants were divided into two groups: • VR training group (n=25): Participants performed VR training 5 days a week for 3 consecutive weeks with sessions lasting 30 min. All the games selected focused on static and dynamic balance and were played either while sitting or standing depending on the functional ability of the participant. The level of difficulty was gradually upgraded based on their performance. • Control group (n=12 matched controls). **Outcome Measures:** BBS, balance section of the Tinetti Performance-Oriented Mobility Assessment (POMA-B), and Functional Reach Score (seated) were assessed pre and post intervention.	
D'Addio et al. (2014); Italy Prospective controlled trial Level 2 N=30	**Population:** 30 participants with SCI; mean (SD) age: 43 (18.7) years; and AIS C-D. **Treatment:** All participants joined in a 12-week training protocol (3 sessions per week) and were assigned randomly to one of the following two groups: • Control group (n=15), receiving standard rehabilitation protocol (SRP) for balance training alone. The SRP refers to a combination of active/passive lower and upper limb stretching, exercises to increase strength and improve posture. Sessions lasted 60 minutes. • Study group (n=15), received in addition to the SRP session, a Nintendo Wii Fit balance training (four games), along with its balance board. **Outcome Measures:** BBS and posturography testing (which consists of two randomized tests, each of 60 seconds: standing on a firm surface with eyes open and eyes closed; in this way has been possible to estimate the Romberg Index) were assessed at the first visit and at discharge.	1. Both groups showed significant ($p<0.04$) improvements in BBS and posturography balance measures between pre- and post-intervention. 2. Additionally, all participants related to the study group showed a greater ($p<0.02$) improvement at discharge than those in the control group as shown by the higher scores obtained in clinical scales and in different kinematic indices.

Villiger et al. (2015); Switzerland Prospective controlled trial Level 2 N=23	**Population**: 9 participants with SCI - 5 males and 4 females; incomplete SCI; all AIS D; Lesion level between C4 to T12; mean age= 55.1 ± 15.8y; years post injury= 1-5y; 14 healthy persons were in the control group - 8 males and 7 females; mean age= 47.1 ± 14.4y. **Treatment**: Patients underwent 4 weeks of intensive VR-augmented lower limb training. The patients with iSCI were trained with the VR movement tasks 16–20 times during the 4 weeks (4–5 × 45 min. per week). The training used a VR-augmented therapy system for lower limbs combining action observation, imagination and execution. Before and after the training period a structural volumetric 3D MRI data set was acquired in patients. Retention of the performance improvements was assessed in a 3–4 months follow-up session. **Outcome Measures:** 10MWT, BBS, LEMS, and SCIM mobility.	1. The intense VR-augmented training of limb control improved significantly balance, walking speed, ambulation, and muscle strength in patients. 2. Retention of clinical improvements was confirmed by the 3–4 months follow-up.
Shin et al. (2021); Korea Pre-post Level 4 N=13	**Population:** 13 participants with SCI; 8 males and 5 females; median (range) age 52 (19-85) years; tetraplegia (n=11) and paraplegia (n=2); AIS C (n=1) and AIS D (n=12); and median (range) time since injury 48 (19-139) days. Participants were subgrouped according to the initial proprioception status: • Normal group (n=6): Participants with grade 2 of proprioception of the ankle and knee. • Abnormal group (n=7): Participants with grade 0 or 1 of proprioception of the ankle and knee. **Treatment:** Participants received RAGT with Morning Walk® with visual feedback (through a VR screen), so the participants could have the experience of walking through a park or the forest according to the gait speed. RAGT were performed for 30 min in the ground-level (starting with a cadence of 30 steps/min, a step length of 30 cm, and 20% BWS; and an estimated progression for each participant). In addition, one hour of	1. After the intervention, the patient with paraplegia AIS C improved to AIS D. 2. After the intervention, BBS, 10MWT, 6MWT, LEMS, and WISCI II significantly improved ($p<0.003$). 3. Based on the subgroup analysis of the initial proprioception status: a. The normal group showed a significant improvement on the BBS, 10MWT, 6MWT and WISCI II ($p\leq0.028$); however, LEMS did not show a significant improvement ($p=0.068$). b. In the abnormal group, BBS, 10MWT, 6MWT, LEMS, and WISCI II were significantly improved ($p\leq0.028$). c. In the between-group comparisons, only the WISCI II showed a statistically significant

	conventional physiotherapy (consisting in sitting and standing balance training, sit-to-stand training, and strengthening exercises) were performed 5 times per week for 4 weeks. **Outcomes measures:** 10MWT, 6MWT, LEMS, proprioception (proprioception of the ISNCSCI at the ankle and knee), BBS, and WISCI II were assessed within 48 h before and after the intervention.	difference (p=0.037); with an improvement favouring the normal group.
Van Dijsseldonk et al. (2018); Netherlands Pre-post Level N=15	**Population:** 15 participants with incomplete and chronic SCI who could walk independently for 2 min without assistance; 11 males and 4 females; mean (± SD) age 59 (± 12) years; AIS level C (n=2) and D (n=13); and mean (± SD) time since injury 42 (± 48) months. **Treatment:** Individualized VR gait training on the GRAIL for 12 1-h training sessions spread over a 6-week period. The GRAIL consisted of an instrumented dual belt treadmill with two embedded force plates and an eight-camera motion capture system. The platform was able to move in several directions to generate mechanical perturbations. In front of the treadmill, VR environments were projected on a 180° semi-cylindrical screen. Reflective markers were adhered to the patients to interact with the virtual environment and to capture kinematic data. The GRAIL system was controlled, and the visual information was matched to the treadmill speed. During the GRAIL training multiple applications (categorized in three themes; "gait adaptability", "walking+", and "balance in stance") were performed in an individualized pattern. **Outcome Measures:** 2MWT on the GRAIL; spatiotemporal parameters (walking speed, stride length, step width, and stride frequency); gait stability measures (dynamic stability margin, extrapolated center of mass relative to the center of pressure in anterior-posterior and medial-lateral, center of mass relative to the center of pressure in anterior-posterior and medial-lateral); and balance confidence	1. Patients' balance confidence significantly increased after GRAIL training (76 ± 18), compared to baseline (69 ± 18) (p=0.001); however, there was no significant difference between post and follow-up measurement.

	(ABC scale) were assessed at baseline (at the 2nd and the 3rd sessions), at the last training session (post measurement), and at 6 months after the last training session (follow-up measurement).	
An & Park (2018); Republic of Korea Pre-post Level 4 N=10	**Population:** 10 participants with chronic SCI; 6 males and 4 females; mean (± SD) age 44.20 (± 8.66) years; level of injury C2 (n=1), C4 (n=3), C6 (n=2), C7 (n=2), and T1 (n=1); AIS level C (n=4) and D (n=6); and mean (± SD) time since injury 19.20 (± 3.93) months. **Treatment:** Participants underwent semi-immersive VR therapy (using an Interactive Rehabilitation Exercise [IREX] 30 min per day, 3 times a week for 6 weeks. Six programs were included: "soccer", "conveyor", "volleyball", "formula racer", "airborne", and "snowboard". Each program was performed for 4 min with a 1-min break between programs. **Outcome Measures:** Standing balance function (limit of stability and BBS) and upright mobility function (TUG, ABC scale and WISCI II) were assessed before and after the intervention.	1. There were no AEs during the semi-immersive VR therapy. 2. The WISCI II score after intervention showed significant improvement from 16.30 to 17.90 ($p<0.05$). 3. On the computerized standing balance test, overall limit of stability score was significantly increased from pre- to post-intervention (32.00 to 46.40, respectively; $P<0.01$); however, forward and backward directional limit of stability scores did not differ significantly after therapy. 4. The BBS score was significantly increased post-intervention (35.70 to 40.10, respectively; $p<0.01$). 5. The TUG time was significantly decreased (19.35 to 17.14, respectively; $p<0.05$), while the ABC scale score was significantly increased (67.90 to 76.85, respectively; $p<0.05$).
Villiger et al. (2017); Switzerland Pre-post Level 4 N=11	**Population:** 11 participants with motor-incomplete SCI and able to sit in a chair without assistive and supporting systems; mean (± SD) age 60 (± 10.2) years; level of injury C4 (n=1), C5 (n=3), C7 (n=2), T4 (n=1), T9 (n=1), T12 (n=2), and L3 (n=1); AIS C (n=1) and AIS D (n=10); and mean time since injury 7.6 years. **Treatment:** All participants were trained at home on the VR tasks over a period of 4 weeks, with 16–20 sessions of 30–45 min each, and with the mobile prototype of the YouKicker system. Around 500 repetitions of ankle movements and 100 knee movements with each leg were performed through different blocks by a typical patient during a training session.	1. None of the participants had any pain while playing the games or after the sessions. 2. At post-assessment, significant increases in comparison with the averaged pre-baseline and baseline were found in balance (BBS, $p=0.008$) and functional mobility (TUG, $p=0.005$). However, there were no significant effects on SCIM-III mobility ($p=0.018$). 3. At follow-up assessment, a significant increase in comparison with the averaged pre-baseline and

	Outcome Measures: LEMS, BBS, TUG, 10MWT, 6MWT, SCIM-III, and WISCI II were tested 4 weeks before treatment (pre-baseline), directly before treatment (baseline), after finishing the training program (post-assessment), and 2-3 months after the treatment program (follow-up).	baseline was found in functional mobility (TUG, p=0.005), but no significant changes were found in balance (BBS, p=0.28) and SCIM-III mobility (p=0.026]).
Villiger et al. (2013); Switzerland Pre-post Level 4 N=14	**Population:** 14 participants - 9 males and 5 females; chronic SCI; 2 AIS C and 12 AIS D; level of injury: C4-T12. mean age= 53y; median years post-injury= 4y. **Treatment:** Participants received 4-5 45-min sessions of intensive VR augmented training sessions per week for a total of 16-20 sessions. **Outcome Measures:** BBS, 10MWT and WISCI II.	1. Significant improvements in 10MWT, BBS and WISCI II were shown after intervention.
Wall et al. (2015); USA Pre-post Level 4 N=5	**Population:** 5 participants with incomplete (AIS D) SCI; WISCI II score>6; able to tolerate static standing for at least five minutes at a time with no greater than minimal assistance; 5 males; mean age: 58.6 years; injury level: C4 (n=1), C5 (n=1), C6 (n=2), L1 (n=1); and mean time since injury: 7.6 years. **Treatment:** The sessions consisted of multiple games from an off the shelf VR training system (Nintendo Wii Fit) to promote weight shifting, stability, balance, and coordination. Games were randomly varied throughout each session. Each session was one hour, two times per week for seven weeks. **Outcome Measures:** TUG test, the forward functional reach test, and the lateral functional reach test were assessed one time per week for three weeks (pre-testing), within one week after the end of the training period, and at four weeks after the last intervention session.	1. There was a significant increase from pre-intervention to post-intervention on gait speed (p= 0.001, d=0.35), forward functional reach test (p<0.001, d=1.12), and lateral functional reach test (p< 0.001, d=0.88). However, there was no change for the TUG (p=0.25, d=−0.04). 2. Survey reports suggested improvements in balance, endurance, and mobility with daily tasks at home.
Other Biofeedback Approaches		
Amatachaya et al. (2023);	**Population:** 44 ambulatory individuals with chronic SCI and with the ability of independent walking with or without a	1. Mobility outcomes: a. After the training programs, participants

Thailand RCT PEDro=6 Level 1 N=44	walking device over a distance of at least 15m: • Control group (n=22): Mean (SD) age: 53.3 (12.1) years; 15M, 7F; AIS: AIS C (n=8) and AIS D (n=14); level of injury: Tetraplegia (n=5) and paraplegia (n=17); and mean (SD) time since injury: 57.6 (34.7) months • Experimental group (n=22): Mean (SD) age: 51.2 (14.9) years; 18M, 4F; AIS: AIS C (n=10) and AIS D (n=12); Level of injury: Tetraplegia (n=8) and paraplegia (n=14); and mean (SD) time since injury: 51.7 (31.4) months **Treatment:** Participants were assigned to the control intervention group (i.e., body-weight shifting and lower limb loading training without augmented loading feedback) or the experimental intervention group (i.e., body-weight shifting and lower limb loading training with augmented loading feedback) for 30min/day, 5days/week, over 4weeks. • Control intervention program (n=22): The participants in this group engaged in stepping training while in a step-standing position, for each leg continuously, as long as they could without fatigue, for 10min/leg. They were then trained to walk on a smooth, flat, and firm surface for 10min. • Experimental intervention group (n=22): The participants were trained using the same protocols as those used in the control intervention group; however, in this group, external augmented loading feedback was also obtained using a visual weight-taking machine. **Outcome Measures:** Incidence of falls was measured 6 months before the start of the intervention and 6 months after finishing the intervention. Mobility outcomes (TUG test, 10MWT, FTSST, and 6MWT) were assessed at baseline, at week two and week four, and after 6 months follow-up.	demonstrated significant improvement in all mobility outcomes at week two and week four (within-group analysis) ($p<0.05$). The mobility outcomes of participants in the experimental intervention group also showed significant improvement at six-month follow-up. b. When adjusted for the baseline data, the mobility improvement of participants in the experimental intervention group at week two and week four was significantly greater than that of the participants in the control intervention group ($p<0.05$). However, this difference was not found at six months after the training programs. 2. Fall data: During the six months after the training, there were nine participants who fell in the control intervention group and four participants who fell in the experimental intervention group. The number of faller participants was significantly different between the groups ($p=0.044$).

Nithiatthawanon et al. (2020); Thailand RCT cross-over PEDro=6 Level 1 N=30	**Population:** 30 community-dwelling participants with SCI who had the ability to walk independently, with or without a walking device, over at least 17 m (FIM Locomotor Score of 5–7); 22 males and 8 females; mean age (± SD) 53.2 (± 11.8) years; level of injury paraplegia (n=20) and tetraplegia (n=10); AIS C (n=12) and AIS D (n=18); and mean (± SD) time since injury 71.9 (± 74.5) months. **Treatment:** All participants involved in a single control and a single experimental session with a 2-week washout period between them: • Control intervention session, consisting of: o Bodyweight shifting and lower limb loading training during stepping (forward and backward) without external feedback for 10 min for each leg. o Overground walking training with an emphasis on lower limb loading, with or without a walking device, according to their ability for 10 min. • Experimental intervention session: The participants were trained using the same protocols as those of the control intervention program but with visual feedback relating to the amount of lower limb loading of the stance leg from a visual weight-taking machine to alert the participants and the therapist of the adequate amount of lower limb loading on the stance limb (at least 80% of the participant's bodyweight). **Outcome Measures:** TUG, 10MWT, FTSTS and maximal lower limb loading ability were assessed prior and immediately following each training session (four times).	1. Both training programs significantly improved all the outcome measures, excepting the TUG and lower limb loading of the less-affected leg, where improvement was found only after the experimental intervention. 2. The improvement after the experimental intervention program was significantly greater than that following the control intervention program for all the outcome measures ($p<0.05$): a. The mean (95% CI) between-group differences for the TUG = 1.9 [0.6–3.3] s.
Cheung et al. (2019);	**Population:** 16 participants with incomplete SCI and able to perform BWSTT; 11 males and 5 females; mean age	1. No AE or discomfort was reported by participants.

China RCT PEDro=8 Level 1 N=16	54.3 ± 9.6 years; level of injury C1-L2; AIS C (n=11) and AIS D (n=5); and mean time since injury 13.7 ± 7.4 months. **Treatment:** All participants received, twice a week, one hour of standard physiotherapy program, including limbs mobilization and strengthening, trunk stabilization, wheelchair maneuver training and overground walking training. Additionally, 3 times per week, for 8 weeks, participants were randomly allocated to: • 30 min of BWSTT with Lokomat system, at comfortable walking speed, with assist-as-needed guidance force, and 40% of BWS. Additionally, EMG-biofeedback system was applied to the bilateral vastus lateralis and audio feedback was generated if the muscle activation was less than 30% of maximal recruitment to encourage active participation during the stance phase of the gait cycle. • Control group: Participants received passive lower limb mobilization training by using lower limb active-passive exerciser. **Outcome Measures:** WISCI II, SCIM-III, LEMS, Lower limb-force (L-force) function in Lokomat system, and quality of gait pattern (by gait analysis system) (walking speed, heel-heel base support, bilateral stance duration and bilateral symmetry [ratio of stride length of two legs]) were collected within 1 week before the start of intervention and within 1 week after the completion of the 8 weeks program.	2. Significant ($p<0.025$) improvements in BWSTT group in the mobility sub-score of SCIM-III and bilateral symmetry were shown, but none of these outcome measures were found to be improved in control group. 3. No significant time x group interaction was found in other outcomes with no significant between group difference ($p>0.05$).
Pramodhyakul et al. (2016); Thailand RCT PEDro=5 Level 2 N=32	**Population**: 32 participants - 26 males and 10 females; incomplete SCI; 26 AIS D and 10 AIS C; mean age= 41.69 ± 10.90y; months post injury= 35.00 ± 24.40 months. **Treatment**: Participants were randomly assigned to the experimental or control groups using stage of injury, severity of SCI, and baseline walking ability as criteria for group arrangement (16 participants per group). The participants were trained to walk over level ground at their fastest safe	1. The participants demonstrated significant improvement in all functional tests after the 5 days of training. The improvement in the group trained using the visuotemporal cue was significantly better than that trained without using the cue.

	speed with or without a visuotemporal cue, 30 min/day, for 5 consecutive days. **Outcome Measures:** 10MWT, 6MWT, TUG test and FTSTS.	
Tamburella et al. (2013); Italy Prospective controlled trial Level 2 N=12	**Population:** 12 participants with SCI; 6 in the vBFB group and 6 in control group. vBFB group: mean (SD) age: 52 (11.74); 3M 3F. Control group: mean (SD) age: 53.5 (13.21); 3M 3F. **Treatment:** 2 groups: vBFB and Rehab group (control). vFBF and control groups underwent 8 wks of rehab 5 times/wk (control: 60 min devoted to Rehab; vBFB: 40 min of rehab plus 20 of vBFB). **Outcome Measures:** BBS; WISCI; 6MWT; 10MWT; TUG; balance performance and kinematic spatio-temporal gait parameters. *vBFB (visual biofeedback task-specific balance training).	1. Only the vBFB group experienced a significant improvement in balance: a. BBS: 26 (10.69) at baseline to 41 (7.8) at end of intervention. b. TUG: 21.70 (10.7) s at baseline to 15.22 (6.14) s at end of intervention 2. The improvement in balance for the vBFB group was maintained at follow-up examinations. 3. vBFB participants experienced greater improvements than control participants for TUG, BBS, and for all balance indices, except for the center of pressure mean velocity with eyes closed.
Houston et al. (2020; 2021) Canada Pre-post Level 4 N=5	**Population:** 5 participants with chronic incomplete SCI; 1 male and 4 females; age range 55-68 years; level of injury C1 (n=1), C3 (n=1), C5 (n=1), T6 (n=1) and T10 (n=1); AIS C (n=3) and AIS D (n=2); and mean time since injury 46.8 months. **Treatment:** Participants completed three 1h training sessions per week for 4 weeks consisting of FES applied bilaterally to the ankle plantarflexors and dorsiflexors while they performed visual feedback balance training (VFBT) exercises. A closed-loop FES system was used in which the CoP was continually monitored and the level of electrical current administered was automatically adjusted. **Outcome Measures:** Outcome measures were collected before beginning the intervention, after completion of training, and 4 and 8 weeks after the intervention: • Clinical assessment: BBS, Mini-BESTest and ABC scale.	1. Improvements were seen for four of the five participants on at least one of the clinical scales following completion of the training intervention. 2. All participants showed greater maximal CoP excursion area during the LOS test after the training intervention, whereas only one participant demonstrated a reduction in PS. 3. Regarding the semi-structured interviews, risk of falling was perceived as slightly reduced or unchanged, but participants felt that their balance confidence had increased. 4. No training-related AEs were reported.

	• Biomechanical assessment: Static balance test (in standing) (measuring postural sway through calculation of CoP velocity and the root-mean-square of the CoP displacement in both anterior-posterior and medio-lateral directions) and dynamic balance test (in standing) (evaluating the LOS). Semi-structured interviews were conducted after completion of the balance training intervention and 8-weeks post-training to understand participants' experiences.	
Sayenko et al. (2010); Canada, Japan Pre-post Level 4 N=6	**Population:** 6 participants- 5 males and 1 female; chronic SCI; 4 AIS C and 2 AIS D; level of injury: C4-T12; mean age= 41y; median years post-injury= 7y **Treatment:** Patients participated in 3 60-min visual feedback training sessions, for a total number of 12 sessions. During training, participants stood on a force platform and were asked to shift their CoP in the indicated directions as represented by a cursor on the monitor. **Outcome Measures:** Static standing eyes open and closed as measured by CoP displacement; Dynamic standing as measured by voluntary CoP displacement.	1. All participants showed substantial improvements in the scores, which varied between 236±94 and 130±14% of the initial values for different exercises. 2. Improvements were all statistically significant for both eyes open and closed except mean velocity in the medial/lateral direction. 3. The balance performance during training-irrelevant tasks was significantly improved: for example, the area inside the stability zone after the training reached 221±86% of the pre-training values.