Case Report

Slacklining Improves Functional Independence, Fatigue and Balance 2 Years Post Severe Traumatic Brain Injury: A Single Case Study

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Abstract

Objective: Individuals with traumatic brain injury (TBI) recover functional independence to varying degrees due to numerous factors. However, plateaued recovery often initiates between 6-12 months. We investigated whether introducing slacklining, a whole-body interactive balance approach, would provide further improvement in a chronic severe-TBI patient.

Methods: A retrospective pragmatic single case-report on a 40-year-old woman two-years post severe-TBI working part-time. Global-functional status had plateaued with ongoing affected balance, left-sided weakness, and fatigue. Slacklining was added to an existing daily multi-disciplinary, self-managed rehabilitation program initially '*ad-hoc'* and self-managed over nine weeks (Phase-1); then formalized therapist-directed over four weeks (Phase-2). The *primary outcome* was global-functional status; *secondary* was the 4-stage 20-step slackline graded-progression, and fatigue; *tertiary* was balance. All outcomes were reported at slacklining initiation (baseline) and Phase-1 and Phase-2 completion.

Findings/ Results: Improvements were found from baseline till Phase-1 completion, and subsequently Phase-2 completion. *Global-functional status* increased 15% in Phase-1 (baseline=22% to completion=37%); and 18% in Phase-2 (completion=55%); *slackline ability* from baseline=step-1 to Phase-1 completion=step-6 then Phase-2 completion=step-10; *balance duration* increased 1.5-fold in Phase-1 and 3-6-fold in Phase-2; and *fatigue* reduced 22% overall baseline=63% to Phase-2=41% (no Phase-1 measure). Balance, confidence, and function were all self-reported as improved from baseline to program completion.

Conclusions: The findings provide evidence for using slacklining to overcome plateaued recovery during rehabilitation of a severe-TBI patient; and imply that supervised programs have greater impact than un-supervised. Further research is required to determine slacklining's efficacy for TBI, and potentially concussion, through dose, frequency, and intensity.

Keywords: Slacklining; Rehabilitation; Traumatic brain injury

1. Introduction

Traumatic brain injury (TBI) is defined as neurological dysfunction or disruption of normal brain function [1], or other evidenced brain pathology from an external force including direct impact or shear force [2]. Severity of TBI is characterized by: an initial Glasgow Coma Scale score below 8/15, post-traumatic amnesia above seven days, and loss of consciousness over 24 hours [3]. In Australia, favorable neurological outcomes at 12 months are achieved in only 49% of severe-TBI patients, compared to 59% with less-severe TBI [4]. Individuals with severe-TBI display a spectrum of deficits including impaired thinking, memory, movement, sensation, emotion, and cognitive changes [5]; and increased fatigue from impaired functional independence, lifestyle demands, and emotional distress [6]. These consequences affect the individual, their family, the immediate community [7], and their support networks [8]. Additionally, cognitive measures of 'reduced information processing speed' affect attention, working memory, and executive function [5]. The cognitive change is strongly associated with poor independence in activities of daily living (ADL) [9] and negatively impacts fatigue, endurance, strength and balance [6]. Rehabilitation for TBI seeks to regain maximum pre-injury ADL and holistic functional independence through physical and psychological therapeutic and preventative approaches [10].

Rehabilitation programs are individualized to integrate the large spectrum of deficits, and delivered over long periods within a multi-disciplinary approach [7]. Importantly, post-rehabilitation improvements for survivors of severe-TBI have demonstrated neuroplastic changes [11] through functional “brain reorganization” within and between cerebral networks related to improved neurocognitive processes [12]. Consequently, some less-favorable neurologic outcomes between 6-18 months post-injury could be related to plateaus in both ADL and functional independence progression [4] that are due to static or varied intensities of the rehabilitation regimen delivery, and an inability to standardize reported progressions for ambulant TBI gait and balance [13]. This infers a response of adaptation to stress and fatigue from the rehabilitation that ensures only maintenance but no additional recovery, thereby affecting a ‘general adaptation syndrome’ [14]. Introducing short bouts of higher neurophysiological demand, like slacklining, could provide the impetus to surpass such plateaus [6]. Slacklining is a complex neuromechanical composite-chain activity, with high neurophysiological demand [15], performed on tightened bands, where whole-body dynamics respond to external environmental changes [16]. Slacklining requires self-developed response strategies for balance-retention through established learning sequences [17]. It innately facilitates muscle recruitment within areas of demand, including the core [18] and lower limb [19], and induces neuroplastic changes [20], effects that may explain some reported improvements in coordination strategies in both injured and healthy individuals [21]. There is growing evidence of slacklining in neurological rehabilitation with positive changes in balance and ADL independence for stroke [22] and confidence in reduced fear of falling for Parkinson’s disease [23]. Despite this use and acceptance in musculoskeletal and neurological rehabilitation, there are no existing reports in TBI rehabilitation. Based on the general adaptation syndrome [24] with “classical” rehabilitation in a chronic TBI patient, slacklining was added at the patient’s direction to existing rehabilitation, initially *ad-hoc* then subsequently formalized, to determine whether it could progress functional independence, fatigue, exercise capacity, and balance.

2. Methods

2.1 Patient

The patient was a 40-year-old woman who sustained a severe-TBI in a road-cycling accident. After 2 years of rehabilitation the patient’s main concerns, as confirmed by assessment were: chronic status of reduced functional independence, reduced exercise capacity, physical, cognitive and neural fatigue, impaired balance, and concurrent psycho-social difficulties (Appendix 1).

2.2 Context

This was a retrospective pragmatic case study to investigate the efficacy of slackline training’s effect on functional independence, exercise capacity, fatigue, and balance. Slacklining was introduced as an adjunct to an existing home-based rehabilitation program after the patient volunteered to trial this approach to improve her plateaued recovery of the preceding 10 months. Slacklining consisted of an initial 9-week unstructured program (Phase-1). Due to self-noted substantial improvements the patient requested and committed to a formalized 4-week therapist directed program (Phase-2), where physiotherapy supervision (author-CPG) included phone/internet-based feedback, instruction and communication. We correspondingly refer to Phase-1 and Phase-2 of slacklining.

Traumatic incident: October 3, 2013

Hospital inpatient: October 3 – December 4, 2013

Outpatient: Rehabilitation

Mid-January 2014 – July 2014 comprising 2 x 1 hour sessions per week Physical Therapy (PT) and musculoskeletal (Msk) rehabilitation; with Occupational Therapy and Speech Pathology being intermittent as required and available approximately once per 6 weeks.

July 2014 – Hydrotherapy, Msk PT (2 sessions per week were added)

August 2014 – Jan 2015: Msk PT (1 session per week); Pilates (2 sessions per week); Independent cardiovascular (CVS) rehab of swim and walk (3 or 4 sessions per week)

Jan 2015–August 30, 2015: Msk PT (1 session per week); Pilates (1 session per week) Independent cardiovascular system (CVS) and prescribed PT and Msk rehab specific exercises

Sept 2015- Dec 2015: Monthly Msk PT; massage plus independent CVS and exercises

Work Status:

September 2014	– 2 hours per day, 2 days per week	Total 4 hours per week
December 2014	– 3 hours per day, 2 days per week	Total 6 hours per week
April 2015	– 4 hours per day, 3 days per week	Total 12 hours per week
May 2015	– 4.5 hours per day, 3 days per week	Total 13.5 hours per week
August 2015	– 6 hours per day, 3 days per week	Total 18 hours per week
September 2015	– variable hours and days per week	Total 24 hours per week

Slacklining: September 20, 2015 – commenced *ad hoc* 9 week program
November 15, 2015 – commenced formal 4 week program

PT = Physiotherapy; Msk = Musculoskeletal; CVS = Cardiovascular

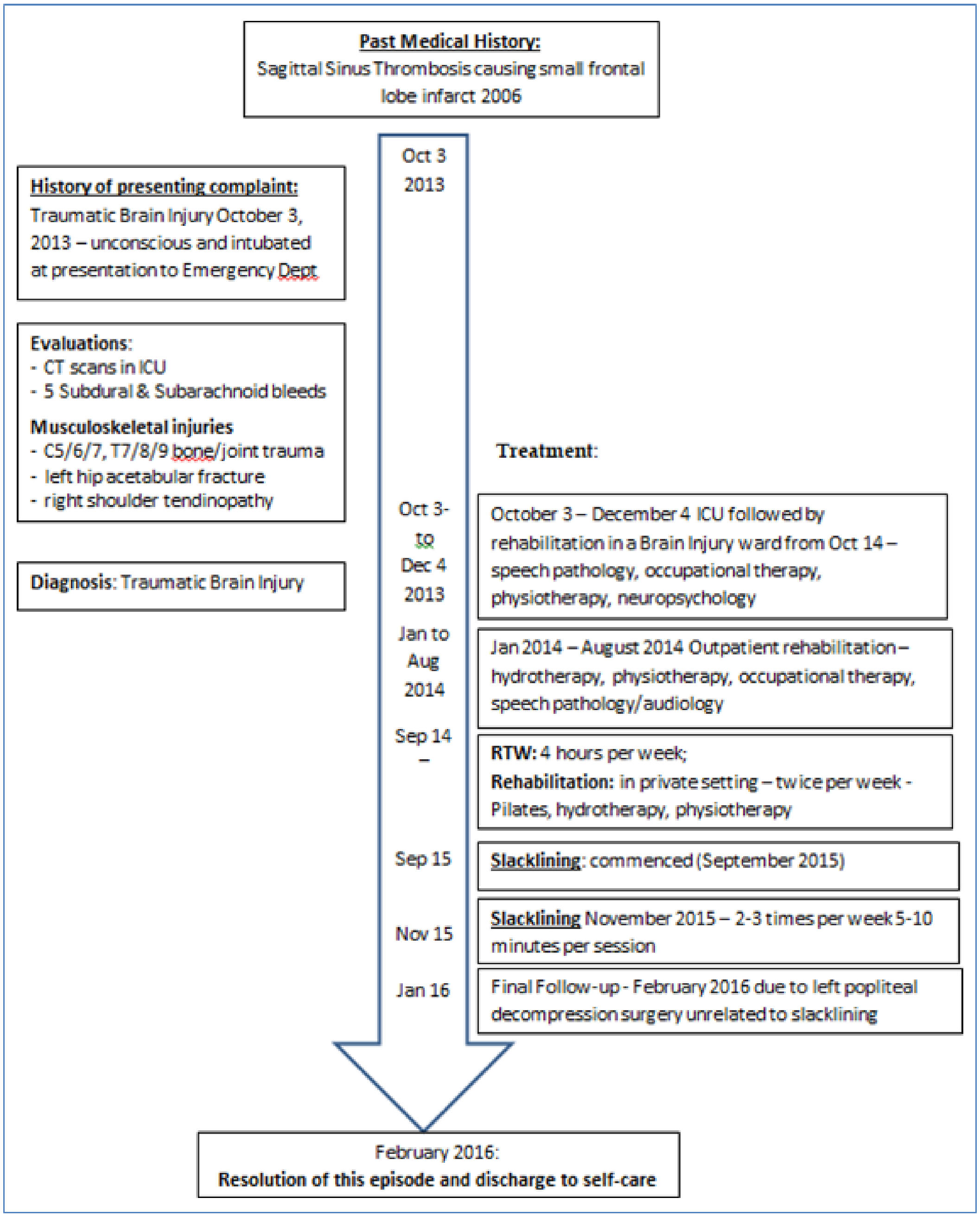
Appendix 1: Synopsis of patient history.

2.3 Approvals and ethics

The patient volunteered, provided informed consent for participation and the de-identified case report publication. This study complied with all institutional policies and Health Insurance Portability and Accountability Act requirements for disclosure of protected health information.

2.4 Interventions

Initial rehabilitation (0-23 months) Post-injury TBI rehabilitation included a 2-month brain-injury rehabilitation-unit stay; outpatient rehabilitation 2-3 times weekly over 16 months; home rehabilitation of exercises and hydrotherapy (see Appendix 2).



Appendix 2: Timeline under 'CARE Guidelines', Two year period from post-injury to completion of Slackline Supplemented Program.

Graded return-to-work commenced 12 months post-injury increasing to 18 hours/week by 24 months without a perceived change in functional independence. Subsequently, work increased to 24 hours/week but hydrotherapy and exercises decreased due to fatigue and poor immunological status. The ‘general adaptation syndrome’ [24] was present by 24-months despite program adherence (6.5 hours/week), as displayed in Figure 1. Weekly rehabilitation included moderate-paced walking over undulating terrain (30 minutes/day), independent hydrotherapy (30 minutes 2/week in reducing depth), balance exercises and individualized clinical-Pilates (120 minutes/week).

Figure 1: History outcome progression chart (ARGS*) attesting the plateau in functional independence between status points 3 and 4.

Visual history over two years with status as a percentage of perceived maximum capacity: Pt#1-4 function improving from 0% (Pt #1when unconscious in ICU) to Pt #2 Hospital Discharge to plateau from 14 months to 23 months. Slacklining was introduced at Pt #4 (status=23%) and used sporadically for nine weeks till a regulated program started at Pt#5 (status=37%) and was measured over the subsequent four weeks (Pt#6=55%). Post-program follow-up with 4 weeks of no slacklining, saw status reduced mildly (Pt#6=55% to Pt#7=52%), this being less than the 5% error suggesting that functional status is retained.

Slacklining (23-26 months): Slacklining was added as a single intervention to prescribed rehabilitation at 23-months post-injury. Phase-1 involved self-directed, unsupervised slacklining, 2-4/weekly for 3-5 minutes. Phase-2 involved following the standardized 4-stage, 20-step protocol [25] with slacklining time increased to 5-10 minutes, 4/weekly, which continued till program completion occurred due to personal commitments (week-13). The patient systematically progressed through 10-steps of Stages 1-beginner and 2-intermediate. Slackline exercises were performed using single and double slacklines (Figure 2) over grass 20cm high, anchored 3.5m apart. At all times immediate close support was provided for safety.

Figure 2: Illustration of slacklining exercises for a TBI Patient

(A) Double line - supine 4-point contact; (B) Double lines - standing 2 feet; (C) Single Line - tandem stance, 2 feet.

2.5 Outcomes

We measured the perceived functional independence using the '*Advise Rehab Global Scale*' (ARGS) [26], and fatigue using the '*modified fatigue impact scale*' (MFIS) [27]; slacklining ability was assessed using the '*slacklining-activity competency phases*' (20-steps over 4-stages) [25]; balance was measured using the '*balance error scoring system*' (BESS) [28] where each test measured maximum errors or time if the designated position was not maintained for the required 20 seconds. All outcomes were administered before beginning slacklining (Pre) then repeated at week-9 (POST1), and week-13 (POST2), with functional independence also measured at week-17, i.e. 1 month post-program completion (POST3).

2.6 Equipment

An off-the-shelf 'Gibbon' 50mmx3.5m slackline attached to trees or poles and torque-ratchet tightened with no gauge to the patient's self-perceived adequate tension to perform the exercises.

2.7 Statistics

Analysis was of Minimal Detectable Change at the 90% confidence interval (MDC_{90}) values for each outcome measures score [25-28]. The minimum scores required to ensure clinically meaningful change were respectively a 5% increase for ARGS [26], 20.2 points decrease for the total score of MFIS [27], 4 to 5 steps increase for slackline-ability [25], and 4 errors decrease for BESS (or returning to the required position in less than 5s since not being able to do so is scored as 10-errors) [28].

3. Results

3.1 Pre-Intervention status

The perceived functional independence using the ARGS scale was unchanged over the preceding year ($ARGS_{pre}$=22%). The $MFIS_{pre}$ total score was 53/84; slackline-ability was Step-1; and BESS time of maintaining 'Double-leg', tandem and single leg stance was respectively 11s, 5s and 5s on a stable surface, but below 5s on an unstable (foam) surface.

3.2 Slackline training

The patient completed all attempted sequences and sessions throughout the program duration.

3.3 POST1 at Phase-1: completion of the *ad-hoc* program (weeks 1-9)

Clinically meaningful change was shown through improvements in: functional independence by 15%, ($ARGS_{POST1}$=37%, i.e. 3xMDC_{90}); slacklining ability from Stage-1 Step-1 to Step-6 (i.e., 1xMDC_{90}). The time for maintaining positions required for the BESS slightly increased, albeit none reached the MDC_{90}. Fatigue was not measured at POST1.

Outcome	Exerciseor subscale	Surface	Eyes	MDC_{90}	Pre (Week 0)	POST1/Phase 1 (Week 1-9)	POST2/Phase-2 (Week 10-13)
ARGS	—	—	—	*+5%*	23%	37%*	55%*
BESS	Double-leg Stance	S	O	18.5 Errors=3 0.8% Total=60 >5sec[2]	11s	15s	47s
		U			2s	3s	19s*
	Tandem Stance	S	O		5s	6s	5s
		U			0s	0s	4s
	Single Left Leg	S	C		5s	6s	10s
		U			1s	2s	2s
MFIS	Physical (max=36)	- -	- -	*-9.9*	32	NA	20*
	Cognitive (max=40)	- -	- -	*-10.6*	14	NA	11
	Psychosocial (max=8)	- -	- -	*-2.3*	7	NA	3*
	Total (max=84)	- -	- -	*-20.2*	53	NA	34

Table 1: ARGS, BESS and MFIS scores before slacklining (Pre), immediately after Phase 1 ad-hoc program (week 1-9, POST1), after Phase 2 of supervised slacklining program (week 10-13 POST2).

Legend and abbreviations: [1] Left side was the non-dominant lower extremity of the patient; [2]MCD_{90} according to King 2014 [28], Table 2 p356; * change above clinically meaningful change; S: Stable, U: Unstable, O: Open, C: Closed. ARGS: Advise Rehab Global System is a 'computerized decision support system' that is a web-hosted, algorithm-based software program used to calculate function as a percentage of perceived normal/pre-injury capacity (0%=complete incapacitation, 100%=normal/pre-injury status) from 18 input fields in 6 separate categories: perceived status, capability, pain, general-function, region-specific function, and patient-specific function; MFIS: *Modified Fatigue Impact Scale* assesses the effects of physical, cognitive, and psychosocial fatigue on general functional status through 21 items from 3 subscales: 9 "physical" items, 10 "cognitive" items, and 2 "psychosocial" items (score 0-84), where higher scores indicate greater impact on quality of life. *Slacklining- ability competency phases:* Quantification of slacklining balance capacity can be made from the sequential 4-stage, 20-step program. A half-stage improvement (3-4 steps) is clinically meaningful progression for both healthy and injured individuals however, statistical validation is not published. The progression stages are defined from 'novice' to 'accomplished' and documented by stage-step achievement in a standardized manner providing an optimal pathway for therapists [25, 34]; BESS: *Balance Error Scoring System* is a standardized test for TBI static postural stability [35] consisting of three *bare-footed* stances (double-leg, single-leg, and tandem-stance) on firm-ground and foam, performed eyes-closed with consistent foot-position on each 20-second trial. Deviations from proper-stance have a 10-error maximum: opening-eyes, lifting hands off hips, stepping, stumbling/falling, lifting forefoot or heel, hip abduction >30°, non-return to start-position >5-seconds [35]. Number of errors in each trial are added together to obtain a total score (out of 60). The BESS is valid for meaningful change in static balance where large differences exist for TBI/concussion/fatigue where >4 is clinically meaningful. Further, being unable to return to the test position in <5 seconds is a 10-error count. Consequently, increasing balance performance to return to the test position in <5 seconds exhibits a clinically meaningful improvement [35].

3.4 POST2 at Phase-2: completion of the formalized program (weeks 9-13)

Clinically meaningful change was found in: functional independence by 19% ($ARGS_{POST2}$=56%); MFIS total score reduced to 34/84 where Physical and Psychosocial subscales both exceeded the MDC_{90} [31]. The time for maintaining 'Double-leg stance scale-Firm and Foam' required for the BESS improved up to 47s and 19s respectively, which exceeded the $MDC_{90,}$ (Table 1). Slacklining ability increased from Stage-2 Step-1 to Stage-2 Step-4, which exceeded the MDC_{90}.

3.5 Follow-up: 1 month post program (week 17)

Only the functional independence was measured 4 weeks after program completion, where $ARGS_{POST3}$=52%, representing a 3% decrease from POST2, which is below the MCD_{90}.

4. Discussion

This is the first case-report of slackline use by a patient with chronic and severe-TBI exhibiting a 'general adaptation syndrome' [24] as shown by the plateau in functional independence. Slacklining was used safely with no adverse effects. The response to slacklining's addition to the existing rehabilitation program showed measurable and clinically important effects on functional independence, fatigue, slackline-ability and balance. This evidence suggested efficacy for slacklining as an adjunct self-managed therapy with a large effect for a small dose/time ratio dedicated to this training. The pre-existing rehabilitation program (6.5 hours or ~390 minutes/week) maintained status and prevented regression, while the addition of 10-20 minutes/week (average ~15 minutes) of slacklining in Phase-1, and 20-40 minutes/week (average ~30 minutes) in Phase-2 produced significant objectively measurable improvements, a clinically meaningful change. The results are consistent with evidence showing that higher intensity rehabilitation gave a better result than simply an increase in time in individuals with stroke [22] and Parkinson's Disease [23]. In this case study, slacklining represented an intervention of higher intensity compared to usual rehabilitation which may explain the reported improvements resulting in “breaking” the ‘*general adaptation syndrome*’.

In detail, the most notable improvement was related to functional independence, which was maintained at follow-up. This result emphasizes the potential promising and durable effect of slackline training. This improvement could be related to fatigue reduction and muscle activation in response to the slackline training. The training exposed the individual to multi-faceted fatigue including the physical, mental, psychosocial, and neurological components [13, 32]. These findings are consistent with previous reported literature that showed slacklining can yield improvements in muscle recruitment, balance and ADL. During slacklining, the individual remains in a state of equilibrium whilst being exposed to high demands [16]. Although the cognitive fatigue decreased after the slacklining program, the change did not reach a clinically important level. This seems to indicate that slacklining, essentially a physical training modality, has a moderate effect on cognitive fatigue of TBI patients. Further explanation is speculative and requires additional investigations.

Slacklining creates an environment with a required sense of survival due to the risk of or desire not to fall, that maximally challenges balance, equilibrium, and stability. The observations from this case study suggest improved balance time during double-leg stance but not during tandem or single-leg stance [28]. Because the patient already had very low balance performance, as shown by the inability to maintain the single-leg testing position for the required 20s during BESS administration, the slackline training performed on both single and dual slacklines was not always transferable to the single leg position in a meaningful manner. This outcome supports previous research [16, 33] that indicated the specificity of slackline training where acquired learned postural adaptations through enhanced coordination and neural facilitation [18] do not always enhance other ADL. Consequently, the individual establishes a new and progressively adapting equilibrium between their acquired deficits and their cognitive function [5] which is achieved from improved balance and core control [34]. Through integrating slacklining within a rehabilitation program, TBI patients may be able to induce neuroplastic change [33] that could in turn facilitate muscular activation and control. These factors require evaluation in controlled clinical trials. This TBI case report demonstrates that slacklining, as part of a rehabilitation program, is safe and may initiate positive changes in functional independence outcomes.

The limitations of this case report include the absence of complete assessment at follow-up due to an unrelated surgical procedure. This prevented the ability to address whether a ceiling effect has been reached, i.e. whether 4, 9 or 13 weeks of training could be recommended as a specific intervention training period for future investigations. We cannot completely explain the effect of slacklining in part because of the limited number of outcome measures and the outcomes choices themselves and that these are not standardized, or because of the retrospective design that has resulted in a lack of completeness in the measures taken. However, the findings are promising as they are the first to report the positive influence of slacklining specifically for TBI rehabilitation. Future prospective studies require a higher level of methodological quality and should include larger samples to confirm any improvements in self-reported functional independence, fatigue, specific exercise ability, and balance. Future research should use a standardized training content to investigate whether single, dual or a combination of strands in slackline training could enhance further improvements. Researchers should also consider the use of other balance measures in order to completely investigate the effects of slacklining in relation to the different levels of TBI severity. These measures could include posturography, standardized measures of functional independence and also strength, somesthesia, walking ability, and quality of life. Finally, neuro-imaging investigation could be valuable for documenting brain activity changes in response to slacklining as TBI patients may demonstrate quantifiable measures of induced neuroplastic change [33] that could in turn facilitate muscular activation and control.

5. Conclusion

This is the first reported case showing the potential of adding slacklining to an existing TBI rehabilitation program to overcome a documented recovery plateau. Slacklining is a cost-effective, safe, and promising technique that could be easily added to classical TBI-rehabilitation. Further research is required using high methodological quality studies to determine slacklining's efficacy for TBI, and potentially concussion, by including dose, frequency, and intensity factors [35] in order to validate demonstrated TBI-patient change.

Documentation

Protocol

The protocol used in this study can be accessed through the published stages of slacklining progression for both health and injured individuals [25, 29].

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Conflict of Interest

Dr CP Gabel is the Research Director of 'Advise Rehab' and was a contributor to the development of the 'Advise Rehab' software and 'ARGS' scoring system that measures functional status in this case study. This company is a holding company that retains the intellectual property of the system. Dr Gabel receives no salary or income from the Company as it does not run at a profit but for the provision of the software at cost to users.

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