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Research

Ballistic resistance training has a similar or better effect on mobility than non-ballistic exercise rehabilitation in people with a traumatic brain injury: a randomised trial

Gavin Williams [a,b], Leanne Hassett [c,d], Ross Clark [e], Adam L Bryant [b], Meg E Morris [f], John Olver [g], Louise Ada [c]

[a]Physiotherapy Department, Epworth Healthcare, Melbourne, Australia; [b]School of Physiotherapy, Faulty of Medicine, Dentistry and Health Sciences, The University of Melbourne, Melbourne, Australia; [c]Sydney School of Health Sciences, Faculty of Medicine and Health, The University of Sydney, Sydney, Australia; [d]Institute for Musculoskeletal Health, The University of Sydney, Sydney Local Health District, Sydney, Australia; [e]School of Health and Behavioural Sciences, University of the Sunshine Coast, Sippy Downs, Australia; [f]The Victorian Rehabilitation Centre Healthscope & Academic and Research Collaborative in Health (ARCH), La Trobe University, Melbourne, Australia; [g]Rehabilitation Medicine, Epworth Healthcare, Melbourne, Australia

KEYWORDS

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ABSTRACT

Questions: In people recovering from traumatic brain injury, is a 3-month ballistic resistance training program targeting three lower limb muscle groups more effective than non-ballistic exercise rehabilitation for improving mobility, strength and balance? Does improved mobility translate to better health-related quality of life? **Design**: A prospective, multicentre, randomised trial with concealed allocation, intention-to-treat analysis and blinded measurement. **Participants**: A total of 144 people with a neurological movement disorder affecting mobility as a result of traumatic brain injury. **Intervention**: For 3 months, the experimental group had three 60-minute sessions of non-ballistic exercise rehabilitation per week replaced by ballistic resistance training. The control group had non-ballistic exercise rehabilitation of equivalent time. The non-ballistic exercise rehabilitation consisted of balance exercises, lower limb stretching, conventional strengthening exercises, cardiovascular fitness training and gait training. **Outcome measures**: The primary outcome was mobility measured using the High-Level Mobility Assessment Tool (HiMAT). Secondary outcomes were walking speed, strength, balance and quality of life. They were measured at baseline (0 months), after completion of the 3-month intervention (3 months) and 3 months after cessation of intervention (6 months). **Results**: After 3 months of ballistic resistance training, the experimental group scored 3 points (95% CI 0 to 6) higher on the 54-point HiMAT than the control group and remained 3 points (95% CI –1 to 6) higher at 6 months. Although there was a transient decrement in balance at 3 months in the experimental group, the interventions had similar effects on all secondary outcomes by 6 months. Participants with a baseline HiMAT < 27 gained greater benefit from ballistic training: 6 points (1 to 10) on the HiMAT. **Conclusion**: This randomised trial shows that ballistic resistance training has a similar or better effect on mobility than non-ballistic training in people with traumatic brain injury. It may be better targeted towards those with more severe mobility limitations. **Trial registration**: ACTRN12611001098921. **[Williams G, Hassett L, Clark R, Bryant AL, Morris ME, Olver J, Ada L (2022) Ballistic resistance training has a similar or better effect on mobility than non-ballistic exercise rehabilitation in people with a traumatic brain injury: a randomised trial. *Journal of Physiotherapy* ■:■–■]**

Introduction

Traumatic brain injury (TBI) is the leading cause of death and disability in adolescents and adults aged up to 45 years.[1] The incidence of TBI in Australia is 300 per 100,000.[1] Mobility limitations are common in people with moderate to severe TBI.[2,3] Reduced walking speed and endurance can restrict the ability to perform everyday activities, access the community, cross roads or keep up with peers. Higher level mobility skills, such as the ability to run and jump, are important for many social, leisure and sporting activities, yet approximately 75% of people with moderate to severe TBI do not resume their pre-morbid activities.[2] Mobility limitations can have pervasive and extensive physiological and psychological sequelae, and are associated with reduced cardiovascular fitness, increased susceptibility to fatigue and reduced ability to exercise aerobically after TBI,[4–6] as well as poor emotional health.[7,8]

Despite the prevalence and severity of motor impairments such as poor balance and spasticity, the main contributor to mobility

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limitations following TBI is low muscle power generation from paretic muscles.[9–11] Many clinical trials have shown strength training to be effective for improving muscle strength for people with neurological conditions, yet these improvements have often failed to translate into improved mobility.[12,13] They appear to have failed for two main reasons: exercises were performed slowly with low power production,[12] and most exercises did not target the three main muscle groups (ie, ankle plantarflexors, hip flexors and hip extensors) that provide the majority of power generation for forward propulsion.[12,14,15] The American College of Sports Medicine publishes guidelines for resistance training,[16] which highlight the importance of exercise specificity. Past failures of clinical trials in neurological cohorts to improve walking have led to the development of a new biomechanics-driven framework for resistance training,[17] which aims to implement resistance exercises that replicate muscle function for walking.

Muscle strength reflects the maximum amount of force a muscle can produce, whereas muscle power reflects how quickly force can be generated, or the 'rate of force production'. Ballistic, or fast, resistance exercises are used to improve muscle power generation,[16] yet are relatively novel in neurological rehabilitation.[18] Ballistic resistance exercises are feasible for people with TBI to improve power generation for mobility;[19,20] they are important as they train muscles to contract quickly, which is required for walking[21] and higher levels of mobility such as stair climbing and running. In people with neurological conditions, ballistic resistance training is safe and feasible,[18] and associated with a 60 to 74% increase in peak power generation.[19] Further, ballistic exercises can improve lower-limb power generation during walking and, in some cases, can reverse compensatory patterns that may develop during the early recovery phase.[22] Most importantly, improved mobility is associated with greater health-related quality of life in TBI,[23] and improved physical outcomes have been identified as an international research priority.[24]

Therefore, the research questions for this prospective, multicentre, randomised trial were:

In people recovering from TBI,

1) is a 3-month ballistic resistance training program more effective than non-ballistic exercise rehabilitation for improving mobility, leg strength and balance?
2) does improved mobility translate to better health-related quality of life?

Methods

Design

A prospective, multicentre, randomised, single blind trial of a 3-month exercise program was conducted during the early phase of rehabilitation following TBI (Figure 1). The trial protocol was registered (Australian New Zealand Clinical Trials Registry ACTRN12611001098921), published,[25] conformed to the CONSORT guidelines[26] (Appendix 1 on the eAddenda) for reporting clinical trials and the CONSERVE statement for reporting trials affected by coronavirus (COVID-19),[27] and was reported using the template for intervention description and replication (TIDieR) checklist (Appendix 2 on the eAddenda).[28] People with TBI were recruited from brain injury units in Victoria, New South Wales and South Australia in Australia. Participants were randomised to the experimental or control group via a randomisation schedule that was prepared by the trial biostatistician who was not involved in recruitment or measurement. Allocation was stratified according to site and level of disability such that participants scoring $\geq$ 27 on the High-level Mobility Assessment Tool (HiMAT) were classified as moderate, and those scoring $<$ 27 were classified as severe. Random permuted blocks were used so that after every block, the two groups contained approximately equal numbers of each level of disability. Group allocation was concealed using consecutively numbered, opaque envelopes, which were opened after completion of the baseline measurement by the therapist delivering the intervention. Due to the nature of the intervention the participants and the therapist delivering the intervention could not be blinded to the participants' group allocation.

For 3 months, participants in the experimental group had three of their 60-minute sessions of usual physiotherapy intervention replaced by three 60-minute sessions of ballistic resistance training per week (including ballistic resistance and gait training), while the control group had three of their 60-minute sessions of usual physiotherapy intervention standardised (including conventional strength, balance, stretch, cardiovascular fitness and gait training) so that all participants had equivalent overall therapy time. The acute recovery phase following TBI is longer than in other areas of neurological rehabilitation, partly due to cognitive deficits affecting learning. However, prior research has shown that a 3-month intervention is sufficient to detect gains in mobility in people who have sustained a TBI within the last 12 months.[29] The therapists were dedicated trial therapists for both groups and the timing of sessions was organised so that participants were unaware of who the other participants were and what their intervention was. An independent clinician trained in collecting outcome measures and blinded to the group allocations measured outcomes at baseline (0 months), after completion of the 3-month intervention (3 months), and 3 months after cessation of intervention (6 months).

Participants, therapists, centres

To be eligible to participate in the study, patients were required to have a neurologically based movement disorder affecting mobility as a result of TBI (TBI severity determined by duration of post-traumatic amnesia measured prospectively using the Westmead post-traumatic amnesia scale[30]). The other inclusion and exclusion criteria are detailed in Box 1.

Information such as age, sex, height, weight, severity of injury (length of time of post-traumatic amnesia), time since injury and orthopaedic injuries was collected to describe the sample.

Therapists delivering the intervention were included if they were physiotherapists or exercise physiologists with a minimum of 3 years of experience working in TBI and neurological rehabilitation.

Dedicated brain injury units were included if they had $\geq$ 50 patients with TBI admitted acutely per year.

Intervention

The experimental group received ballistic resistance training (Appendix 3 on the eAddenda) that was performed according to the American College of Sports Medicine guidelines governing frequency, duration, intensity and progression to ensure an optimal training stimulus and transfer of training gains.[16] The muscle groups targeted for power generation were the ankle plantarflexors, hip flexors and hip extensors, and the muscle groups targeted for power absorption were the knee extensors. Ballistic resistance training was tailored to the severity of strength deficits with initial loads being low to facilitate high contraction velocities. When participants could consistently perform the high velocity exercises, the load was progressively increased.[16] The exercises included: leg extension jumps on a 'leg sled'; calf raises on a 'leg sled'; stair ascent and descent; reciprocal leg extension on a mini-trampoline; and fast cyclical hip and knee flexion in standing.[25]

The control group received balance exercises, lower limb stretching, conventional strengthening exercises, cardiovascular fitness training and gait training.[6,8,31] The exercises included: static balance exercises (single limb or tandem stance); dynamic balance exercises (figure of eight or heel-to-toe walk); stretching of major muscle groups; conventional strengthening exercises on a leg press or quadriceps curl focusing on high resistance and slow force production; and cardiovascular fitness training using an exercise bike or arm ergometer.

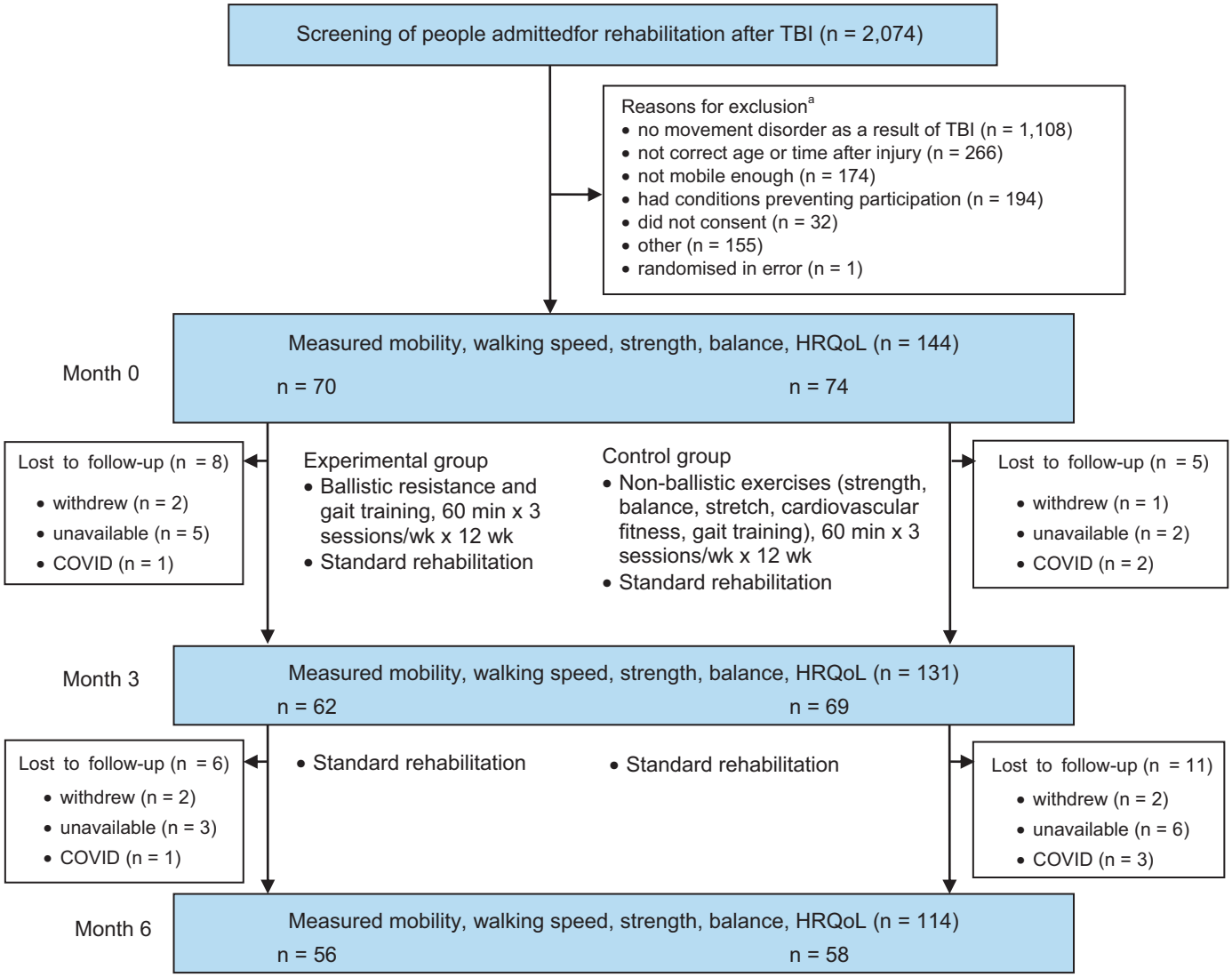

Figure 1. Design and flow of participants through the trial.
[a] Participants could be excluded for more than one reason.
COVID = coronavirus, HRQoL = health-related quality of life, TBI = traumatic brain injury.

Box 1. Eligibility criteria for participants.

Patients with TBI were included if they:

- had a neurologically based movement disorder affecting mobility as a result of TBI
- out of post-traumatic amnesia
- were aged 15 to 65 years
- were < 12 months post-injury
- could fully weight bear and walk independently (without assistance from an aid or therapist) for 10 m
- had a mobility limitation (scored < 50 for males, < 44 for females on the HiMAT)

Patients were excluded if they:

- or their proxy, were unwilling or unable to provide informed consent
- had a previously diagnosed central nervous system disorder
- had severe cognitive or behavioural problems that prevented participation
- had orthopaedic conditions (eg, osteoarthritis) or injuries restricting mobility.

HiMAT = High-level Mobility Assessment Tool, TBI = traumatic brain injury.

Both groups received up to 10 minutes of gait training each session focusing on: the quality of walking; walking outdoors and over uneven surfaces; and road crossing for community access.

Dedicated trial therapists received training in delivery of the experimental and control interventions to ensure consistency. Independent annual inspections were conducted at each facility to ensure the fidelity of the intervention. The content of sessions for both groups was recorded so that adherence to the protocol could be reported.

Outcome measures

Primary outcome

The primary outcome was mobility measured using the HiMAT.[32,33] It consists of 13 mobility items such as walking, stair use, running, skipping, hopping and jumping. The HiMAT was selected as the primary outcome measure because people with TBI are typically younger than people with other neurological health conditions and therefore require higher levels of mobility to participate fully in their community. Each item is measured using either a stopwatch or tape measure and scored and summed for a total HiMAT score (0 to 54), where higher scores indicate better performance. The HiMAT has been validated for use in TBI, with a 4-point improvement being considered clinically worthwhile.[33]

Table 1
Characteristics of participants and centres at baseline.

Characteristic	All (n = 144)	Randomised (n = 144)		Lost to month 3 follow-up (n = 13)		Lost to month 6 follow-up (n = 30)	
		Exp (n = 70)	Con (n = 74)	Exp (n = 8)	Con (n = 5)	Exp (n = 14)	Con (n = 16)
Participants							
Age *(yr)*, mean (SD)	34 (14)	34 (14)	34 (14)	33 (17)	38 (18)	31 (14)	33 (16)
Sex, n males (%)	112 (78)	54 (77)	58 (78)	6 (75)	3 (60)	12 (86)	11 (69)
Height (*m*), mean (SD)	1.77 (0.09)	1.77 (0.09)	1.77 (0.09)	1.71 (0.09)	1.80 (0.13)	1.73 (0.08)	1.76 (0.09)
Weight (*kg*), mean (SD)	76 (14)	75 (16)	77 (12)	70 (19)	69 (9)	73 (17)	73 (10)
Time since trauma (*days*), mean (SD)	115 (76)	114 (76)	116 (77)	88 (24)	81 (36)	117 (93)	103 (77)
Time in PTA (*days*), mean (SD)	59 (40)	61 (41) (n = 68)	57 (40) (n = 73)	48 (23)	45 (39)	61 (39)	53 (53) (n = 15)
Lower-limb orthopaedic injuries, n (%)							
0 fractures	122 (85)	58 (83)	64 (86)	7 (88)	4 (80)	12 (81)	13 (81)
1 fracture	16 (11)	10 (14)	6 (8)	1 (12)	1 (20)	2 (14)	2 (13)
2 fractures	6 (4)	2 (3)	4 (5)	0 (0)	0 (0)	0 (0)	1 (6)
Glasgow Coma Scale *(1 to 15)*, mean (SD)	6 (4)	6 (4)	6 (4)	5 (2)	7 (5)	6 (3)	7 (4)
Affected side, n right (%)	64 (44)	30 (43)	34 (46)	3 (38)	2 (40)	6 (43)	6 (38)
Centres, n participants (%)							
A	91 (63)	45 (64)	46 (62)	5 (63)	2 (40)	8 (57)	7 (44)
B	16 (11)	7 (10)	9 (12)	1 (13)	0 (0)	1 (7)	2 (13)
C	25 (17)	12 (17)	13 (18)	2 (25)	2 (40)	4 (29)	5 (31)
D	1 (1)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
E	11 (8)	5 (7)	6 (8)	0 (0)	1 (20)	1 (7)	2 (13)

PTA = post-traumatic amnesia.

Secondary outcomes

Self-selected walking speed was measured using the 10-m walk test and reported in metres per second.

Muscle strength was measured with a six-repetition maximum seated single leg press performed on the participant's more-affected leg and reported in kilograms.

Balance was measured with the Single Leg Stance test for each leg with eyes open and eyes closed, and the average of the four conditions reported in seconds (maximum 30 seconds).

Health-related quality of life was measured with the Assessment of Quality of Life (AQOL-6D) and reported as a score from –0.04 to 1.00, with higher scores indicating better quality of life. It consists of 20 questions across six domains (independent living, social, mental health, coping, pain and sensory perception). It has been validated in an Australian sample of people with TBI, and has been used to demonstrate that improved mobility is associated with better quality of life following TBI.[23] An adolescent version was used for participants aged $<$ 18 years.

Data analysis

Sample size calculations were based on data obtained from two studies where the HiMAT was the primary outcome measure.[10,29] These data were from TBI populations similar to the current sample. The planned sample size of 66 patients per group (ie, 132 in total) was based on an analysis of covariance (ANCOVA) primary endpoint analysis. This sample size allowed reporting of a clinically worthwhile difference in HiMAT scores ($\geq$ 4 points out of 54) at the 5% level (two-tailed), with a power of 90%. Allowing for a drop-out rate of 20% equated to 83 per group (ie, a total sample size of 166).

The endpoint was 6 months after admission to the study. ANCOVA was used to estimate group differences at 3 and 6 months. The analysis was adjusted for baseline HiMAT score, patient age, sex and severity of injury (length of time of post-traumatic amnesia). The three missing post-traumatic amnesia scores were replaced with the group mean. The primary analysis was intention-to-treat. Given that there was a high delivery of the intervention, the planned per protocol analysis was not undertaken but the analysis according to initial mobility (ie, baseline $<$ 27 or $\geq$ 27 on HiMAT) was undertaken. Statistical analysis[a] was carried out by an independent statistician.

Results

Flow of participants through the trial

A total of 144 people with TBI were recruited from five rehabilitation centres across Australia. Participants in the experimental and control groups were similar in terms of age, sex, height/weight, affected side, orthopaedic injuries, time in post-traumatic amnesia and Glasgow Coma Scale scores (Table 1). By month 3, 13 participants (9%) were lost to follow-up and by month 6, 30 participants (21%) were lost to follow-up (Figure 1). The reasons for loss to follow-up were: unavailability due to returning to a regional area (n = 16), COVID restrictions (n = 7) and withdrawal or refusal (n = 7). The primary outcome was collected from 100% of the retained participants at month 3 and month 6.

Eight therapists delivered the intervention (mean 28 participants, SD 8): they had on average 6 years of clinical experience (SD 2) and four (50%) had postgraduate qualifications.

Compliance with trial method

For the participants who were analysed at 3 months, the mean number of sessions delivered was 31 (SD 3) out of a possible 36 (ie, 86%) and this was similar between the experimental group (mean 30, SD 2) and the control group (mean 32, SD 4). The mean session time was 43 minutes (SD 8). A total of 191 sessions were missed due to COVID, and recruitment was placed on hold for extended periods at three sites. Participants in the experimental group spent an average of 41 minutes exercising per 60-minute session (total time 2,878 minutes) compared with 45 minutes for the control group (total time 3,252 minutes). There were two study-related adverse events in the experimental group; both were non-injurious falls that did not prevent the participant from continuing the session. The secondary outcome measure–muscle power generation–was not measured in this trial as originally intended. A preliminary study used a string potentiometer as a surrogate measure of muscle power generation.[19] Further testing of this method demonstrated that it was not a valid measure of muscle power in a clinical setting, which meant that this secondary outcome measure had to be removed from the protocol. Examination of protocol adherence did not find any other protocol breaches.

Table 2
Mean (SD) of groups, mean (95% CI) difference within groups, and mean (95% CI) difference between groups (intention-to-treat analysis).

Outcome	Groups						Difference within groups				Difference between groups[a]	
	Month 0		Month 3		Month 6		Month 3 minus Month 0		Month 6 minus Month 0		Month 3 minus Month 0	Month 6 minus Month 0
	Exp (n = 70)	Con (n = 74)	Exp (n = 62)	Con (n = 69)	Exp (n = 56)	Con (n = 58)	Exp	Con	Exp	Con	Exp minus Con	Exp minus Con
Mobility HiMAT *(0 to 54)*	19 (12)	18 (12)	30 (13)	25 (15)	32 (14)	28 (15)	11 (9)	8 (9)	14 (11)	11 (10)	3 (0 to 6)	3 (−1 to 6)
Walking speed 10-m walk test *(m/s)*	1.06 (0.41)	0.98 (0.41)	1.34 (0.35)	1.24 (0.42)	1.39 (0.35)	1.31 (0.43)	0.27 (0.34)	0.28 (0.29)	0.34 (0.36)	0.35 (0.33)	0.01 (−0.10 to 0.11)	−0.01 (−0.13 to 0.11)
Muscle strength 6RM seated leg press *(kg)*	33 (20)	37 (22)	50 (24) (n = 60)	59 (35) (n = 68)	55 (32) (n = 51)	63 (33)	19 (18)	22 (24)	25 (24)	24 (24)	−3 (−11 to 4)	0 (−9 to 9)
Balance Single Leg Stance Test *(s)*	9.1 (6.7)	7.1 (6.2)	12.2 (7.6)	11.7 (7.7)	12.9 (7.0)	11.7 (7.9)	3.0 (4.2)	5.0 (5.5)	3.8 (4.8)	5.0 (6.3)	−1.9 (−3.6 to −0.3)	−1.0 (−3.0 to 0.9)
HRQoL AQOL-6D *(−0.04 to 1.00)*	0.46 (0.11) (n = 64)	0.46 (0.11) (n = 67)	0.39 (0.11) (n = 58)	0.42 (0.10) (n = 64)	0.40 (0.14) (n = 54)	0.41 (0.11) (n = 54)	−0.07 (0.09) (n = 58)	−0.04 (0.10) (n = 63)	−0.06 (0.11) (n = 53)	−0.06 (0.11) (n = 53)	−0.03 (−0.06 to 0.01)	−0.01 (−0.04 to 0.04)

AQOL-6D = Assessment of Quality of Life, Con = control group, Exp = experimental group, HiMAT = High-level Mobility Assessment Tool, HRQoL = health-related quality of life, 6RM = six-repetition maximum.
[a] ANCOVA adjusted for baseline HiMAT score, age, sex and length of time in post-traumatic amnesia.

Effect of intervention

In terms of mobility, the experimental group scored 3 points (95% CI 0 to 6) higher on the HiMAT than the control group (Table 2) after 3 months of ballistic resistance training. By 6 months, they scored 3 points (95% CI −1 to 6) higher than the control group.

For walking speed, the groups had similar results. At 3 months, the experimental group walked 0.01 m/s (95% CI −0.10 to 0.11) faster than the control group. By 6 months, they were 0.01 m/s (95% CI −0.11 to 0.14) slower than the control group.

For muscle strength, the groups had similar results. The experimental group was 3 kg (95% CI −4 to 11) weaker than the control group at 3 months and they were equivalent (95% CI −9 to 9) by 6 months.

In terms of balance, the experimental group could stand on one leg for 1.9 s (95% CI 0.3 to 3.6) less than the control group at 3 months; however, the groups were again similar by 6 months, when the experimental group could stand on one leg for 1.0 s (95% CI −0.9 to 3.0) less.

For health-related quality of life, the groups had similar results. At 3 months, the experimental group scored 0.03 points (95% CI −0.01 to 0.06) lower on the AQOL-6D than the control group. By 6 months, they scored 0.01 points (95% CI −0.04 to 0.04) lower than the control group.

Subgroup analysis

At 3 months, ballistic resistance training produced an extra 6 points (95% CI 1 to 10) on the 54-point HiMAT in the subgroup of participants with a baseline HiMAT < 27 (Table 3).

For all outcomes, individual participant data are presented in Table 4 on the eAddenda.

Discussion

This randomised trial found that replacing three sessions per week of non-ballistic exercise rehabilitation with ballistic resistance training resulted in similar or better mobility. This was largely maintained at 6 months. The two types of exercise rehabilitation had similar effects on the secondary outcome measures. An exploratory subgroup analysis found the use of ballistic resistance training led to even greater improvements in mobility among those with more severe disability.

Although the 3 months of ballistic resistance training resulted in better mobility than non-ballistic exercise rehabilitation, it was not as a consequence of faster walking. The increase in HiMAT scores reflected an increase in the ability to perform tasks that involve a flight phase (ie, running, skipping, hopping and jumping). In addition, there was no important between-group difference in strength, probably because strength was measured as force production rather than power generation, which was trained in the experimental group. There was a transient observation at 3 months, where the control group had better balance than the experimental group and this may have been because balance training was included in their intervention, which reflected usual physiotherapy intervention. By 6 months, the between-group difference had weakened to only 1 second, with enough uncertainty that it became unclear whether any effect is sustained.

The participants in this trial had extremely severe traumatic brain injuries.[30] They were 4 months post injury and had spent around two of those months in post-traumatic amnesia. Their Glasgow Coma Scale score was on average 6, which is considered to be a very severe brain injury. They were mostly male, in their mid-30s and although they walked at about two-thirds of normal speed, their balance was poor. Nevertheless, both groups made marked gains over the 6 months of the trial, with walking speed and strength increasing to normal levels, although balance remained fairly poor. However, quality of life did not change over this time; this may be because the participants, who were primarily recruited as hospital inpatients, were subsequently faced with restrictions to societal participation

Table 3
Post-hoc subgroup analysis of low scorers (< 27 on HIMAT) versus high scorers (≥ 27 on HiMAT) for 3-month mobility.

Outcome	Groups				Between-group difference within subgroups[a]	
	Subgroup < 27		Subgroup ≥ 27		Subgroup < 27	Subgroup ≥ 27
	Exp (n = 55)	Con (n = 58)	Exp (n = 16)	Con (n = 15)	Exp minus Con	Exp minus Con
Mobility at 3 months HiMAT *(0 to 54)*	25 (12) (n = 46)	21 (13) (n = 56)	42 (9) (n = 16)	44 (9) (n = 13)	6 (1 to 10) (n = 102)	0 (−7 to 6) (n = 29)

Con = control group, Exp = experimental group, HiMAT = High-level Mobility Assessment Tool.
[a] Linear regression model adjusted for baseline HiMAT score, age, sex and length of time in post-traumatic amnesia.

once they had been discharged from hospital. In general, higher levels of mobility are associated with greater societal participation and quality of life after traumatic injury.[23] However, transitioning home in the subacute rehabilitative phase is a time of considerable adjustment and likely to have impacted quality of life.

The improvement in mobility is in line with an earlier study of ballistic resistance training in stroke.[34] The differential benefit for those with lower mobility at baseline is an unusual finding in neurological mobility studies, where the trend is for the more mobile to benefit more from clinical interventions.[35,36] However, the more mobile participants in studies of stroke are comparable with the less mobile people with TBI in this current study. Taken together, it appears that people walking > 0.5 m/s but scoring < 27 on the HiMAT may be most likely to benefit from ballistic resistance training.

This randomised trial had both strengths and weaknesses. Its main strengths were that it was fully powered, the groups were similar in baseline characteristics, there was concealed allocation to groups, measurers were blinded to group allocation, and an intention-to-treat analysis was performed. Furthermore, most of the intervention was delivered despite the disruptions caused by the COVID-19 pandemic. However, there was no blinding of participants or therapists, which is difficult in complex physiotherapy interventions. Furthermore, there was > 20% loss to follow-up at 6 months, so these results need to be interpreted with caution.

The main clinical implications of this study are two-fold. First, specific resistance training,[16,17] which requires exercises to be prescribed in a way that replicates how muscles function (ie, is fast or ballistic), has a similar or better effect on mobility than non-ballistic exercise rehabilitation in people recovering from TBI. Second, the exploratory subgroup analysis indicates that it may be beneficial to target those who can walk independently yet still score < 27 on the HiMAT.

In conclusion, this randomised trial suggests that ballistic resistance training has a similar or better effect on mobility than non-ballistic exercise rehabilitation in people following TBI and may be particularly helpful for individuals with more severe mobility limitations, but not at the expense of balance training.

What was already known on this topic: Mobility limitations are common in people with a traumatic brain injury. Although poor balance and spasticity are common, the main contributor to mobility limitations after traumatic brain injury is low muscle power generation.
What this study adds: Ballistic resistance training has a similar or better effect on mobility than non-ballistic exercise rehabilitation in people with a traumatic brain injury. Using ballistic resistance training in place of some non-ballistic exercise rehabilitation seems particularly useful among those with low baseline mobility.

Footnotes: [a]Stata Statistical Package v17, StataCorp, College Station, TX, USA.

eAddenda: Appendices 1 to 3, Table 4 available at https://doi.org/10.1016/j.jphys.2022.09.004

Ethics approval: Human Research Ethics Committee, Epworth Healthcare, Melbourne, Australia (53211) and Alfred Health Human Research and Ethics Committee (project number: 144/16). Data were collected after informed consent was gained.

Competing interests: Nil.

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Correspondence: Gavin Williams, Physiotherapy Department, Epworth Healthcare, Australia. Email: gavin.williams@epworth.org.au

References

1. O'Connor P. Hospitalisation due to traumatic brain injury (TBI), Australia 1997-98. In: *Injury Research & Statistics*. Adelaide: Australian Institute of Health and Welfare; 2002.
2. Ponsford JL, Olver JH, Curran C. A profile of outcome: 2 years after traumatic brain injury. *Brain Inj*. 1995;9:1–10.
3. Olver JH, Ponsford JL, Curran CA. Outcome following traumatic brain injury: a comparison between 2 and 5 years after injury. *Brain Inj*. 1996;10:841–848.
4. Hassett L, Moseley A, Harmer A. The Aetiology of Reduced Cardiorespiratory Fitness Among Adults with Severe Traumatic Brain Injury and the Relationship with Physical Activity: A Narrative Review. *Brain Impairment*. 2015;17:43–54.
5. Sullivan SJ, Richer E, Laurent F. The role of and possibilities for physical conditioning programmes in the rehabilitation of traumatically brain-injured persons. *Brain Inj*. 1990;4:407–414.
6. Bateman A, Culpan FJ, Pickering AD, Powell JH, Scott OM, Greenwood RJ. The effect of aerobic training on rehabilitation outcomes after recent severe brain injury: a randomized controlled evaluation. *Arch Phys Med Rehabil*. 2001;82:174–182.
7. Curran CA, Ponsford JL, Crowe S. Coping strategies and emotional outcome following traumatic brain injury: a comparison with orthopedic patients. *J Head Trauma Rehabil*. 2000;15:1256–1274.
8. Basford JR, Chou LS, Kaufman KR, Brey RH, Walker A, Malec JF, et al. An assessment of gait and balance deficits after traumatic brain injury. *Arch Phys Med Rehabil*. 2003;84:343–349.
9. Williams GP, Morris ME. Tests of static balance do not predict mobility performance following traumatic brain injury. *Physiother Can*. 2011;63:58–64.
10. Williams GP, Schache AG, Morris ME. Mobility after traumatic brain injury: relationships with ankle joint power generation and motor skill level. *J Head Trauma Rehabil*. 2013;28:371–378.
11. Williams G, Banky M, Olver J. Distribution of Lower Limb Spasticity Does Not Influence Mobility Outcome Following Traumatic Brain Injury: An Observational Study. *J Head Trauma Rehabil*. 2015;30:E49–E57.
12. Williams G, Kahn M, Randall A. Strength Training for Walking in Neurologic Rehabilitation Is Not Task Specific: A Focused Review. *Am J Phys Med Rehabil*. 2014;93:511–522.
13. Dorsch S, Ada L, Alloggia D. Progressive resistance training increases strength after stroke but this may not carry over to activity: a systematic review. *J Physiother*. 2018;64:84–90.
14. Neptune RR, Sasaki K, Kautz SA. The effect of walking speed on muscle function and mechanical energetics. *Gait Posture*. 2008;28:135–143.
15. Liu MQ, Anderson FC, Pandy MG, Delp SL. Muscles that support the body also modulate forward progression during walking. *J Biomech*. 2006;39:2623–2630.
16. Ratamess NA, Alvar BA, Evetoch TK, Housh TJ. Progression Models in Resistance Training for Healthy Adults. *Med Sci Sports Exercise*. 2009;41:687–708.
17. Williams G, Hassett L, Clark R, Bryant A, Olver J, Morris ME, et al. Improving Walking Ability in People With Neurological Conditions: A Theoretical Framework for Biomechanics-Driven Exercise Prescription. *Arch Phys Med Rehabil*. 2019;100:1184–1190.
18. Cordner T, Egerton T, Schubert K, Wijesinghe T, Williams G. Ballistic Resistance Training: Feasibility, Safety, and Effectiveness for Improving Mobility in Adults

With Neurologic Conditions: A Systematic Review. *Arch Phys Med Rehabil*. 2021;102:735–751.
19. Williams GP, Clark RAP, Hansson JB, Paterson KP. Feasibility of Ballistic Strengthening Exercises in Neurologic Rehabilitation. *Am J Phys Med Rehabil*. 2014;96:828–833.
20. Williams GP, Schache AG. Evaluation of a conceptual framework for retraining high-level mobility following traumatic brain injury: two case reports. *J Head Trauma Rehabil*. 2010;25:164–172.
21. Mentiplay BF, Banky M, Clark RA, Kahn MB, Williams G. Lower limb angular velocity during walking at various speeds. *Gait Posture*. 2018;65:190–196.
22. Williams G, Schache AG. The distribution of positive work and power generation amongst the lower-limb joints during walking normalises following recovery from traumatic brain injury. *Gait Posture*. 2016;43:265–269.
23. Williams G, Willmott C. Higher levels of mobility are associated with greater societal participation and better quality-of-life. *Brain Inj*. 2012;26:1065–1071.
24. Zitnay GA, Zitnay KM, Povlishock JT, Hall ED, Marion DW, Trudel T, et al. Traumatic brain injury research priorities: the Conemaugh International Brain Injury Symposium. *J Neurotrauma*. 2008;25:1135–1152.
25. Williams G, Ada L, Hassett L, Morris ME, Clark R, Bryant AL, et al. Ballistic strength training compared with usual care for improving mobility following traumatic brain injury: protocol for a randomised, controlled trial. *J Physiother*. 2016;62:164.
26. Schulz KF, Altman DG, Moher D. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. *BMJ*. 2010;340:c332.
27. Orkin AM, Gill PJ, Ghersi D, Campbell L, Sugarman J, Emsley R, et al. Guidelines for Reporting Trial Protocols and Completed Trials Modified Due to the COVID-19 Pandemic and Other Extenuating Circumstances: The CONSERVE 2021 Statement. *JAMA*. 2021;326:257–265.
28. Hoffmann TC, Glasziou PP, Boutron I, Milne R, Perera R, Moher D, et al. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ*. 2014;348:g1687.
29. Williams GP, Morris ME. High-level mobility outcomes following acquired brain injury: a preliminary evaluation. *Brain Inj*. 2009;23:307–312.
30. Shores EA, Marosszeky JE, Sandanam J, Batchelor J. Preliminary validation of a clinical scale for measuring the duration of post-traumatic amnesia. *Med J Aust*. 1986;144:569–572.
31. Marshall S, Teasell R, Bayona N, Lippert C, Chundamala J, Villamere J, et al. Motor impairment rehabilitation post acquired brain injury. *Brain Inj*. 2007;21:133–160.
32. Williams G, Robertson V, Greenwood K, Goldie P, Morris M. The high-level mobility assessment tool (HiMAT) for traumatic brain injury. Part 2: content validity and discriminability. *Brain Inj*. 2005;19:833–843.
33. Williams G, Robertson V, Greenwood K, Goldie P, Morris ME. The concurrent validity and responsiveness of the high-level mobility assessment tool for measuring the mobility limitations of people with traumatic brain injury. *Arch Phys Med Rehabil*. 2006;87:437–442.
34. Hendrey G, Clark RA, Holland AE, Mentiplay BF, Davis C, Windfeld-Lund C, et al. Feasibility of Ballistic Strength Training in Subacute Stroke: A Randomized, Controlled, Assessor-Blinded Pilot Study. *Arch Phys Med Rehabil*. 2018;99:2430–2446.
35. Dean CM, Rissel C, Sherrington C, Sharkey M, Cumming RG, Lord SR, et al. Exercise to Enhance Mobility and Prevent Falls After Stroke: The Community Stroke Club Randomized Trial. *Neurorehab Neural Repair*. 2012;26:1046–1057.
36. Dean CM, Ada L, Lindley RI. Treadmill training provides greater benefit to the subgroup of community-dwelling people after stroke who walk faster than 0.4 m/s: a randomised trial. *J Physiother*. 2014;60:97–101.