PHYSIOTHERAPY THEORY and PRACTICE

http://informahealthcare.com/ptp
ISSN: 0959-3985 (print), 1532-5040 (electronic)

Physiother Theory Pract, Early Online: 1–11
 DOI: 10.3109/09593985.2013.819952

informa healthcare

CASE REPORT

# A multidimensional physical therapy program for individuals with cerebellar ataxia secondary to traumatic brain injury: a case series

Cecelia Sartor-Glittenberg, MS, PT, NCS[1], and Lori Brickner, PT[2]*

[1]Physical Therapy Program, Arizona School of Health Sciences, A.T. Still University, Mesa, AZ, USA and [2]St. Joseph's Hospital and Medical Center, Barrow Neurological Institute, Phoenix, AZ, USA



**Abstract**

The purpose of this case series is to describe changes in impairments and activity limitations in three individuals with severe cerebellar ataxia from traumatic brain injury (TBI) who participated in a long-term, multidimensional physical therapy program. A secondary purpose is to document use of a climbing wall for these persons. Each of the individuals had a TBI, severe ataxia and was admitted to a transitional neuro-rehabilitation day treatment program. The first person, a 22-year-old, was 6 years post injury and had 127 individual physical therapy sessions over 12 months. The second person, a 16-year-old, was 5½ months post injury and had 187 individual therapy sessions over 19 months. The third person, a 20-year-old, was 6 months post injury and had 89 individual therapy sessions over 23 months. An integrative treatment approach was used, and the individuals participated in activities to minimize ataxia and improve mobility. Each of them made gains in coordination, balance, balance confidence, endurance and mobility. The three individuals with cerebellar ataxia participated in a long-term, individualized, multidimensional physical therapy treatment program, and made improvements in all areas of impairment and activity limitations. This study reinforces the need for long-term, multidimensional physical therapy for individuals with ataxia.

**Keywords**

Ataxia, brain injury, rock climbing

**History**

Received 2 May 2012
Revised 4 April 2013
Accepted 23 May 2013
Published online 25 July 2013

## Introduction

Cerebellar pathology from a traumatic brain injury (TBI) often results in impairments in balance and coordination that affect mobility (Fulk, 2007; Schmitz, 2007a; Shumway-Cook and Woollacott, 2007). *Cerebellar ataxia*, a term that describes movement coordination problems associated with cerebellar pathology (Schmitz, 2007a), is characterized by jerky, inaccurate voluntary movement of normal strength (Lundy-Ekman, 2007).

Cerebellar ataxia can arise from hereditary or acquired disorders (National Institute of Neurological Disorders and Stroke, 2012) that affect the cerebellum and/or the cerebellum's input or output pathways (Marsden and Harris, 2011). Through the circuitry and afferent and efferent connections, the cerebellum contributes to coordination, balance and locomotion (Armultlu, 2013). The cerebellum receives and compares information about the intended and actual motor performance and modulates motor output of the motor cortex and brainstem (Shumway-Cook and Woollacott, 2012). The cerebellum also has a role in modulating muscle tone and in timing of movement (Shumway-Cook and Woollacott, 2012).

Movement problems differ depending on the part of the cerebellum that is affected (Mauritz, Dichgans, and Hufschmidt, 1979), and control of single-joint movement and especially multi-joint movement is difficult (Bastian, 1997; Morton and Bastian, 2004). Lesions of the vermis and flocculonodular lobe result in truncal ataxia, paravermal lesions result in gait and limb ataxia and lateral cerebellar lesions result in hand ataxia (Lundy-Ekman, 2007). Mauritz, Dichgans, and Hufschmidt (1979) found that individuals with lesions of the anterior lobe demonstrated a stiff-legged, wide-based gait and had exaggerated postural reactions; those with neocerebellar syndrome had hypotonia and limb ataxia and no or little postural instability; and individuals with vestibulo-cerebellar lesions had a severe disturbance in equilibrium, had severe postural ataxia and required assistance for standing.

The cerebellum contributes to motor and nonmotor learning (Shumway-Cook and Woollacott, 2012). Motor learning can be affected with cerebellar injury (Ioffe, Chernikova, and Ustinova, 2007; Schmitz, 2007a), particularly learning to predict the timing of implicit motor responses (Boyd and Winstein, 2004).

Although there is little published research on effective strategies for the management of ataxia (Marsden and Harris, 2011; Martin, Tan, Bragge, and Bialocerkowski, 2009; Morton, Dordevic, and Bastian, 2004; O'Sullivan, 2007a), numerous interventions are used to improve: stability (Kabat, 1955; O'Sullivan, 2007a;b; Shumway-Cook and Woollacott, 2012); balance (Gibson-Horn, 2008; Gill-Body, Popat, Parker, and Krebs, 1997; O'Sullivan, 2007a,b); extremity coordination (O'Sullivan, 2007a); gaze stabilization (Gill-Body, Popat, Parker, and Krebs, 1997; O'Sullivan, 2007a); gait (Cernak, Stevens, Price, and Shumway-Cook, 2008; O'Sullivan, 2007a,b; Vaz et al, 2008); and functional mobility (O'Sullivan, 2007a; Shumway-Cook and Woollacott, 2007). A recent systematic review provided some evidence that physical therapy improved

*Ms. Brickner is now with Mercy Gilbert Medical Center, Gilbert, AZ, USA.

Address correspondence to Cecelia Sartor-Glittenberg, MS, PT, NCS, Physical Therapy Program, Arizona School of Health Sciences, A.T. Still University, 5850 E, Still Circle, Mesa, Arizona 85206, United States. E-mail: cglittenberg@atsu.edu

trunk control, gait and activity limitations in individuals with cerebellar damage, but revealed no evidence for long-term carryover of gains (Martin, Tan, Bragge, and Bialocerkowski, 2009). This paucity of research suggests that more investigation on treatment of ataxia is required (Bastian, 1997; Marsden and Harris, 2011; Martin, Tan, Bragge, and Bialocerkowski, 2009).

The purpose of this retrospective case series is to describe the changes in impairments, activity limitations and participation restrictions that occurred in three individuals with moderate to severe ataxia from cerebellar injury due to TBI who participated in a long-term, multidimensional physical therapy program. A secondary purpose is to document the use of a climbing wall as an adjunct therapy for these individuals.

## Methods

Following TBI and prior courses of rehabilitation, the individuals in this report were admitted to an out-patient, day rehabilitation program for adolescents and adults with brain injury to enable them to gain home independence, work reentry and/or school reentry. Each of the individuals received neuropsychology services, recreation therapy, speech and language therapy, physical therapy, occupational therapy and dietician consultation. Two of the individuals, KS and AL, also received vocational counseling. Therapy was provided in individual treatment sessions and in group or milieu sessions. People admitted to the out-patient, day rehabilitation program were seen by all or most disciplines 4 to 5 days per week in the beginning and middle of their course of rehabilitation. As goals were achieved and integration into work or school settings occurred, therapies were gradually discontinued with neuropsychology often the last service to be discontinued.

### Description of tests and measures

Tests and measures standard to the facility were conducted at admission, monthly and at discharge. Selection of the set of tests and measures had occurred over years of working with individuals with TBI, utilizing the clinical expertise of the therapists and the evidence from the literature supporting these tests. Tests of somatosensation (light touch, proprioception and sharp/dull sensation) (Schmitz, 2007b); tone (resistance to passive stretch and presence/absence of ankle clonus) (O'Sullivan, 2007c); and strength (manual muscle test of back extensors and abdominals and major muscle groups of hip, knee and ankle with 0–5 scale) were conducted (Kendall, Kendall, and Wadsworth, 1971). Two tests were used to examine coordination of the lower extremities: (1) the number of seconds to complete 10 heel-to-shin movements (average of three trials); and (2) the number of toe taps completed in 10 s (average of three trials) (Schmitz, 2007a). The ability to smoothly perform at least three heel-to-shin movements is part of the Brief Ataxia Rating Scale (Cronbach's alpha = 0.90) (Schmahmann, Gardner, MacMore, and Vangel, 2009). The number of toe taps completed in 10 s has been used to measure voluntary muscle activation in healthy young and older adults ($47 \pm 1$ taps/10 s and $34 \pm 1$ taps/10 s, respectively) (Kent-Braun and Ng, 1999). Individuals with cerebellar injury have increased variability in rhythmic tapping of the foot ipsilateral to the lesion in comparison to the contralateral foot (Ivry, Keele, and Diener, 1988).

The Berg Balance Scale (BBS), one leg stance time (OLST), stand on one leg eyes closed (SOLEC) and the NeuroCom® Sensory Organization Test (SOT) were used to measure balance. The BBS (Berg, Wood-Dauphinee, Williams, and Maki, 1992) is comprised of 14 different tasks graded on a 56-point scale (Feld, Rabadi, Blau, and Jordan, 2001). The BBS has good test-retest reliability (ICC = 0.986) for individuals with TBI (Newstead, Hinman, and Tomberlin, 2005) and correlates with Functional Independence Measure scores at admission and discharge from neurorehabilitation ($r = 0.86$; $p < 0.01$ and $r = 0.56$; $p < 0.01$, respectively) (Feld, Rabadi, Blau, and Jordan, 2001). Individuals with acquired brain injury who reported at least one fall in the past 6 months had lower BBS than nonfallers ($p \leq 0.03$) (McCulloch, Buxton, Hackney, and Lowers, 2010). Utilizing BBS values of five individuals with TBI (Newstead, Hinman, and Tomberlin, 2005), Steffen and Seney (2008) calculated a minimal detectable change score utilizing a 95% confidence interval ($MDC_{95}$) of 4 for the BBS.

The average time of three trials for the OLST and the SOLEC was recorded for this case series. Single-leg stance time is one of the most common balance measures used by physical therapists (Sibley et al, 2011). Mean single-leg stance times with eyes open and closed have been established for adults and inter-rater reliability is excellent (ICC = 0.994 for eyes open and 0.998 for eyes closed) (Springer et al, 2007). Mean OLST in seconds for individuals aged 18 to 39 years is 43.5 SD 3.8 for females and 43.2 SD 6.0 for males and mean SOLEC is 8.5 SD 9.1 for females and 10.2 SD 9.6 for males (Springer et al, 2007). Reliability of OLST has not been determined in persons with TBI.

The SOT protocol examines the ability to maintain balance under six different sensory conditions (Chong, Horak, Frank, and Kaye, 1999). A composite equilibrium score (0–100% with 100% being best performance), which is the average of the scores of all sensory conditions (Newton, 1989; Riemann and Guskiewicz, 2000), was recorded for the current case series. Kaufman et al (2006) reported that mean composite SOT scores ($70 \pm 12$) for individuals with mild or moderate TBI differed significantly ($p = 0.04$) from matched healthy individuals ($80 \pm 8$).

The Falls Efficacy Scale (FES) is a 10-item questionnaire used to measure fear of falling (total score 0–100, 100 = high self-efficacy) (Tinetti, Richman, and Powell, 1990). Test–retest reliability in community-dwelling older adults was good ($r = 0.71$) (Tinetti, Richman, and Powell, 1990). For individuals with brain injury, fallers score lower on the FES than non-fallers ($p < 0.05$) (Medley, Thompson, and French, 2006).

The 6-minute walk test (6MWT) (Butland et al, 1982) was used to measure endurance. The 6MWT has excellent test-retest reliability (ICC = 0.94–0.96) for individuals with TBI (Mossberg, 2003; van Loo et al, 2004). For individuals with TBI, 6MWT and peak oxygen consumption have been found to be moderately correlated ($r = 0.58$) (Mossberg and Fortini, 2012). Although there is no minimal detectable change established for the 6MWT for individuals with TBI, Flansbjer et al (2005) found that the smallest real difference (SRD%) in 6-minute walk distance, representing the smallest change that indicates a real improvement, was 13% for individuals with a stroke.

Observation was used to examine gait deviations (Norkin, 2007). Description of level of assistance required for mobility activities, ranging from dependent to independent, was determined utilizing the definitions of assistance as outlined in the Functional Independence Measure (Granger et al, 1986). The Functional Independence Measure has demonstrated reliability, validity and responsiveness in individuals with neurological disorders (Hobart et al, 2001).

Participation in work, school, leisure activities and community activities was determined from interview of the individuals, observation in various community settings and from vocational rehabilitation reports.

### Description of interventions

Physical therapy was conducted in individual and group formats, each session lasting 40–45 min. Interventions selected for the

individuals in this case series focused primarily on reducing their ataxia and improving their functional mobility. There were commonalities among the interventions used in each of the individual's therapy programs; however, the programs were customized for each person's particular needs. Stability, coordination and balance are all affected with cerebellar damage and fall under the umbrella term of *ataxia* (Schmitz, 2007a). To reduce ataxia, activities were chosen to increase proximal stability, improve coordination of extremities and improve balance (Table 1).

Various interventions to improve gait and independence in mobility were used including bed mobility, sit to stand and transfer training (O'Sullivan, 2007a); walking with and without various assistive devices including poles (Schmitz, 2007c; Shumway-Cook and Woollacott, 2012), canes, walkers and weighted devices (O'Sullivan, 2007a); walking on various surfaces and in the community (Armutlu, Karabudak, and Nurlu, 2001; Gibson-Horn, 2008; Schmitz, 2007c); curb and obstacle negotiation (Schmitz, 2007c); carrying objects while walking (Schmitz, 2007c); walking at various speeds and in varying directions (Gibson-Horn, 2008; Schmitz, 2007c); walking with light weights on extremities (O'Sullivan, 2007a); and stairclimbing (Ilg et al, 2009).

Impairments in strength and endurance were also addressed during individual and group therapy sessions. Various means of trunk strengthening were used including prone extension and trunk extension while lying on a support (Schmitz, 2010) such as a therapy ball; and activities in quadruped, kneeling and half-kneeling (Schmitz, 2007c). Lower extremity strengthening (Gibson-Horn, 2008) included activities such as proprioceptive neuromuscular facilitation patterns with wrist and ankle weights or pulleys (O'Sullivan, 2007b) and heel and toe raises (Schmitz, 2007c). Endurance should be targeted in individuals with TBI (Fulk, 2007), so endurance activities such as treadmill walking and biking were included.

All interventions were modified or progressed based on the patient's abilities and response to treatment. Examples of how interventions were progressed include reducing the amount of therapist's assistance, working in more challenging anti-gravity positions, providing more resistance during strengthening exercises, increasing the number of repetitions of activities or time holding positions, changing the speed of movements, changing the support surface, changing the visual demands of the task, walking with less supportive devices, walking further distances, standing and walking with a narrow base of support, adding dual-task activities and weighting the trunk, extremities, or assistive devices and then reducing the weight.

Rock climbing on an artificial climbing wall (Highsmith et al, 2010) at an indoor rock climbing gym was used as a therapeutic tool for the individuals in this case series to decrease their ataxia and to promote their participation in recreational activities. Sport climbing is a branch of climbing where protection points are placed in rock or an indoor wall (Sheel, 2004). The climber ascends the wall by using hand and foot holds attached to the wall, and climbing requires sustained and intermittent isometric forearm muscle contractions for upward propulsion (Sheel, 2004). Visual acuity and visual perception are used to determine the location and orientation of the hand and foot holds and to select which hand and foot holds to use in subsequent moves (Ilich, n.d.). A physical therapist, occupational therapist and recreation therapist accompanied the individuals, and while climbing the person with the TBI was always belayed on a

Table 1. Interventions to improve proximal stability, coordination of extremities, and balance.

| Aim of interventions | Interventions used in case series |
|---|---|
| Proximal stability | • Therapy ball activities (O'Sullivan, 2007b)<br>• Weight-bearing exercise in quadruped, kneeling, half-kneeling and bridging (Armutlu, Karabudak, and Nurlu, 2001; Ilg et al, 2009; O'Sullivan, 2007b; Schmitz, 2007c; Shumway-Cook and Woollacott, 2012)<br>• Manual resistance to trunk in various antigravity postures (O'Sullivan, 2007b)<br>• Neurodevelopmental treatment techniques including encouraging postural alignment in sitting and standing with facilitation at shoulders and pelvis (Gialanella, Bertolinelli, Monguzzi, and Santoro, 2005; O'Sullivan, 2007b)<br>• Resisted gait (O'Sullivan, 2007b; Schmitz, 2007c)<br>• Weighting the trunk (Gibson-Horn, 2008; O'Sullivan, 2007a) |
| Coordination of extremity movement | • Reciprocal movements of the arms and legs in various antigravity postures on stable surfaces and unstable surfaces such as a therapy ball (O'Sullivan, 2007a, b)<br>• Kick ball while sitting (O'Sullivan, 2007b)<br>• Gait training with poles (Schmitz, 2007c; Shumway-Cook and Woollacott, 2012)<br>• Gait training with various assistive devices encouraging normal gait mechanics (O'Sullivan, 2007a)<br>• Tandem gait, braiding and toe walking (Gill-Body, Popat, Parker, and Krebs, 1997; Schmitz, 2007c)<br>• Varying speed of performance of functional activities (Shumway-Cook and Woollacott, 2012)<br>• Walking at fast speeds (Schmitz, 2007c) moving into light jogging<br>• Exercising with correct pace and timing (Shumway-Cook and Woollacott, 2012) to an exercise video<br>• Treadmill walking (Vaz et al, 2008)<br>• Rock climbing |
| Balance | • Exercises in standing while performing proprioceptive neuromuscular facilitation extremity patterns (O'Sullivan, 2007b)<br>• Therapy ball activities (O'Sullivan, 2007b)<br>• Sitting on unstable surfaces such as a balance disc (O'Sullivan, 2007b)<br>• Weight shifting in standing, varying speed and direction (Armutlu, Karabudak, and Nurlu, 2001; O'Sullivan, 2007b)<br>• Tandem standing and tandem walking on floor (Armutlu, Karabudak, and Nurlu, 2001; Gibson-Horn, 2008; Gill-Body, Popat, Parker, and Krebs, 1997) and narrow surface (O'Sullivan, 2007b) such as a balance beam<br>• Jumping and hopping activities such as jumping jacks (Schmitz, 2007a)<br>• Walking with head turns (O'Sullivan, 2007b; Schmitz, 2007c)<br>• Walking with eyes closed (Armutlu, Karabudak, and Nurlu, 2001; Gill-Body, Popat, Parker, and Krebs, 1997)<br>• Standing activities on foam (Gill-Body, Popat, Parker, and Krebs, 1997; O'Sullivan, 2007b)<br>• Tai Chi (Shapira et al, 2001)<br>• Balance while performing multiple tasks (Shumway-Cook and Woollacott, 2007) such as standing on a beam while playing catch |

safety rope by one of the therapists and supervised by trained rock climbing personnel.

## Case descriptions

### Case 1

*History*

KS was a 22-year-old female, admitted 6 years following a motor vehicle accident. Initial results of neurodiagnostic imaging showed multiple skull fractures, traumatic subarachnoid hemorrhage, external injury of cerebellum and frontal lobes, diffuse axonal injury, multifocal shear injuries, mild subdural hematoma, cerebellar hemorrhages and punctate hemorrhages in the mesencephalon. Initial Glasgow Coma Scale (GCS) rating was 3. She also had a fracture of the left (L) clavicle. One year later electroencephalography showed abnormal slowing in the posterior temporal regions bilaterally, especially on the right (R). Course of therapy prior to admission to the out-patient, day-long treatment program consisted of 4 weeks of acute care, 8 weeks of sub-acute rehabilitation, 5 weeks of in-patient acute rehabilitation and approximately 3 years of intermittent out-patient therapy. Status at the time of discharge from acute rehabilitation was minimal assistance for bed mobility, minimal to moderate assistance for level transfers, moderate assistance for sit to stand and ambulation with a bilateral platform front-wheeled walker (FWW) with minimal assistance of one to two persons. Prior to the injury, she was described as very sociable and participated in biking, rollerblading and babysitting. At the time of admission she was living at home with her family and enjoyed shopping, talking on the phone, watching television, listening to music, visiting with friends and going out to eat and to the movies. Although she had a wheelchair and assistive devices for walking at home, her primary means of mobility was walking while holding onto to her mother for support. She was admitted to the work reentry program and her stated goals were to live independently, to go out more in the community and to enjoy herself.

*Examination*

Initial examination of KS revealed intact lower extremity (LE) somatosensation. LE strength was 4/5 to 5/5. Abdominal and back extensor strength were both 4/5. She had severe LE ataxia, with slow and dysmetric heel-to-shin and toe taps: R toe taps (19.0 repetitions/10 s); L toe taps (2.4 repetitions/10 s); R heel-to-shin (10 repetitions/14.8 s); and L heel-to-shin (10 repetitions/17.2 s). She scored 26/56 on the BBS and 91/100 on the FES (Table 2). OLST was 2 s bilaterally; she could not perform SOLEC. She was modified independent in wheelchair mobility and required stand-by assistance for wheelchair and toilet transfers. She ambulated with a FWW with contact guard assistance for short distances. She walked 171 meters on the 6MWT with maximum assistance without an assistive device. The 6MWT was conducted without an assistive device as she had a history of not using an assistive device at home. Gait deviations were LE scissoring and loss of balance a minimum of 15 times. Neuropsychological testing revealed impairments in executive cognitive functioning. Three months after admission she was tested using the SOT, receiving a composite score of 40%.

*Evaluation and prognosis*

The examination revealed severe cerebellar ataxia with impairments in coordination, balance and gait and KS required assistance for transfers and walking. Her low GCS rating (Foreman et al, 2007; Ono et al, 2001) and long time since injury were factors that could potentially affect her potential for improvement (Katz, 1992). Her youth was a factor favoring a better outcome (Katz, White, Alexander, and Klein, 2004; Willemse-van Son, Ribbers, Verhagen, and Stam, 2007). With long-term goals of work reentry and independent living, the initial goals of physical therapy were modified independence with transfers and ambulation with a FWW indoors on level surfaces and independence in a home exercise program (HEP). Because KS had a goal to live independently, physical therapy also recommended she increase use of her wheelchair and FWW at home, thus decreasing her dependence on her mother for assistance with walking.

Table 2. Scores on tests and measures of impairments.

| Case | Measure | Initial | Discharge | Change |
|---|---|---|---|---|
| 1 (KS) | Berg Balance Scale | 26 | 43 | +17[a] |
| | Falls Efficacy Scale | 91 | 94 | +3 |
| | One Leg Stance Time (s) | | | |
| | RLE | 2.0 | 2.9 | +0.9 |
| | LLE | 2.0 | 2.7 | +0.7 |
| | Sensory organization test (%) | 40 | 47 | +7 |
| | 6-minute walk (meters) | 171 | 247 | +76[b] |
| 2 (EB) | Berg Balance Scale | 4 | 23 | +19[a] |
| | Falls Efficacy Scale | 37 | 95 | +58 |
| | One Leg Stance Time (s) | | | |
| | RLE | 0 | 3.5 | +3.5 |
| | LLE | 0 | 1.5 | +1.5 |
| | Sensory organization test (%) | NT | NT | |
| | 6-minute walk (meters) | 61 | 259 | 198[b] |
| 3 (AL) | Berg Balance Scale | 34 | 51 | +17[a] |
| | Falls Efficacy Scale | 72 | 97 | +25 |
| | One Leg Stance Time (s) | | | |
| | RLE | 6.3 | 20.0 | +13.7 |
| | LLE | 3.7 | 6.6 | +2.9 |
| | Sensory organization test (%) | 62 | 73 | +11 |
| | 6-minute walk (meters) | 282 | 549 | 267[b] |

Abbreviations: RLE, right lower extremity; LLE, left lower extremity.
[a]Met minimal detectable change utilizing 95% confidence interval; [b]Met smallest real difference.

*Intervention*

KS was in the out-patient, day-long treatment program for 20 months and received physical therapy for the first year, after which she only received neuropsychology, speech therapy and vocational counseling. Initially she received physical therapy 3 to 4 d per week, decreasing to 2 d per week. She received 127 individual physical therapy sessions, 17 therapeutic balance group sessions, 41 motor group sessions, 2 pool therapy sessions and 1 session of rock climbing. The physical therapist attended two work-trial sessions with KS and visited her fitness facility. Physical therapy interventions utilized during individual treatment sessions and the aims of the interventions for KS are listed in Table 3. Balance group activities included Tai Chi and other balance activities, which were performed in various positions and conditions (using a walker and/or assistance as needed). Motor group sessions consisted of cardiovascular exercise and included exercising on an Airdyne bike (Nautilus, Inc., Vancouver, WA), using an upper body ergometer and walking on a treadmill. She participated in one session of rock climbing 7 months after her admission, climbing one beginner wall and one intermediate wall.

She was instructed in a daily HEP that included simple flexibility and coordination exercises and the HEP was modified over the course of treatment. She documented her adherence to the program with a home independence checklist that she shared with the therapist. As KS demonstrated increased independence and safety with walking, her use of the wheelchair decreased over

Table 3. Individual therapy session interventions and aims for case 1 (KS).

| Interventions | Aims |
|---|---|
| Trunk strengthening | Proximal stability, abdominal strength |
| Therapy ball exercises | Proximal stability, coordination, balance |
| Exercise in quadruped | Proximal stability coordination, strength |
| Gait training with reciprocal poles (weighted and un-weighted), front-wheeled walker, forearm crutches, four-wheeled walker, without assistive device; various surfaces; in community | Coordination, gait, independence in mobility |
| Neurodevelopmental treatment | Proximal stability |
| Proprioceptive neuromuscular facilitation using wrist and ankle weights or pulleys while in standing | Strength, balance |
| Carrying objects while walking with and without walker | Balance and independence in mobility |
| Transfer training | Independence in mobility |
| Resisted gait | Proximal stability, gait |
| Standing weight shifting; walking in various directions while stabilizing against a wall; walking at various speeds; walking in all directions with weighted extremities, walking eyes open and closed | Balance, gait |

Listed interventions are from daily notes and monthly reports in the person's medical record.



the course of treatment and her time walking with the walker increased from using it in the afternoons at the out-patient, day-long treatment program and as often as possible at home to using a four-wheeled walker as her sole means of mobility.

*Outcome*

At discharge, LE strength was 4+/5 to 5/5. Abdominal and back extensor strength were both 4/5. She had moderate LE ataxia: R toe taps (25 repetitions/10 s); L toe taps (24 repetitions/10 s); R heel-to-shin (10 repetitions/7.3 s); and L heel-to-shin (10 repetitions/7.2 s). She scored 43/56 on the BBS (17-point change) and 94/100 on the FES (3-point change) (Table 2). OLST was 2.9 s on the RLE and 2.7 s on the LLE; KS could not perform SOLEC. She received a composite score of 47% on the SOT (7-point change). She was modified independent with transfers. She ambulated with a four-wheeled walker with modified independence indoors and supervision outdoors. She walked 247 meters on the 6MWT with a four-wheeled walker (76-meter change); gait observation revealed minimal veering from the path, no loss of balance or toe dragging, minimal to moderate ataxia with good stride length and base of support and no scissoring. At discharge, KS continued to live with family and was working part-time. She was instructed to continue strengthening and cardiovascular exercise 3 to 5 d per week.

## Case 2

*History*

EB was a 16-year-old male, admitted to the out-patient, day-long treatment program 5 months after an auto-pedestrian accident. Initial GCS rating and results of initial neurodiagnostic imaging were not included in his admission record to the out-patient, day-long treatment program. Immediately after the injury he underwent an L craniotomy for evacuation of a frontaltemporal epidural hematoma. Other injuries included an L clavicular fracture and L temporal skull fracture. He had respiratory failure, requiring a tracheostomy, and he developed pseudomonas pneumonia. Neurodiagnostic imaging 15 weeks after injury revealed innumerable foci throughout the deep white matter of bilateral cerebellar hemispheres and cerebral hemispheres consistent with diffuse axonal injury. Course of therapy prior to admission to the out-patient, day-long treatment program consisted of 2 weeks of acute care, 10 weeks of sub-acute rehabilitation and 9 weeks of in-patient acute rehabilitation. During the course of acute rehabilitation, EB was discharged to acute care for a repair of a tracheocutaneous fistula, and was then re-admitted to the acute rehabilitation unit 3 d later. His status at the time of final discharge from acute in-patient rehabilitation is described below under initial examination findings. At the time of the injury, EB was a sophomore in high school and was enrolled in honors and advanced placement classes. He enjoyed soccer, music, school, playing instruments, traveling, attending sporting events and participating in civic clubs. At the time of admission, he was living at home with his family and he enjoyed watching television and movies, searching the Internet and playing cards and computer games. He used a wheelchair for mobility. He was admitted to the home independence and school reentry program. When admitted, he stated his goals were to return to school, walk by himself, improve his talking, improve use of his R upper extremity and decrease his double vision. He was admitted to the out-patient, day-long treatment program for a total of 77 weeks, receiving 29 weeks of treatment at initial admission, followed by a 23-week break when he returned to school and received school-based and out-patient therapy, and then received 48 weeks of treatment after readmission. This report includes examination findings of EB when he was first admitted to the out-patient, day-long treatment program, interventions he received during his initial admission and readmission and outcomes at his final discharge.

*Examination*

Initial examination revealed intact LE somatosensation. Strength was 3/5 to 5/5 on the RLE and 3/5 to 4+/5 on the LLE. Abdominal strength was 4/5 and back extensor strength 1/5. He had mild hypertonia in the plantar flexors bilaterally. He had severe ataxia, with slow heel-to-shin and toe taps: R toe taps (20 repetitions/10 s); L toe taps (19 repetitions/10 s); R heel-to-shin (10 repetitions/12 s); and L heel-to-shin (10 repetitions/10.7 s). BBS was 4/56 and FES 37/100 (Table 2). OLST could not be performed. He was independent rolling and required supervision for sidelying to sitting. He was independent in wheelchair mobility and required minimal assistance for sit to stand, moderate assistance for stand to sit and maximum assistance for mat and wheelchair transfers. He was able to maintain sitting with upper extremity support with supervision and could not accept minimal challenge in sitting. He required maximum assistance to maintain standing. He walked 61 meters on the 6MWT with a FWW and maximum assistance of two people; gait deviations included severe bilateral LE ataxia and narrow base of support. Neuropsychological testing revealed depression, average-level performance on executive function tasks without a motor component and decreased cognition relative to

pre-injury abilities. One month after admission he received a composite score of 17% on the SOT.

*Evaluation and prognosis*

The examination revealed severe cerebellar ataxia with impairments in coordination, balance and gait and EB required assistance for bed mobility, transfers and walking. EB had bilateral cerebellar involvement and numerous medical complications which would most likely affect his outcome (Fulk, 2007), but his youth (Katz, White, Alexander, and Klein, 2004; Willemse-van Son, Ribbers, Verhagen, and Stam, 2007) and admission to the program within 6 months after injury would be related to potential for greater improvement (Katz, 1992). With the long-term goal of home independence and return to school, the initial goals of physical therapy were minimal assistance for bed and wheelchair transfers and instruct in a HEP.

*Intervention*

During the first admission, he was seen 4 to 5 d per week (schedule varied with school schedule), receiving 101 individual physical therapy sessions, 16 balance group sessions, 2 pool therapy sessions and 1 session of rock climbing. During readmission, he was seen 1 to 2 d per week, receiving 86 individual physical therapy sessions, 2 balance group sessions and 5 pool therapy sessions. Individual session physical therapy interventions and aims for EB are listed in Table 4. During the first admission, the physical therapist completed a wheelchair evaluation and prescribed a wheelchair to promote efficient wheelchair propulsion and postural alignment. He walked on a treadmill at home with contact guard assistance for 5 to 10 min at 1 mph. He participated in one session of rock climbing approximately 24 weeks after his first admission, climbing three different climbing walls during the session.

At readmission, multitasking was incorporated into physical therapy to address his goal of returning to school and his ability to transfer and ambulate safely in case of distraction. During the readmission, the physical therapist attended a school session with EB, where he walked on various surfaces, including outdoors and crossing a street. The physical therapist attended nine community outings with EB, having him walk on various surfaces, in various lighting conditions, and for long distances. Balance group sessions included balance activities in various positions and conditions, often with maximum assistance. He participated in a daily HEP, consisting of simple flexibility and coordination exercises, which was modified as indicated. He documented his adherence to the program with a home independence checklist that he shared with the therapist. As he continued to use his wheelchair as his means of mobility, he engaged in progressive ambulation activities utilizing various assistive devices to determine the most appropriate device for him. Toward the end of the readmission, he had a goal of walking across the stage for graduation independently.

*Outcome*

At discharge, RLE strength was 4/5 to 5/5 and LLE was 4+/5 to 5/5. Abdominal and back extensor strength were both 5/5. He had mild RLE dysmetria and moderate to severe LLE ataxia: R toe taps (23 repetitions/10 s); L toe taps (24 repetitions/10 s); R heel-to-shin (10 repetitions/8.6 s); and L heel-to-shin (10 repetitions/8.6 s). He scored 23/56 on the BBS (19-point change) and 95/100 on the FES (58-point change) (Table 2). OLST on the RLE was 3.5 s, and 1.5 s on the LLE. He was independent with bed mobility and with bed, chair, and toilet transfers. He walked 259 meters on the 6MWT with a four-wheeled walker and stand-by assistance (198-meter change), with three episodes of loss of balance that he self-corrected. At discharge, he was using the wheelchair as his primary means of mobility and discharge recommendations were to ambulate with the four-wheeled walker with stand-by assistance when indoors and contact guard assistance when outdoors. For graduation, the therapist recommended he walk across the stage with a four-wheeled walker independently.

## Case 3

*History*

AL, a 20-year-old male, was admitted to the out-patient, day-long treatment program 6 months after an auto-bicycle accident. Results of initial neurodiagnostic imaging revealed a temporalparietal epidural hematoma and a subdural hemorrhage. Imaging 30 months after the injury revealed evidence of prior shear injury of the corpus callosum, L superior cerebellar peduncle, L cerebral peduncle and the L cerebellar hemisphere. His initial GCS rating was 5. Other injuries included an L facial fracture. He developed seizures, required a tracheostomy, underwent placement of a gastrostomy and jejunostomy tube and developed pneumonia. Course of therapy prior to admission consisted of 6 weeks of acute care, 4 weeks of in-patient acute rehabilitation and 16 weeks of out-patient therapy. Status at the time of discharge from out-patient rehabilitation is

Table 4. Individual therapy session interventions and aims for case 2 (EB).

| Interventions | Aims |
|---|---|
| Bed mobility activities[a] | Independence in mobility |
| Transfer training[a]; practice sit to stand[b] | Balance, independence in mobility |
| Therapy ball exercises[a,b]; sitting on balance disc[b] | Proximal stability, coordination, balance |
| Strengthening trunk extensors in prone, sitting on ball[a] | Proximal stability, back extensor strength |
| Exercise in quadruped, kneeling,[a] half-kneeling[b] | Proximal stability coordination, strength |
| Gait training with reciprocal poles,[a] forearm crutches,[b] front-wheeled walker,[a] bilateral straight canes,[a] four-wheeled walker[a,b]; in community[a,b] | Coordination, gait, independence in mobility |
| Manual resistance to trunk; core stability exercises; neurodevelopmental treatment; bridging[b] | Proximal stability |
| Proprioceptive neuromuscular facilitation sitting on ball and in standing[b] | Balance |
| Coordination and speed of movement activities[b] | Coordination, balance |
| Standing weight shifting; sidestepping; braiding; step-ups; head turning while walking[b] | Balance, gait |
| Alternate upper extremity and lower extremity movement activities[b]; kick-ball[b] | Coordination |
| Lower extremity strengthening with pulleys; heel-toe raises[b] | Lower extremity strength |

[a]First admission.
[b]Second admission.
Listed interventions are from daily notes and monthly reports in the person's medical record.

described under initial examination findings. Prior to the injury, he had dropped out of high school in the 11th grade, worked as an inventory stocker and planned on attending community college. He enjoyed playing guitar, reading, going out with friends and road biking. He had a history of attention deficit disorder. At the time of admission, he was living at home with his mother and enjoyed using the computer, playing the guitar and watching television. He used a FWW with assistance when walking in the community, but held onto the walls (rather than the walker) when walking at home. He was admitted to the home independence and school/work reentry program. When admitted, he stated his goals were to return to work and school, and to play the guitar.

*Examination*

At initial examination, AL had intact LE somatosensation. LE strength was 3+/5 to 5/5. Abdominal strength was 3/5 and back extensor strength 5/5. He had ankle clonus on the R. He had LE ataxia: R toe taps (33 repetitions/10 s); L toe taps (16 repetitions/10 s); R heel-to-shin (10 repetitions/12 s); and L heel-to-shin (10 repetitions/12.3 s). BBS was 34/56 and FES 72/100 (Table 2). OLST was 6.3 s on the RLE and 3.7 s on the LLE; SOLEC was 3.6 s on the RLE and could not be performed on the LLE. On the SOT, he received a composite score of 62%. He required supervision for transfers and ambulated with a FWW with minimal assistance. He walked 282 meters on the 6MWT with a FWW; gait deviations consisted of heavy use of the walker with moderate to severe gait ataxia, LLE hip retraction and external rotation and minimal to no trunk rotation. Turns were slow and deliberate. The interdisciplinary team documented the presence of behavioral issues.

*Evaluation and prognosis*

The examination revealed moderate to severe cerebellar ataxia with impairments in coordination, balance and gait, and AL required assistance for transfers and walking. His lower GCS rating at the time of injury (Foreman et al, 2007; Ono et al, 2001) and multiple medical problems were factors that could affect his outcome (Fulk, 2007), but his youth (Katz, White, Alexander, and Klein, 2004; Willemse-van Son, Ribbers, Verhagen, and Stam, 2007) and admission to the program at 6 months after the injury were factors favoring potential for improvement (Katz, 1992). With the long-term goal of home independence and return to school/work, the initial goals of physical therapy were modified independence with transfers and walking with a FWW and independence in a HEP.

*Intervention*

AL was at the out-patient, day-long treatment program for 24 months and received physical therapy for 23 months. Initially he received physical therapy 4 to 5 d per week, decreasing to 1 to 2 d per week. He received 89 individual physical therapy sessions, 26 balance group sessions, 54 motor group sessions, 3 pool therapy sessions and 1 session of rock climbing. The physical therapist also attended a work-trial session and three city bus training sessions, and made three visits to his fitness facility. Physical therapy interventions conducted during individual therapy sessions are listed in Table 5. Multitasking was incorporated into physical therapy sessions to improve his ability to perform dual tasks so that he could ambulate safely at school and work. A backpack was utilized to weight the trunk for stability and was also functional for return to school. During the course of intervention, a leg length discrepancy (3/4 inch) became evident during gait observation. Further examination, including performance of a Thomas Test (Dutton, 2012), by the physical therapist and an orthotist determined that the discrepancy was likely from shortening of connective tissue at the hip due to the individual walking in a more flexed posture to compensate for proximal instability. The physical therapist prescribed shoe modification for the leg length discrepancy, allowing for improved biomechanical alignment. Group balance interventions included Tai Chi, single-leg stance and other balance activities. Motor group sessions consisted of exercise on the Airdyne bike, treadmill walking and stationary bicycle exercise. He participated in one session of rock climbing approximately 9 months after his admission, climbing three walls during the session.

He was instructed and advanced in a daily HEP including simple flexibility, coordination and strengthening exercises modified over the course of treatment. He documented his adherence to the program with a home independence checklist. Over the admission, his use of the FWW was discontinued, and he progressed to walking without the walker, but wearing a backpack for stability. He eventually walked without a backpack.

*Outcome*

At discharge, LE strength was 4+/5 to 5/5. Abdominal and back extensor strength were both 5/5. He had mild ankle clonus. Heel-to-shin and toe taps were performed smoothly: R toe taps (39 repetitions/10 s); L toe taps (24 repetitions/10 s); R heel-to-shin (10 repetitions/7.1 s); and L heel-to-shin (10 repetitions/7.3 s). He scored 51/56 on the BBS (17-point change) and 97/100 on the FES (25-point change) (Table 2). OLST was 20 s on the RLE, 6.6 s on the LLE; SOLEC on the RLE was 3.7 s and he

Table 5. Individual therapy session interventions and aims for case 3 (AL).

| Interventions | Aims |
|---|---|
| Therapy ball exercises | Proximal stability, coordination, balance |
| Gait training with reciprocal poles, weighted walker, front-wheeled walker, bilateral straight canes, without device; varying surfaces; in community | Coordination, gait, independence in mobility |
| Proprioceptive neuromuscular facilitation with wrist and ankle weights or pulleys in standing | Balance, strength |
| Balance beam activities with and without multitasking | Balance, dual tasks |
| Tandem gait; braiding; toe walking; jumping jacks; jumping and hopping activities | Coordination, balance, gait |
| Resisted gait | Proximal stability, gait |
| High level balance activities using weight shifting, increasing speed of movement, changing direction of movement; walking with head turns | Balance |
| Stair climbing without handrail and at increasing speeds; curb and obstacle negotiation | Coordination, balance, independence in mobility |
| Exercise to exercise video; jogging on floor, treadmill | Coordination, balance, speed, dual tasks |
| Donning and doffing backpack, walking with backpack | Proximal stability, participation in school |

Listed interventions are from daily notes and monthly reports in the person's medical record.

could not perform LLE SOLEC. He received a composite score of 73% on the SOT (11-point change). He walked 549 meters on the 6MWT (267-meter change); gait observation revealed L genu recurvatum, moderate external rotation and decreased deceleration in preparation for heel strike. He was independent in transfers and community ambulation, including using the city bus. At discharge, he was taking community college classes and working part-time. He was instructed to continue LE stretching and strengthening at home and at his fitness facility.

## Discussion

The individuals in this case series with cerebellar ataxia due to TBI demonstrated improvements in body functions (impairments), activities and participation following involvement in a long-term, multidimensional physical therapy intervention program. The multidimensional program was customized for the severity of each person's impairments and activity limitations, and incorporated the person's goals and lifestyle. The program contained traditional interventions for ataxia, such as work in quadruped (O'Sullivan, 2007b), but also included: strengthening and endurance activities; balance activities incorporating sitting, standing and walking under various environmental conditions; Tai Chi; multitasking; pool therapy; rock climbing; and task-specific practice of ambulation in the clinic, home and community to improve learning and carryover. The physical therapist visited the individual's prospective workplace, school and fitness facility.

Recommendations for treatment of ataxia often come from the literature on ataxia related to diagnoses other than TBI such as cerebellar degeneration (Ilg et al, 2009; Sliwa, Thatcher, and Jet, 1994); Charcot-Marie-Tooth disease (Vinci, 2003) or multiple sclerosis (Armutlu, Karabudak, and Nurlu, 2001; O'Sullivan, 2007a). Similar to this study, Armutlu, Karabudak, and Nurlu (2001) used a multidimensional treatment approach for ataxic multiple sclerosis. Examples of interventions included in that study were Frenkel's exercises, proprioceptive neuromuscular facilitation, balance training, Cawthorne-Cooksey exercises, pressure splints and ambulation on various surfaces, and the authors concluded that a combination of suitable techniques should be used, particularly for the more resistant symptoms (Armutlu, Karabudak, and Nurlu, 2001). For individuals with cerebellar degeneration, Ilg et al (2009) used a program of balance exercises, whole body movements and strategies and training to prevent falling.

The individuals in this case series received therapy over a long period of time. Longer duration and increased intensity of training have been recommended for individuals with cerebellar ataxia in previous studies (Cernak, Stevens, Price, and Shumway-Cook, 2008; Dordel, 1987; Morton and Bastian, 2004). Duration of programs vary from: 4 weeks (Ilg et al, 2009; Vaz et al, 2008); 6 weeks (Gill-Body, Popat, Parker, and Krebs, 1997); and 7 months (Dordel, 1987). However, Dordel (1987) remarked that therapy is often discontinued too soon. For instance, Balliet, Harbst, Kim, and Stewart (1987) reported improvements in one patient 10 years post TBI after 2 years of therapy.

All of the individuals BBS scores at discharge exceeded the 4-point $MDC_{95}$ for individuals with TBI (Newstead, Hinman, and Tomberlin, 2005; Steffen and Seney, 2008); 17 points, 19 points and 17 points for KS, EB and AL, respectively. All of individuals change in 6MWT distances surpassed the 13% relative improvement (SRD%) (Flansbjer et al, 2005) needed to indicate a real clinical improvement for individuals with stroke. KS walked 76 meters further at discharge (22 meters were needed to exceed 13%); EB walked 198 meters further at discharge (8 meters were needed); and AL walked 267 meters further (37 meters were needed). Although all of the individuals improved in the number of toe taps completed in 10 s, none of them met the foot-tapping rate of 47 repetitions in 10 s for young adults (Kent-Braun and Ng, 1999). The ability to perform repeated rapid movements such as toe tapping is important for the performance of activities of daily living (Kent-Braun and Ng, 1999), so difficulty with toe tapping may be associated with decreased independence in the individuals in this study. All of the persons improved their single-leg stance time with their eyes open, but none of them met the values for their age and gender group (Springer et al, 2007). Further, AL was the only individual who could perform SOLEC (RLE only) at discharge. KS and AL made improvements in their SOT composite equilibrium scores; however, the composite score for KS remained low, which may indicate a higher risk of fall (Oliveira et al, 2011).

The degree of improvement for the persons in this case series varied according to the severity of their ataxia and time since onset of injury. AL was 6 months post injury and had the highest functional outcome. Despite initial severe ataxia, his ataxia lessened significantly following 2 years of intensive therapy. KS and EB had severe ataxia. EB had received 5 months of therapy prior to admission and was severely physically impaired at admission. Although his ataxia lessened by discharge, it still limited his ability to ambulate without assistive devices and supervision. KS made gains 6 years post injury, but continued to have moderately severe ataxia at discharge. The significance of ataxia as an impairment is consistent with research by Walker and Pickett (2007) who showed that, following TBI, all neuromotor impairment measures improved in the first 6 months, except for tremor, and that ataxia was the most frequent motor impairment at every time point of measurement. The individuals in this case series all had improvements in ataxia 1 to 6 years post injury which contradicts Walker and Pickett (2007) showed that most improvement in motor impairment occurred in the first 6 months, leveled off by 12 months, and no improvements were seen from 12 months to 2 years.

The individuals in this case series with significant activity limitations met and surpassed expectations. Katz, White, Alexander, and Klein (2004) found that the mean time for recovering independent ambulation following TBI for individuals aged 15 to 87 years was $5.7 \pm 4.3$ weeks and that more than 73% of persons were independent in ambulation within 5 months post injury. The authors also stated that if persons with TBI had not achieved independent ambulation by 3 to 4 months therapists should be cautious setting a goal of independent ambulation. The authors did note that younger patients and those with less severe injuries and better initial gait scores were quicker to recover independent ambulation. The persons in the current case series were younger, but did not have less severe injury or better initial gait scores.

Rock climbing on an artificial climbing wall was used as a therapeutic intervention to decrease their ataxia and promote participation in recreational activities. It may seem contradictory to use rock climbing as a therapeutic intervention with individuals with a history of TBI or severe ataxia, but all three individuals with TBI safely executed rock climbing despite having significant ataxia and activity limitations at the time. The physical therapist documented that they demonstrated determination and focus and had good safety skills with hand and footholds when rock climbing. Further, they successfully climbed two to three walls using good weight shifting and reciprocal upper extremity and LE movements for placing and holding onto the wall. The therapist observed that their ataxia was minimized during the activity and they were visibly fatigued from climbing. All three individuals in this study stated they enjoyed the rock climbing experience and would like to continue this activity in the future. When treating

ataxia the literature supports work in: quadruped (O'Sullivan, 2007b); weight bearing (Shumway-Cook and Woollacott, 2012); bilateral work (Boyd and Winstein, 2004); use of slow movements (Armultlu, 2013; Bastian, 1997); and concentration (O'Sullivan, 2007a). Rock climbing incorporates all of these techniques in a single activity. These three individuals were relatively strong, which is consistent with the definition of ataxia (Lundy-Ekman, 2007), so they could take advantage of their strength for climbing. Studies on the benefits of rock climbing are restricted to physical realm. Rock climbing on a climbing wall has been shown to improve cardiorespiratory fitness and muscular endurance in experienced climbers (Mermier, Robergs, McMinn, and Heyward, 1997; Sheel et al, 2003). There is little written on psychosocial benefits of climbing. Kelley, Coursey, and Selby (1997) reported improved self-efficacy and self-esteem in individuals with mental illness after participating in an indoor recreation program that included rock climbing. Research has been conducted on the use of a climbing wall for individuals with amputation (Highsmith et al, 2010), but the research needs to be extended to other pathologies, including TBI. Interestingly, the results of a recent case series on the use of a climbing wall in four individuals with cerebellar ataxia from various neurologic conditions revealed improved movement velocity and more symmetric movement speed profile in arm and leg pointing movements, and improvement in balance was made by the two persons with the most severe gait ataxia (Marianne Anke et al, 2011).

## Limitations

This case series report has several limitations including use of retrospective data and inclusion of individuals of one age group. There was inconsistency in time since onset from injury to time of admission. Future research on interventions for cerebellar ataxia due to TBI should include persons with TBI of all age groups and receiving longer-term interventions. This case series did not outline a specific therapy regime for ataxia or document the effectiveness of one particular intervention for ataxia, both of which are thought to be missing from the literature (Martin, Tan, Bragge, and Bialocerkowski, 2009). The study did not include a measure of quality of life. The persons in this case series only participated in one session of rock climbing. Although they climbed two to three times during that session, future research needs to include more bouts of climbing and quantitative data collection. Despite these limitations, the similarity in age and severity of impairments and activity limitations, the standardized outcome measures used, the multidimensional nature of the interventions conducted and the improvements made increase the validity of the findings of this case series. The inclusion of rock climbing as an intervention for individuals with ataxia adds to the body of knowledge related to intervention for individuals with cerebellar ataxia.

## Conclusion

The individuals in this case series with moderate to severe cerebellar ataxia due to a TBI with significant coordination, balance and gait impairments and activity limitations met and surpassed expectations following a physical therapy program that was long-term, multidimensional and customized to address the unique needs of each of the individuals. This case series reinforces the need for long-term, multidimensional intervention for individuals with cerebellar ataxia.

## Declarations of interest

The authors have no conflicts of interest to disclose regarding this report.

## References

Armultlu K 2013 Ataxia: Physical therapy and rehabilitation applications for ataxic patients. In: Stone JH, Blouin M (eds) International encyclopedia of rehabilitation. http://cirrie.buffalo.edu/encyclopedia/en/article/#s11. Accessed March 29, 2013.

Armutlu K, Karabudak R, Nurlu G 2001 Physiotherapy approaches in the treatment of ataxic multiple sclerosis: A pilot study. Neurorehabilitation and Neural Repair 15: 203–211.

Balliet R, Harbst KB, Kim D, Stewart RV 1987 Retraining of functional gait through the reduction of upper extremity weight-bearing in chronic cerebellar ataxia. International Rehabilitation Medicine 8: 148–153.

Bastian AJ 1997 Mechanisms of ataxia. Physical Therapy 77: 672–675.

Berg KO, Wood-Dauphinee SL, Williams JI, Maki B 1992 Measuring balance in the elderly: Validation of an instrument. Canadian Journal of Public Health 83: S7–11.

Boyd LA, Winstein CJ 2004 Cerebellar stroke impairs temporal but not spatial accuracy during implicit motor learning. Neurorehabilitation and Neural Repair 18: 134–143.

Butland RJ, Pang J, Gross ER, Woodcock AA, Geddes DM 1982 Two-, six-, and 12-minute walking tests in respiratory disease. British Medical Journal (Clinical Resesearch Edition) 284: 1607–1608.

Cernak K, Stevens V, Price R, Shumway-Cook A 2008 Locomotor training using body-weight support on a treadmill in conjunction with ongoing physical therapy in a child with severe cerebellar ataxia. Physical Therapy 88: 88–97.

Chong RK, Horak FB, Frank J, Kaye J 1999 Sensory organization for balance: Specific deficits in Alzheimer's but not in Parkinson's disease. Journals of Gerontology. Series A, Biological Sciences and Medical Sciences 54: M122–128.

Dordel HJ 1987 Mobility training following brain trauma-Results of intensive individual treatment. International Journal of Rehabilitation Research 10: 279–290.

Dutton M 2012 Dutton's Orthopaedic examination, evaluation, and intervention, 3rd edn, pp 791–797. New York, McGraw-Hill Companies.

Feld JA, Rabad, MH, Blau AD, Jordan B 2001 Berg balance scale and outcome measures in acquired brain injury. Neurorehabilitation and Neural Repair 15: 239–244.

Flansbjer UB, Holmback AM, Downham D, Patten C, Lexell J 2005 Reliability of gait performance tests in men and women with hemiparesis after stroke. Journal of Rehabilitation Medicine 37: 75–82.

Foreman BP, Caesar RR, Parks J, Madden C, Gentilello LM, Shafi S, Carlile MC, Harper CR, Diaz-Arrastia RR 2007 Usefulness of the abbreviated injury score and the injury severity score in comparison to the Glasgow Coma Scale in predicting outcome after traumatic brain injury. Journal of Trauma Injury Infection and Critical Care 62: 946–950.

Fulk GD 2007 Traumatic brain injury. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, p 898. Philadelphia, FA Davis Company.

Gialanella B, Bertolinelli M, Monguzzi V, Santoro R 2005 Walking and disability after rehabilitation in patients with cerebellar stroke. Minerva Medica 96: 373–378.

Gibson-Horn C 2008 Balance-based torso-weighting in a patient with ataxia and multiple sclerosis: A case report. Journal of Neurologic Physical Therapy 32: 139–146.

Gill-Body KM, Popat RA, Parker SW, Krebs DE 1997 Rehabilitation of balance in two patients with cerebellar dysfunction. Physical Therapy 77: 534–552.

Granger C, Hamilton B, Keith R, Zielezny M, Sherwin F 1986 Advances in functional assessment for medical rehabilitation. Topics in Geriatric Rehabilitation 1: 59–74.

Highsmith MJ, Kahle JT, Fox JL, Shaw KL, Quillen WS, Mengelkoch LJ 2010 Metabolic demands of rock climbing in transfemoral amputees. International Journal of Sports Medicine 31: 38–43.

Hobart JC, Lamping DL, Freeman JA, Langdon DW, McLellan DL, Greenwood RJ, Thompson AJ 2001 Evidence-based measurement: Which disability scale for neurologic rehabilitation? Neurology 57: 639–644.

Ilg W, Synofzik M, Brotz D, Burkard S, Giese MA, Schols L 2009 Intensive coordinative training improves motor performance in degenerative cerebellar disease. Neurology 73: 1823–1830.

Ilich M (n.d.) MetaHolds: A rock climbing interface for the visually impaired. https://courses.ece.ubc.ca/518/previous/hit2008/papers/Ilich.pdf.

Ioffe ME, Chernikova LA, Ustinova KI 2007 Role of cerebellum in learning postural tasks. Cerebellum 6: 87–94.
Ivry RB, Keele SW, Diener HC 1988 Dissociation of the lateral and medial cerebellum in movement timing and movement execution. Experimental Brain Research 73: 167–180.
Kabat H 1955 Analysis and therapy of cerebellar ataxia and asynergia. A.M.A. Archives of Neurology and Psychiatry 74: 375–382.
Katz DI 1992 Neuropathology and neurobehavioral recovery from closed head injury. Journal of Head Trauma Rehabilitation 7: 1–15.
Katz DI, White DK, Alexander MP, Klein RB 2004 Recovery of ambulation after traumatic brain injury. Archives of Physical Medicine and Rehabilitation 85: 865–869.
Kaufman KR, Brey RH, Chou LS, Rabatin A, Brown AW, Basford JR 2006 Comparison of subjective and objective measurements of balance disorders following traumatic brain injury. Medical Engineering and Physics 28: 234–239.
Kelley MP, Coursey RD, Selby PM 1997 Therapeutic adventures outdoors: A demonstration of benefits for people with mental illness. Psychiatric Rehabilitation Journal 20: 61–73.
Kendall HO, Kendall FP, Wadsworth GE 1971 Muscles – Testing and function, 2nd edn, pp 157–232. Baltimore, Williams and Wilkins Company.
Kent-Braun JA, Ng AV 1999. Specific strength and voluntary muscle activation in young and elderly women and men. Journal of Applied Physiology 87: 22–29.
Lundy-Ekman L 2007 Basal ganglia, cerebellum, and movement. In: Lundy-Ekman L (ed) Neuroscience, fundamentals for rehabilitation, pp 261–264. Philadelphia, Saunders.
Marianne Anke S, Sylvie K, Jerome P, Shahid B, Thomas F, Dieter Georg R, Karin D 2011 Effect of long-term climbing training on cerebellar ataxia: A case series. Rehabilitation Research and Practice 2011: 1–8.
Marsden J, Harris C 2011 Cerebellar ataxia: Pathophysiology and rehabilitation. Clinical Rehabilitation 25: 195–216.
Martin CL, Tan D, Bragge P, Bialocerkowski A 2009 Effectiveness of physiotherapy for adults with cerebellar dysfunction: A systematic review. Clinical Rehabilitation 23: 15–26.
Mauritz KH, Dichgans J, Hufschmidt A 1979 Quantitative analysis of stance in late cortical cerebellar atrophy of the anterior lobe and other forms of cerebellar ataxia. Brain 102: 461–482.
McCulloch KL, Buxton E, Hackney J, Lowers S 2010 Balance, attention, and dual-task performance during walking after brain injury: Associations with falls history. Journal of Head Trauma Rehabilitation 25: 155–163.
Medley A, Thompson M, French J 2006 Predicting the probability of falls in community dwelling persons with brain injury: A pilot study. Brain Injury 20: 1403–1408.
Mermier CM, Robergs RA, McMinn SM, Heyward VH 1997 Energy expenditure and physiological responses during indoor rock climbing. British Journal of Sports Medicine 31: 224–228.
Morton SM, Bastian AJ 2004 Cerebellar control of balance and locomotion. Neuroscientist 10: 247–259.
Morton SM, Dordevic GS, Bastian AJ 2004 Cerebellar damage produces context-dependent deficits in control of leg dynamics during obstacle avoidance. Experimental Brain Research 156: 149–163.
Mossberg KA 2003 Reliability of a timed walk test in persons with acquired brain injury. American Journal of Physical Medicine and Rehabilitation 82: 385–390.
Mossberg KA, Fortini E 2012 Responsiveness and validity of the six-minute walk test in individuals with traumatic brain injury. Physical Therapy 92: 726–733.
National Institute of Neurological Disorders and Stroke 2012 NINDS Ataxias and Cerebellar or Spinocerebellar Degeneration Information Page.
Newstead A, Hinman MR, Tomberlin JA 2005 Reliability of the Berg Balance Scale and balance master limits of stability tests for individuals with brain injury. Journal of Neurological Physical Therapy 29: 18–23.
Newton RA 1989 Recovery of balance abilities in individuals with traumatic brain injury. Paper presented at the American Physical Therapy Association Forum, Nashville, TN.
Norkin CC 2007 Examination of gait. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, pp 320–333. Philadelphia, FA Davis Company.
Oliveira CB, Medeiros IR, Greters MG, Frota NA, Lucato LT, Scaff M, Conforto AB 2011 Abnormal sensory integration affects balance control in hemiparetic patients within the first year after stroke. Clinics (Sao Paulo) 66: 2043–2048.
Ono J, Yamaura A, Kubota M, Okimura Y, Isobe K 2001 Outcome prediction in severe head injury: Analyses of clinical prognostic factors. Journal of Clinical Neuroscience 8: 120–123.
O'Sullivan, SB 2007a Multiple sclerosis. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, pp 801–804. Philadelphia, FA Davis Company.
O'Sullivan SB 2007b Strategies to improve motor function. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, pp 498–516. Philadelphia, FA Davis Company.
O'Sullivan SB 2007c Examination of motor function: Motor control and motor learning. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, pp 234–236. Philadelphia, FA Davis Company.
Riemann BL, Guskiewicz KM 2000 Effects of mild head injury on postural stability as measured through clinical balance testing. Journal of Athletic Training 35: 19–25.
Schmahmann JD, Gardner R, MacMore J, Vangel MG 2009 Development of a brief ataxia rating scale (BARS) based on a modified form of the ICARS. Movement Disorders 24: 1820–1828.
Schmitz TJ 2007a Examination of coordination. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, 5th edn, pp 198–214. Philadelphia, FA Davis Company.
Schmitz TJ 2007b Examination of sensory function. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, pp 141–145. Philadelphia, FA Davis Company.
Schmitz TJ 2007c Locomotor training. In: O'Sullivan SB, Schmitz TJ (eds) Physical rehabilitation, pp 524–535. Philadelphia, FA Davis Company.
Schmitz TJ 2010 Interventions to improve bed mobility and early trunk control. In: O'Sullivan SB, Schmitz TJ (eds) Improving functional outcomes in physical rehabilitation, pp 60–61, 77. Philadelphia, FA Davis.
Shapira M, Chelouche M, Yanai R, Kaner C, Szold A 2001 Tai Chi Chuan practice as a tool for rehabilitation of severe head trauma: 3 case reports. Archives of Physical Medicine and Rehabilitation 82: 1283–1285.
Sheel AW 2004 Physiology of sport rock climbing. British Journal of Sports Medicine 38: 355–359.
Sheel AW, Seddon N, Knight A, McKenzie DC, Warburton, DER 2003 Physiological responses to indoor rock-climbing and their relationship to maximal cycle ergometry. Medicine and Science in Sports and Exercise 35: 1225–1231.
Shumway-Cook A, Woollacott MH 2007 Motor control: Translating research into clinical practice, 3rd edn, pp 387–456. Philadelphia, Lippincott Williams and Wilkins.
Shumway-Cook A, Woollacott MH 2012 Motor control: Translating research into clinical practice, 4th edn, pp 71–126. Philadelphia, Lippincott Williams and Wilkins.
Sibley KM, Straus SE, Inness EL, Salbach NM, Jaglal SB 2011 Balance assessment practices and use of standardized balance measures among Ontario physical therapists. Physical Therapy 91: 1583–1591.
Sliwa JA, Thatcher S, Jet J 1994 Paraneoplastic subacute cerebellar degeneration: Functional improvement and the role of rehabilitation. Archives of Physical Medicine and Rehabilitation 75: 355–357.
Springer BA, Marin R, Cyhan T, Roberts H, Gill NW 2007 Normative values for the unipedal stance test with eyes open and closed. Journal of Geriatric Physical Therapy 30: 8–15.
Steffen T, Seney M 2008 Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism. Physical Therapy 88: 733–746.
Tinetti M, Richman D, Powell L 1990 Falls efficacy as a measure of fear of falling. Journal of Gerontology 45: 239–243.
van Loo MA, Moseley AM, Bosman JM, de Bie RA, Hassett L 2004 Test-re-test reliability of walking speed, step length and step width measurement after traumatic brain injury: A pilot study. Brain Injury 18: 1041–1048.

Vaz DV, Schettino Rde C, Rolla de Castro TR, Teixeira VR, Cavalcanti Furtado SR, de Mello Figueiredo E 2008 Treadmill training for ataxic patients: A single-subject experimental design. Clinical Rehabilitation 22: 234–241.

Vinci P 2003 Gait rehabilitation in a patient affected with Charcot-Marie-Tooth disease associated with pyramidal and cerebellar features and blindness. Archives of Physical Medicine and Rehabilitation 84: 762–765.

Walker WC, Pickett TC 2007 Motor impairment after severe traumatic brain injury: A longitudinal multicenter study. Journal of Rehabilitation Research and Development 44: 975–982.

Willemse-van Son AH, Ribbers GM, Verhagen AP, Stam HJ 2007 Prognostic factors of long-term functioning and productivity after traumatic brain injury: A systematic review of prospective cohort studies. Clinical Rehabilitation 21: 1024–1037.