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The effects of backward walking training on balance and mobility in an individual with chronic incomplete spinal cord injury: A case report

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Abstract

Background/Purpose—Individuals with incomplete spinal cord injuries (ISCIs) commonly face persistent gait impairments. Backward walking training may be a useful rehabilitation approach, providing novel gait and balance challenges. However, little is known about the effects of this approach for individuals with ISCIs. The purpose of this case report was to describe the effects of backward walking training on strength, balance and upright mobility in an individual with chronic ISCI.

Methods—A 28-year-old female, 11-years post ISCI (C4, AIS D) completed 18-sessions of backward walking training on a treadmill with partial body-weight support and overground. Training emphasized stepping practice, speed, and kinematics. Outcome measures included: Lower Extremity Motor Score, Berg Balance Scale (BBS), Sensory Organization Test (SOT); 10-Meter Walk Test (10MWT), 3-meter backward walking test, Timed Up and Go (TUG), and Activities-Specific Balance Confidence (ABC) Scale.

Results—Strength did not change. Improved balance was evident based on BBS (20 to 37/56) and SOT scores (27 to 40/100). Upright mobility improved based on TUG times (57 to 32.7 s), increased 10MWT speed (0.23 to 0.31 m/s), and backward gait speed (0.07 to 0.12 m/s). Additionally, self-reported balance confidence (ABC Scale) increased from 36.9% to 49.6%.

Conclusions—The results suggest that backward walking may be a beneficial rehabilitation approach; examination of the clinical efficacy is warranted.

Keywords

backward walking; rehabilitation; spinal cord injury; locomotion; locomotor control

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Declaration of Interest

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INTRODUCTION

There are more than 12,000 new cases of spinal cord injury (SCI) each year and more than 270,000 individuals with SCIs live in the United States (National Spinal Cord Injury Statistical Center, 2013). Greater than half of these individuals sustain injuries classified as incomplete SCI (ISCI) (National Spinal Cord Injury Statistical, 2013) and recovery of walking is a primary goal and focus of rehabilitation (Ditunno, Patrick, Stineman, and Ditunno, 2008; Scivoletto et al, 2008). Contemporary gait rehabilitation approaches emphasize intense, task-specific training to activate the neuromuscular system and promote walking recovery (Behrman and Harkema, 2000; Harkema et al, 2012; Jones et al, 2014). Individuals with ISCI demonstrate gains in walking function such as increased speed, improved kinematics and decreased reliance on assistive devices (Field-Fote and Roach, 2011; Harkema et al, 2012; Jones et al, 2014). Many individuals, however, continue to face persistent gait impairments and may benefit from an alternative gait rehabilitation approach.

Backward walking training is an emerging rehabilitation approach used to promote the recovery of forward walking (Kim et al, 2013; Moriello et al, 2014; Weng et al, 2006; Yang et al, 2005). Backward walking training may afford some unique and potentially beneficial differences compared with forward walking approaches. For instance, compared with forward walking, muscle activation is greater during backward walking at similar speeds, (Grasso, Bianchi, and Lacquaniti, 1998; Winter, Pluck, and Yang, 1989) and the metabolic requirements and oxygen consumption of backward walking are greater than during forward walking (Chaloupka, Kang, Mastrangelo, and Donnelly, 1997; Flynn et al, 1994). Lower extremity kinematics are reversed during backward walking, yet remain similar to forward walking (Lee, Kim, Son, and Kim, 2013). Step lengths, however, are shorter during backward walking and gait speed is slightly slower which may be due to altered or absent visual feedback when walking backward (Grasso, Bianchi, and Lacquaniti, 1998; Lee, Kim, Son, and Kim, 2013). Overall, these differences in the requirements of backward walking may provide unique balance and movement challenges, especially when practiced repetitively as part of a rehabilitation program.

Another primary consideration for the use of backward walking as a training strategy is whether this form of training engages and activates the neural pathways that control forward walking. Indeed, studies examining various modes of locomotion in animal and human models indicate that the neural control of rhythmic, reciprocal stepping in both a forward and backward direction is fundamentally similar (Hsu, Orlovsky, and Zelenin, 2014; Lamb and Yang, 2000; van Deursen, Flynn, McCrory, and Morag, 1998). This is evident in humans from studies of limb coordination patterns (Lamb and Yang, 2000; Winter, Pluck, and Yang, 1989) as well as studies of synergistic muscle activation (Ivanenko, Cappellini, Poppele, and Lacquaniti, 2008; Lacquaniti, Ivanenko, and Zago, 2012). In addition, studies of lower vertebrates indicate that the spinal neural networks that control reciprocal limb motion for forward locomotion also may be engaged in the control of backward locomotion (Grillner et al, 2008; Hsu, Orlovsky, and Zelenin, 2014). Similar neural control mechanisms suggest that training that incorporates backward walking may activate appropriate neural networks and potentially be an effective strategy to promote the recovery of forward walking.

Furthermore, the differential biomechanical and metabolic requirements of backward walking may afford some advantages over forward training approaches.

Studies of the effects of rehabilitation that incorporate backward walking support these assumptions and have demonstrated beneficial effects in individuals with neurologic injuries such as stroke (Weng et al, 2006; Yang et al, 2005) and children with cerebral palsy (Kim et al, 2013). Evidence of the effects of backward walking in individuals with SCIs, however, is currently limited to a single case report. Moriello et al. (2014) compared the effects of backward walking to forward walking training in an individual with ISCI and demonstrated greater improvements in standing function and spatiotemporal gait characteristics following backward walking. However, this study was conducted on an individual only 8-months post injury with impairments consistent with central cord syndrome, a specific form of ISCI with deficits most evident in the upper extremities. Thus, preliminary evidence in individuals with neurologic injuries suggests that backward walking training may be an effective gait rehabilitation approach. However, evidence of the effects of this approach in individuals with SCIs is particularly limited (Moriello et al, 2014). The primary purpose of this case report, therefore, was to describe the effects of backward walking training on strength, balance, and upright mobility in an individual with a chronic ISCI.

Guidelines for the application of backward walking as a rehabilitation approach have not been established. However, contemporary walking rehabilitation paradigms are based on the neural control of walking and emphasize key principles to activate the neuromuscular system and promote neuroplasticity (Behrman and Harkema, 2007; Edgerton et al, 2006; Harkema et al, 2012). Thus, our secondary purpose was to examine the feasibility of applying walking rehabilitation principles to a backward walking training program.

CASE DESCRIPTION

Participant Background and Examination

The participant was a 28-year-old female who sustained a cervical ISCI at 17 years of age secondary to a diving accident. Initially, her injury was classified according to the American Spinal Injury Association (ASIA) International Standards for Neurological and Functional Classification of SCI as C4, ASIA Impairment Scale (AIS) 'C' (motor incomplete) (Kirshblum et al, 2011). At the time of the initial examination for this case report, her injury was classified as C4, AIS 'D'. An examination was conducted prior to the initiation of training and her injury was classified as C4, AIS 'D'. The examination also included an interview, tests of motor function, and the specific outcomes measures described in the sections below. The participant provided consent to participate in this clinical case report. The patient's primary physical therapist, who was an expert in neurologic physical therapy, conducted the pre- and post-assessments and delivered all treatment sessions.

The Modified Ashworth Scale (MAS) was used to quantify the participant's lower extremity muscle tone (Bohannon and Smith, 1987). Upon examination in the supine position, she demonstrated a score of 3 on the MAS in the bilateral quadriceps, gastrocnemii, and hip adductor muscles. She reported taking 10 mg of baclofen twice a day for management of hypertonicity. Over the 11 years since her injury, she participated in regular (2–3 times per

week) outpatient physical and occupational therapies that focused on improving overall strength, standing balance, and functional mobility.

At the time of examination, she relied on a power wheelchair for mobility, but occasionally used Lofstrand crutches to ambulate short household distances. She reported walking less secondary to sustaining a fall a year prior that increased her fear of falling. Additionally, she described feeling especially fearful when stepping backwards while transferring, and stated that backward walking training had never been incorporated into her rehabilitation sessions. Her goal was to improve her walking function and balance to gain confidence when walking without assistance. She reported previous participation in a locomotor training program several years prior with marginal improvements. We hypothesized that a backward walking training program would improve her strength, balance, and forward walking function.

Design and Outcome Measures

The purpose of this case report was to determine the effects of backward walking training on strength, balance, and upright mobility. Outcome measures were assessed prior to and following 18 sessions of backward walking training. To ensure a stable baseline, upright mobility tests were conducted both 1-week and 3-days prior to initiation of training. Tests of strength and balance were conducted 3-days prior to training and all post-training assessments were completed 3-days post backward walking training. For each outcome measure used to assess upright mobility, a minimum of two trials was conducted and the average value for the two trials was calculated.

Strength

Lower Extremity Motor Score (LEMS)—Strength was assessed according to the ASIA International Standards for Neurological Classification of SCI and according to standard guidelines for calculating the LEMS (Bohannon and Smith, 1987; Marino et al, 2008). The LEMS is based on strength in five key muscle groups bilaterally with a total possible score of 50.

Balance

Berg Balance Scale (BBS)—Standing balance was assessed using the BBS. The BBS is considered to be the gold standard for functional balance assessment in various patient populations, and is both valid and reliable in the SCI population (Lemay and Nadeau, 2010; Wirz, Muller, and Bastiaenen, 2010).

Sensory Organization Test (SOT)—The SOT was performed using computerized dynamic posturography (CDP) on the NeuroCom® Balance Master® (NeuroCom International, Inc., Clackamas, OR). The SOT is a standardized balance assessment that includes six conditions based on the Clinical Test of Sensory Interaction and Balance (CTSIB) (Ford-Smith et al, 1995; Whitney, Marchetti, and Schade, 2006). Postural sway in response to each condition is measured using a force platform. The SOT composite equilibrium score ranges from 0 to 100; higher scores indicate greater stability (Whitney, Marchetti, and Schade, 2006). Psychometric properties of the CTSIB and the SOT that are specific to the SCI population have not been reported.

Upright Mobility

Walking Index for Spinal Cord Injury II (WISCI II)—The WISCI II was used to classify the patient's level of walking independence and use of assistive devices and/or braces required for walking. The WISCI II is a 20-item scale ranging from 0 (the patient is unable to walk) to 20 (the patient can ambulate for 10 meters without assistance, devices, or braces) (Ditunno and Ditunno, 2001). The WISCI II has been shown to have excellent validity and reliability in both the acute and chronic SCI patient populations (Ditunno and Ditunno, 2001; Morganti et al, 2005).

10 Meter Walk Test (10MWT)—The 10MWT was used to measure the participant's forward gait speed. This test is a valid and reliable assessment and demonstrates good responsiveness to change in ambulatory patients with SCI (Lamb and Yang, 2000; van Hedel, Wirz, and Dietz, 2005).

Backward Walking Assessment—Validated assessments of backward walking have not been established. For this case, backward walking was assessed using a timed test for a distance of three meters.

Timed Up and Go (TUG)—The TUG, which requires an individual to rise from a chair, walk three meters, and return to the chair, was used to assess walking function and upright mobility (van Hedel, Wirz, and Dietz, 2005). The TUG demonstrates excellent test-retest and inter-rater reliability in the SCI population (Lam, Noonan, Eng, and Team, 2008; van Hedel, Wirz, and Dietz, 2005).

Spatiotemporal Gait Characteristics—Spatiotemporal characteristics of step length (cm), stride length (cm), cadence (steps/min), and velocity (m/s) were assessed at self-selected and fastest-comfortable walking speeds using a 14-foot instrumented walkway (GAITRite™, CIR Systems, Inc., Cincinnati, OH) (Nair, Hornby, and Behrman, 2012; Webster, Wittwer, and Feller, 2005). Lofstrand crutches were used pre- and post-training. Four trials were conducted at each speed and the average values were calculated.

Activities-Specific Balance Confidence (ABC) Scale—The ABC Scale was used to assess the participant's self-reported confidence with various upright mobility tasks. This outcome measure is both valid and reliable in other neurologic populations, but has not been validated for persons with SCIs (Botner, Miller, and Eng, 2005).

INTERVENTION

Backward walking training was conducted 3 days per week for 6 weeks (18 sessions). Each 60-minute session began with ~40 minutes of backward walking training on a treadmill using partial body weight support (BWS). Stepping and standing rest breaks were alternated in bouts of ~5 and 3 minutes, respectively, with a goal of at least 25 minutes of stepping per session. The remaining 20 minutes of each session focused on overground training and consisted of ~5-minute bouts of backward walking with ~3-minute rest breaks and a final bout (5 minutes) of forward walking.

The backward walking training program emphasized walking rehabilitation principles previously described in the literature (Behrman and Harkema, 2007). Accordingly, the backward walking intervention focused on intense, repetitive practice while minimizing the use of assistive devices. The backward walking training also emphasized stepping with appropriate limb kinematics, upright trunk posture, reciprocal arm movements, maximizing lower extremity loading and stepping speed (Behrman and Harkema, 2007).

Backward Walking Training on the Treadmill

During backward walking training on the treadmill (TheraStride™, St. Louis, MO), the participant wore a harness and was provided partial BWS equal to or less than 30% of her body weight (Behrman and Harkema, 2007). This level of BWS promoted faster stepping speeds while also promoting loading on the lower extremities. As shown in Figure 1A, the assistance from a trunk trainer and two leg trainers was applied to maintain upright trunk posture and appropriate stepping kinematics. During standing rest breaks, BWS was decreased to 5% to maximize weight-bearing through the lower extremities. Additionally, stepping and standing activities were completed without upper extremity support and reciprocal arm swing was encouraged (Behrman and Harkema, 2007).

Repetition and practice intensity were emphasized in two ways. First, the number of steps practiced during each session was counted and recorded. As seen in Table 1, each training session aimed to increase the number of steps on the treadmill and overground (Lohse, Lang, and Boyd, 2014). Training intensity was promoted by encouraging treadmill speeds that aimed to approximate normal backward walking speed (1.1 m/s) (Behrman and Harkema, 2007; Lee, Kim, Son, and Kim, 2013). The participant was unable to achieve normal backward walking speeds due to lower extremity spasms that were elicited at higher speeds. However, a primary goal was to increase treadmill speed each session.

Backward Walking Training Overground

Following backward walking training on the treadmill, backward walking was practiced overground. As seen in Figure 1B, backward walking overground was performed without BWS. Training intensity during overground practice was emphasized by encouraging fast stepping speeds and minimizing upper extremity support. Assistive devices were not used, but some bouts included physical assistance from one physical therapist for intermittent, hand-held assistance. Occasionally, manual assistance from a second physical therapist was provided to facilitate foot clearance and emphasize stepping speed and number of steps practiced.

Each training session concluded with one bout of forward walking overground with specific emphasis on stepping with appropriate kinematics. Forward walking was performed without assistive devices and the bout was limited to five minutes in duration.

OUTCOMES

Following 18 sessions of backward walking training improvements in balance and upright mobility were evident. Outcomes are summarized below with details reported in Tables 2–4. Lower extremity strength remained stable and did not change based on her LEMS. Increases

in balance were evident based on improvements in the BBS score (20/56 to 37/56) that exceeded the established minimal detectable change (MDC) values (Stevenson, 2001). Although minimal clinically important difference (MCID) values for the BBS have not been established, higher BBS scores are associated with greater mobility independence, walking speed, and endurance (Forrest et al, 2012; Wirz, Muller, and Bastiaenen, 2010). Additionally, as noted in table 3, the participant achieved a score of 3 or 4 on several BBS test items that she previously was unable to perform (score = 0). Furthermore, she was able to perform a full 360-degree turn independently for the first time since her injury. Her composite SOT score increased by 13 points (27 to 40/100) which surpassed the MDC value of 9.75 (Broglia, Ferrara, Sopiartz, and Kelly, 2008). MCID values for the SOT have not yet been reported in the literature.

Classification of her walking independence remained at 16 on the WISCI II based on her ability to ambulate 10 meters using two crutches without assistance. Improvements in upright mobility were evident based on changes in the time to complete the 10MWT, 3-meter backward walking test, and the TUG. Gait speed, as assessed by the 10MWT, improved by 0.08 m/s which did not surpass the MDC value of 0.13 m/s that has been established in the SCI patient population (Lam, Noonan, Eng, and Team, 2008). However, her improvement in gait speed exceeded the established MCID value of 0.06 m/s for the incomplete spinal cord injury patient population (Musselman, 2007). Changes exceeded the MDC values on both the TUG (MDC: 10.8 s; time decreased by 24.3 s) and the ABC Scale (MDC: 11.12%; score improved by 12.7%) (Dal Bello-Haas, Klassen, Sheppard, and Metcalfe, 2011; Lam, Noonan, Eng, and Team, 2008). MCID values have not been reported for the TUG or the ABC Scale. Table 4 lists spatiotemporal characteristics of her forward walking pattern prior to and after backward walking training.

Subjectively, the participant reported improved balance with activities of daily living such as dressing and cooking. She noted that she was able to stand for longer periods of time when cooking or cleaning, whereas, in the past, she remained seated to perform these activities. With regards to walking, she stated that it was easier to initiate steps, and subsequently, she was walking more throughout the day. Additionally, she described feeling stronger when standing and transferring in and out of the bed, wheelchair, and van.

Overall, the participant in this case completed all 18-sessions of backward walking as scheduled and described the training to be challenging and beneficial. Walking rehabilitation principles previously described for the practice of forward walking were applied to backward walking training (Behrman and Harkema, 2007). Thus, backward walking training carried out in a manner consistent with previously established walking rehabilitation principles was feasible.

DISCUSSION

Following 18 sessions of intense backward walking training, a 28 year-old female 11-years post ISCI demonstrated gains in balance and upright mobility. Forward and backward gait speeds increased and improvements were particularly evident in balance and during gait tasks such as turning and stepping backward. Concomitant with these gains, her self-

reported confidence during upright mobility tasks increased. Backward walking training may be an effective rehabilitation approach because of the unique biomechanical requirements of stepping backwards. Backward walking training also may activate shared neural resources important for the control of both forward and backward walking (Lacquaniti, Ivanenko, and Zago, 2012). The backward walking training program applied in this case emphasized walking rehabilitation principles known to promote neuromuscular activation and recovery in individuals with ISCIs (Harkema et al, 2012). Overall, outcomes from this case suggest that backward walking training emphasizing key rehabilitation principles was feasible and effective for promoting ongoing recovery in an individual with chronic ISCI.

The participant participated in regular, ongoing physical and occupational therapies for 11 years since the onset of her cervical ISCI. Although she recovered walking function using Lofstrand crutches, her walking remained slow and labored, and she used a power wheelchair for mobility. Following 18 sessions of backward walking training, modest gains in forward walking speed were evident. Most notable were the improvements in upright mobility and balance, as evidenced by decreased time to complete the TUG and increased scores on the BBS and SOT, which are highlighted in table 2. A post-hoc video review of her performance on the TUG suggested that her reduced time to complete this test primarily was due to increased speed and stability while turning 180° to in preparation for sitting down (stepping backward and adjusting her foot position). Similarly, as seen in table 4, the gains in her BBS score were most evident in her increased ability to turn 360° and maintain balance with a narrow base of support (e.g. feet together or one foot in front). The impact of her improved mobility on her balance self-efficacy was apparent in her subjective comments and gains in her self-reported confidence (ABC scale). Balance confidence is associated with activity and participation levels in individuals with neurologic injuries (Schmid et al., 2012) and increased fear of falling is negatively associated with postural control in individuals post SCI (John, Cherian, and Babu, 2010). Thus, these gains may be particularly important for this individual who previously reported increasing fear of falling and declines in upright mobility activities.

To our knowledge, only a single case by Moriello et al. (2014) has been published on the effects of backward walking on an individual with ISCI. The Moriello et al. (2014) case describes the comparative effects of forward versus back walking training in an adult only 8-months post-ISCI. An ABABAB design was used; 3-weeks of twice weekly sessions of each treadmill-based intervention were conducted across 18 weeks. Overall improvements in gait function and endurance were reported, but balance changes were not detected. Outcomes were similar for forward and backward walking except backward walking led to greater improvements in the sit-to-stand test. Although we also applied 18-sessions of backward walking training, our intervention differed in that it was completed in 6-weeks, included physical guidance by trainers to promote appropriate kinematics and upright posture, and did not incorporate the use of gait devices. In contrast to Moriello et al. (2014), our participant demonstrated measurable gains in balance, improvements in varied upright mobility tasks, and increased self-reported balance and mobility confidence. Further, our case report was conducted in an individual with ISCI for 11-years (compared with 8-months) who reported limited improvements from other rehabilitation approaches. Compared with studies of

locomotor training, our training sessions were similar in duration (60 min), but we completed fewer sessions (18) than typically reported (~40 sessions). Despite fewer training sessions, the outcomes demonstrated in this case are consistent with prior studies of locomotor training (Morawietz and Moffat, 2013).

Biomechanical and Neural Control of Forward and Backward Walking

The rationale for backward walking training is two-fold. First, there are important similarities in the biomechanical and neural control of backward and forward walking. Second, there also are key differences in the two forms of locomotion that may be advantageous when using backward walking as a rehabilitation approach. For instance, in contrast to forward walking, backward walking requires the combined motion of hip extension with knee flexion and ankle dorsiflexion. This movement pattern differs from the abnormal movement patterns often exhibited by individuals with neurologic injuries (van der Salm et al, 2005). The participant described in this case exhibited increased muscle tone in the quadriceps and plantar flexor muscles, which likely contributed to her slow and labored gait pattern. The lower extremity movements required during backward walking promote joint motions away from this abnormal pattern. Based on this, repetitive backward walking practice which incorporates active hip and knee extension with ankle dorsiflexion may have benefitted this individual (Yang et al, 2005). Furthermore, a predominant gait deviation associated with neurologic injury and use of an assistive device is decreased hip extension during stance (van der Salm et al, 2005). Hip extensor muscle strength also is impaired post ISCI (Kim, Eng, and Whittaker, 2004). Backward walking promotes concentric activation of the hamstring muscles to extend the hip and flex the knee during early swing (Thorstensson, 1986). Repeated practice of this pattern may have been beneficial for this individual who previously relied on a power wheelchair or Lofstrand crutches for mobility.

From a neural control perspective, backward and forward walking share similar control mechanisms, but also engage disparate neural pathways. Basic science investigations of locomotion indicate that the spinal neural networks that contribute to forward locomotion also participate in other forms of locomotion (Berkowitz, 2008; Earhart and Stein, 2000; Grillner et al, 2008), including backward locomotion (Hsu, Orlovsky, and Zelenin, 2014; Musienko et al, 2012). Studies of human locomotion also support this notion—that a variety of rhythmic, reciprocal locomotor activities are controlled by shared neural mechanisms (Fox et al, 2013; Wannier, Bastiaanse, Colombo, and Dietz, 2001; Zehr et al, 2007) and that backward and forward walking may engage overlapping spinal networks (Lamb and Yang, 2000). The biomechanical and neural control mechanisms associated with backward walking training were not tested in this case. However, these factors provided the rationale for applying backward walking training and these factors could be one explanation of the changes observed in the participant.

The neural control of forward and backward walking may be most disparate in the supraspinal mechanisms associated with both forms of locomotion (Hoogkamer, Meyns, and Duysens, 2014; Kurz, Wilson, and Arpin, 2012; Musienko et al, 2012). Recent studies suggest that supraspinal control of backward walking differs from forward walking (Musienko et al, 2012) and the overall level of cortical activation during backward walking

is greater than forward walking (Kurz, Wilson, and Arpin, 2012). Increased cortical activation may be an advantage of this training approach by promoting engagement of intact cortical centers or increasing descending drive to stimulate connections and activation of damaged spinal pathways. Dissimilarity in the cortical control of the two forms of locomotion may be associated with differences such as stability requirements, greater novelty of stepping backwards, as well as differing visual inputs or optic flow while stepping backward. Moreover, backward walking is most commonly used during daily activities associated with adaptive gait tasks or transitional movements such as backing up to a chair or maneuvering in narrow spaces. Compared with steady-state forward walking, cortical activation is greater during stepping maneuvers that require accurate foot placement or precise gait adaptations (Beloozerova, Farrell, Sirota, and Prilutsky, 2010). In this case, the patient demonstrated notable improvements in several upright mobility tasks requiring stepping adaptations or stepping accuracy.

Limitations

There are several limitations of this case report. The primary limitation is that it includes only one participant and the outcomes cannot be generalized to other individuals with ISCIs. Additionally, backward walking training was not compared to other gait rehabilitation strategies and therefore, the relative effectiveness of backward walking training for this individual is not known. However, the impetus to initiate backward walking training in this individual was her prior limited response to forward walking rehabilitation programs. Another limitation of this case report is the role of the primary physical therapist in carrying out the intervention and also in conducting the tests and measures. Additionally, only upright mobility tests were repeated to establish a stable baseline prior to initiating the intervention. These factors could have influenced the outcomes.

Finally, gains in strength were not evident based on the LEMS. This outcome is consistent with prior reports on the effects of locomotor training and may reflect changes in neural control that are not evident based on tests of isolated joint motions (Behrman et al, 2005). It also is possible that the participant may have gained strength in muscle groups not tested by the LEMS, such as the hip extensors and knee flexors, which are active during the swing phase of backward walking. Improved trunk stability also may have contributed to the improvements demonstrated in this case. In particular, the backward walking training also included brief bouts of standing practice that likely contributed to improved trunk control and standing balance.

Summary

This case report demonstrates improvements in balance and walking function in an adult with chronic ISCI following participation in an intense backward walking training program. Walking rehabilitation principles were applied to promote intense, task-specific practice. Backward walking training may be a beneficial rehabilitation strategy for promoting balance and mobility recovery after ISCI. It is particularly notable that this participant demonstrated meaningful gains more than 11 years after her injury and after 18-sessions of training. Future research should include a comparison in a larger patient population of forward and backward walking training adhering to the same training protocol. Additionally, further

study of the effects and mechanisms associated with backward walking training is necessary to understand the use of this gait rehabilitation strategy.

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Figure 1. Intense backward walking training was performed both in the treadmill environment (A) and overground (B). Key walking rehabilitation principles were used to guide and progress the intervention in both training environments.

Table 1

Summary of Backward Walking Training

Sessions	Avg. Treadmill Speed (m/s)	Avg. Treadmill Steps/Session	Avg. Overground Steps/Session
1–3	0.13 – 0.18	994	127
4–6	0.45 – 0.54	1,408	166
7–9	0.45 – 0.58	1,392	155
10–12	0.36 – 0.54	919 ^α	301
13–15	0.45	557 ^α	505
16–18	0.54 – 0.72	1,222	164
TOTAL:	--	19,475	4,169

^α Step time and step count decreased secondary to 1–2 sessions with increased overground training and decreased backward walking training on the treadmill due to increased lower extremity muscle tone and fatigue.

Table 2

Clinical Outcome Measures

Outcome Measure	Pre-Training Assessment	Post-Training Assessment
Strength		
Lower Extremity Motor Score	36/50	36/50
Balance		
Berg Balance Scale ²⁸	20/56	37/56 [∞]
Sensory Organization Test (Composite Score) ³⁹	27	40 [∞]
Upright Mobility		
Walking Index for Spinal Cord Injury (WISCI II)	16/20	16/20
10 Meter Walk Test (m/s)	0.23	0.31
Backward Walking Assessment [3 Meters] (m/s)	0.07	0.12
Timed Up and Go Test ³³ (s)	57	32.7 [∞]
Activities-Specific Balance Confidence Scale ³⁶ (%)	36.9	49.6 [∞]

[∞] Exceeded the MDC values established in the literature for each outcome measure.

Table 3

Berg Balance Scale Scores Pre- and Post-Backward Walking Training

Berg Balance Scale Item	Pre-Training	Post-Training
Sitting to Standing	3	3
Standing Unsupported	3	3
Sitting with Back Unsupported	4	4
Standing to Sitting	3	3
Transfers	1	3
Standing Unsupported with Eyes Closed	2	3
Standing Unsupported with Feet Together	1	4
Forward Reach While Standing	1	3
Pick Up Object from Floor From Standing	1	3
Turning to Look Behind Over Left and Right Shoulders While Standing	1	3
Turn 360 Degrees	0	2
Placing Alternate Foot on Step or Stool While Standing Unsupported	0	0
Standing Unsupported One Foot in Front	0	2
Standing on One Leg	0	1

Table 4

Spatiotemporal Gait Characteristics Pre- and Post-Backward Walking Training

	Pre-Training Self-Selected Pace	Pre-Training Fast Pace	Post-Training Self-Selected Pace	Post-Training Fast Pace
Step Length (cm)				
Left:	31.7	33.0	36.6	37.7
Right:	35.1	35.1	40.6	45.5
Stride Length (cm)				
Left:	66.7	67.9	77.2	83.3
Right:	68.1	69.1	79.0	85.1
Cadence (steps/min)	32.0	36.0	33.5	42.1
Velocity (m/s)	0.18	0.20	0.23	0.27