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A randomized controlled trial of the effects of intensive sit-to-stand training after recent traumatic brain injury on sit-to-stand performance

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Objective: To examine the effectiveness of intensive practice of sit-to-stand on motor performance, exercise capacity and exercise efficiency in traumatic brain-injured patients during early inpatient rehabilitation.
Design: Single-blind randomized controlled pilot study.
Setting: Brain injury rehabilitation unit.
Subjects: Twenty-four subjects who had recently sustained a severe traumatic brain injury (TBI) were randomized into an experimental ($n = 13$) and a control ($n = 11$) group.
Interventions: In addition to their usual rehabilitation programme, subjects in the experimental group participated in four weeks of intensive training of sit-to-stand and step-up exercises with the aim of improving performance of sit-to-stand. The control group did no additional sit-to-stand or step-up training.
Main outcome measures: Total number of sit-to-stands in 3 min as a measure of motor performance; peak oxygen consumption during a maximal 3-min sit-to-stand test ($\dot{V}o_2$peak) as a measure of exercise capacity; oxygen consumption during a 3-min equivalent workload sit-to-stand test ($\dot{V}o_2$equiv) as a measure of exercise efficiency. Pre- and post-training measurements were made.
Results: The exercise programme resulted in a 62% improvement in motor performance (number of repetitions of sit-to-stand in 3 min) for the experimental group compared with the control group's 18% improvement ($p < 0.05$). There was no significant difference between groups for changes in exercise capacity or efficiency. In the experimental group, the increase in $\dot{V}o_2$peak from pre-test to post-test correlated with the increase in sit-to-stand repetitions ($p < 0.05$).
Conclusions: Intensive task-specific training is recommended as an important component of rehabilitation early following severe traumatic brain injury.

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Introduction

Sit-to-stand is one of the most mechanically demanding of everyday tasks[1] and crucial to independence. After traumatic brain injury (TBI) many individuals have difficulty performing the action due to motor impairments that arise as a direct result of the lesion, including weakness and poor motor control. In addition, many individuals experience a period of coma following severe TBI, with a secondary deterioration of muscle function and exercise capacity associated with bed rest and inactivity (e.g., refs 2 and 3) that can impact on functional performance.

Studies of individuals who have completed rehabilitation after TBI have found both reduced exercise capacity[4] and reduced exercise efficiency.[4-6] A raised energy cost of walking has also been reported.[6] Several clinical trials have shown that exercise capacity can be improved, using circuit training,[6] a combined exercise programme involving treadmill, bicycle ergometer and mechanical stairs,[4] and a bicycle ergometer programme.[7] Physical conditioning programmes have not shown improved exercise efficiency.[4,6]

A recent randomized controlled trial was carried out early during inpatient rehabilitation. The effects of exercise training performed on a cycle ergometer were evaluated in a group of individuals with single incident brain injury including TBI.[8] Following training, subjects showed improved exercise capacity, measured as peak work rate on the cycle ergometer, compared with the control group. Functional outcomes, including walking velocity, did not, however, improve. This study showed evidence of a specificity effect for the exercise practised, in that cycle training had an impact specifically on cycling exercise capacity. Exercise and training that is specific to task and context has also been shown to improve performance in functional activities after stroke[9] and TBI.[10]

Given the relevance of sit-to-stand to functional outcome and the specificity of training effects, the present study was developed to test the impact of intensive sit-to-stand practice on motor performance and on exercise capacity. The major aims were (1) to determine the efficacy of practice of sit-to-stand on motor performance, exercise capacity and exercise efficiency, and (2) to investigate the feasibility of intensive training of sit-to-stand early after TBI, and of measuring oxygen consumption during this action.

Methods

Subjects

A sample of 24 subjects who had recently sustained a severe TBI and who were attending rehabilitation as inpatients were recruited by physiotherapists working in the Brain Injury Rehabilitation Service. The purpose of the study was explained to each subject who signed informed consent documents. In the case of subjects who were in post-traumatic amnesia (PTA) on entry to the study, consent was also given by their next-of-kin. All procedures were performed in accordance with ethics approval granted by the University of Sydney and Westmead Hospital, Sydney.

To participate subjects had to meet the following criteria: a severe TBI within the previous 12 months; no orthopaedic condition that would prevent participation in training; a score of at least 2 (able to stand up by any method with standby help only) on the sit-to-stand item of the Motor Assessment Scale[11]; ability to follow simple instructions and to sit on a chair with feet plantigrade.

A randomized group design with pre- and post-training evaluations was used (Figure 1). The randomization process involved drawing a card, with a concealed group allocation, from a box. Thirteen subjects were allocated to the experimental group and 11 to the control group. Individual subject characteristics are outlined in Table 1. All subjects were within the normal range of weight for height.

Training programme

Subjects in the experimental group participated in four weeks of repetitive training of sit-to-stand and step-up exercises with the aim of improving performance of sit-to-stand. Step-up exercises were included as a means of increasing lower limb muscle neuromuscular co-ordination, since they involve similar lower limb dynamic characteristics to sit-to-stand. Subjects were trained individually with the aim of completing

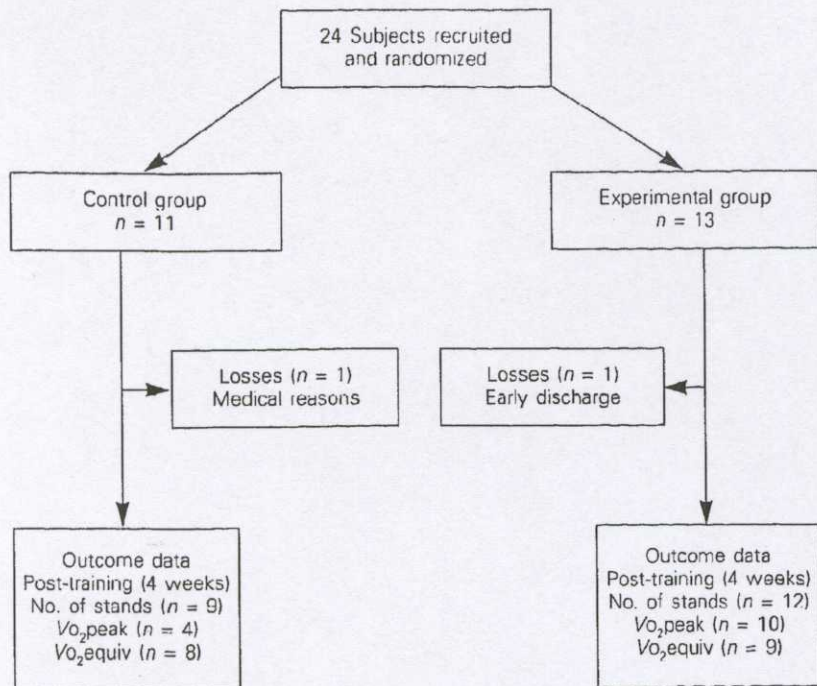

Figure 1 Study design. Ten control subjects and 12 experimental subjects completed the study. Data were incomplete for several variables due to impaired ability to control behaviour (e.g., talking during testing) and physical incapacity (e.g., inability to perform sufficient stands in the equivalent test). Equipment failure (faulty gas bags) also contributed to loss of data, particularly in the control group.

100 repetitions of sit-to-stand and 60 step-ups per day, five days a week. The initial height of the chair for sit-to-stand training was 110% of lower leg length and the height of the step for step-ups was 10 cm. Over the four weeks, the height of the chair was lowered incrementally as subjects' ability to perform multiple repetitions improved, in order to provide a progressive resistance training effect. For the majority of subjects the height of chair was lowered to 90% of lower leg length by the fourth week of training. For subjects with unilateral strength impairments, attention was directed towards generating vertical force through the weaker lower limb. To increase complexity, a second task, such as holding a cup of water, was incorporated into sit-to-stand practice. To maintain motivation, subjects were challenged to increase speed. They were given specific feedback, via stop watch, about the time taken to complete sets of 10 repetitions and challenged to decrease this time. Both experimental and control groups participated in their usual rehabilitation programme throughout the training programme. The control group did not receive additional sit-to-stand or step-up training.

Measurement procedures

Three variables were measured to determine the efficacy of sit-to-stand training: motor performance, exercise capacity and exercise efficiency. A 3-min maximum workload test measured motor performance and exercise capacity. Subjects stood up and sat down as many times as possible in 3 min. Exercise capacity was measured by peak oxygen consumption during the final minute of the maximum test (Vo_2peak), and motor performance by the maximum number of repetitions (STS reps).

A 3-min equivalent workload test measured exercise efficiency. Subjects stood up and sat down once every 10 s for 3 min, i.e., a total of 18 times. Oxygen consumption was measured during the final minute (Vo_2equiv).

For the measurement of Vo_2, subjects breathed through a mouthpiece (with nose occluded) attached to a two-way valve (#2700; Hans Rudolph, Kansas City, MO, USA). Expired gas passed through tubing from the expiratory port of the two-way valve to a Douglas bag. For each test, expired gas was collected during the last minute of exercise. Gas from the Douglas bag was analysed for fraction of expired oxygen (F_EO_2) and fraction of expired carbon dioxide (F_ECO_2) using a paramagnetic oxygen analyser and a rapid-response nondispersive infra-red carbon dioxide analyser respectively (V_{max}29 Cardiopulmonary Exercise Testing Instrument, Sensormedics Corporation, California, USA). Expired minute volume was measured using a dry gas meter (Vacumetrics, Ventura, CA, USA). From these measurements, Vo_2 was calculated using standard equations.

All tests were performed prior to and on completion of the four-week training programme. The equivalent test was performed first followed by a rest period of 30 min before performing the maximum test. Both tests were performed using a chair with no arms and adjusted to 110% of the subject's lower leg length. Assessors were blinded to group allocation for all subjects and were not involved in their treatment.

Table 1 Subject characteristics at baseline

Subject	Age	Gender	Time since injury (days)	Lowest GCS score	Time in PTA (days)	Pre-test STS score on MAS
Control						
C1	19	M	127	6	141	2
C2	26	F	63	4	64	6
C3	52	M	44	3	21	6
C4	21	M	97	3	83	2
C5	26	M	80	3	84	6
C6	22	M	104	3	99	6
C7	19	F	72	N/A	41	2
C8	26	F	56	3	48	6
C9	21	M	105	N/A	CA	5
C10	24	F	98	3	73	6
Mean	25.60		84.60	3.5	72.67	4.7
SD	9.67		25.90	1.1	35.27	1.9
Experimental						
E1	29	M	44	6	53	6
E2	16	M	91	3	CA	2
E3	18	M	55	3	42	2
E4	20	M	208	3	159	2
E5	17	M	53	5	81	6
E6	18	M	66	6	60	6
E7	46	M	80	4	CA	5
E8	20	F	64	N/A	66	6
E9	22	F	90	N/A	58	3
E10	25	M	26	3	25	6
E11	46	M	38	4	76	4
E12	20	M	88	5	132	5
Mean	24.75		75.25	4.2	75.20	4.4
SD	10.55		46.89	1.2	40.84	1.7

GCS, Glasgow Coma Scale; PTA, post-traumatic amnesia; STS, sit-to-stand; MAS, Motor Assessment Scale; CA, chronic amnesia; N/A, not available.

Data analysis

Three variables were analysed: STS reps, $V\text{o}_2$peak (litres. min^{-1}) and $V\text{o}_2$equiv (litres. min^{-1}). Repeated measures analyses of variance were used to compare the changes in these three variables between groups over time. In order to examine feasibility of training, the number of sit-to-stand and step-up repetitions was analysed descriptively.

Post-hoc analysis was performed on the data for the experimental group. The improvement in $V\text{o}_2$peak from pre-test to post-test was analysed using a t-test for dependent samples. Change scores from pre-test to post-test were calculated for STS reps and $V\text{o}_2$peak and Pearson's product moment correlational analysis was performed on these scores. Significance level for all statistical tests was set at $p < 0.05$.

Results

Adherence to exercise programme and testing procedures

Over the four-week programme, experimental subjects performed 1735 ± 300 repetitions of STS, with an average of 87 repetitions each working day. They also performed 831 ± 397 step-ups over the four weeks or training, an average of 42 repetitions per day. The time taken to complete practice of sit-to-stand varied from 10 min to 60 min a day. This variability reflects differences in the ability to exercise, as well as the subjects' tolerance of the regimen. Some weaker individuals could manage very few repetitions initially. Many subjects had difficulty coping with the concept of the need to exercise and would have stopped the exercise sessions sooner without encouragement.

STS motor performance

Although both groups increased the maximum number of repetitions of sit-to-stand (STS reps) by post-test, the changes in the experimental group were significantly greater than those in the control group (Table 2). Individual data showed that all 12 subjects in the experimental group were able to do more repetitions of standing up in 3 min at post-test, with increases ranging from 7 to 70. In contrast, for the control subjects the increase in number of stands ranged from 1 to 38, and two of the 10 subjects recorded fewer stands on post-test than on pre-test.

Exercise capacity and efficiency

Both groups increased their exercise capacity ($V\text{o}_2$peak) during repetitive standing up, the experimental group on average by 0.39 litres. min^{-1}, and the control group by 0.22 litres. min^{-1}. However, the increase made by the experimental group was not significantly greater than that of the control group (Table 2). Changes in exercise efficiency ($V\text{o}_2$equiv) were negligible for both groups (Table 2).

Within-group analysis showed that the increase in $V\text{o}_2$peak from pre-test to post-test for the experimental group was significant ($t = -4.09$, $p < 0.01$). Furthermore, the increase in $V\text{o}_2$peak was significantly correlated with the increase in STS reps ($r = 0.65$, $p < 0.05$).

Table 2 Means (standard deviations) and statistical results for group × time interactions

Variables	Experimental			Control			Statistical results
	n	Pre-test	Post-test	n	Pre-test	Post-test	
Number of stands	12	49.0 (21.3)	79.3 (33.7)	9	74.3 (34.2)	87.7 (33.9)	$F_{(1,19)} = 5.20$ $p = 0.03$*
$V\text{o}_2$peak (litres. min^{-1})	10	0.75 (0.19)	1.14 (0.37)	4	0.83 (0.26)	1.05 (0.21)	$F_{(1,12)} = 0.91$ $p = 0.36$
$V\text{o}_2$equiv (litres. min^{-1})	9	0.47 (0.09)	0.50 (0.21)	8	0.52 (0.12)	0.46 (0.13)	$F_{(1,15)} = 0.83$ $p = 0.38$

*Statistically significant result.
n = number of subjects with complete data for each variable.

Discussion

Intensive and repetitive practice of sit-to-stand and step-up exercises early during inpatient rehabilitation for traumatic brain injury, supplementary to the existing training programme, resulted in significant improvements in performance of sit-to-stand. The short four-week programme of task-oriented training resulted in a 62% improvement in the number of repetitions of sit-to-stand performed in 3 min for the experimental group, compared with only 18% improvement for the control group.

The greater improvement in number of sit-to-stands by the experimental group could be accounted for by differences in baseline performance recorded by the two groups. This interpretation needs to be considered because, despite random allocation, the control group performed somewhat better than the experimental group at pre-test, with the observed difference in number of stands approaching statistical significance ($F_{(1,19)} = 4.35$, $p = 0.051$). However, there was no suggestion of between-group differences at pre-test for the other outcome measures (Vo_2peak, Vo_2equiv) or for any of the indicators of severity at pre-test (GCS score; time in PTA; sit-to-stand item of the Motor Assessment Scale). Overall, therefore, the two groups were comparable at baseline. It is also possible that the improvement in the number of stands demonstrated by the control group was limited by a ceiling effect on the test of motor performance. However, a ceiling effect was not evident, since the number of stands for the control group at posttest (87.7 ± 33.9) was well below the mean score (132.4 ± 28.1) for a healthy group ($n = 9$) of similar age (26.7 ± 7.9) (unpublished data).

Clinical messages

- Intensive sit-to-stand training during early inpatient rehabilitation after severe traumatic brain injury is effective in improving performance of sit-to-stand.
- The number of stands performed during a 3-min maximum workload sit-to-stand test is a feasible outcome measure.

Therefore, it is reasonable to conclude that the increased extent of improvement made by the experimental group can be attributed to the intervention.

The findings show that subjects trained in sit-to-stand increased exercise capacity when tested during this action. These increases were not, however, significantly greater for the experimental group than those for the control group. A power analysis shows that, even with missing data, there was sufficient power to detect a clinically significant effect size of 0.50 litres. min^{-1} for Vo_2peak. The measured effect size was, however, only 0.17 litres. min^{-1}.

We were not able to show, therefore, that the additional sit-to-stand training was effective in improving peak oxygen consumption over and above the improvement gained during the standard rehabilitation programme. One possible explanation for this finding is that the intensity of the training was too low for some subjects. A recent study[12] in the acute period has shown that brain-injured subjects may undergo several weeks of training before they are able to exercise at sufficient intensity to have a cardiovascular training effect. Another possible explanation is that the duration of the exercise programme (four weeks) was too short. Studies demonstrating increased peak oxygen consumption following exercise training in the chronic period have used training programmes of three months duration at an intensity of 60–80% of predicted maximum heart rate.[4,6]

It was hypothesized that an increase in the number of sit-to-stands by the experimental group would be accompanied by lower oxygen consumption for an equivalent workload, suggesting improved exercise efficiency in performing the action. However, both groups showed minimal changes in oxygen consumption during the equivalent workload test. This finding is consistent with other studies that have shown no change in efficiency following exercise training in chronic TBI subjects.[4,6] In our study, a certain level of motor performance was necessary in order to be able to perform the test of efficiency, and the standing up task was constrained within certain parameters (such as seat height). It is possible, therefore, that initially the task was relatively efficient, and this may help to explain why

there was no reduction in $V\text{o}_2$ at an equivalent workload.

The significant correlation between changes in sit-to-stand performance and changes in exercise capacity for the experimental group suggest that improved exercise capacity may contribute to improved sit-to-stand performance or vice versa. Other factors that may contribute to improved sit-to-stand performance and exercise capacity include task-dependent increases in strength and endurance of lower limb muscles, and increased inter-segmental co-ordination. There have been previous reports of improvement in muscle endurance following circuit training,[6] and in co-ordination,[13] in this patient population. Improved attention to task, memory and concentration may also have played a part, as reported elsewhere.[14] These factors were not, however, investigated.

This study demonstrates that intensive and repetitive practice of sit-to-stand is feasible as part of an exercise training programme during early inpatient rehabilitation following severe TBI. There was a wide range of disability in the groups. Some subjects needed considerable encouragement to complete their practice and many would not have done so without close supervision with motivating feedback. For the three subjects who achieved a score of only 2 on the Motor Assessment Scale at pre-test, sit-to-stand would have been a challenging physical task, and, although difficult, would have been perceived as relevant. However, for the five who had already achieved the highest score on the sit-to-stand item of the MAS at pre-test, the repetitive sit-to-stand training as performed for the study would not have been sufficiently challenging and it was difficult to maintain interest. It has been reported elsewhere that subjects needed a great deal of encouragement to maintain a constant cycling speed when using a cycle ergometer both during rehabilitation[7] and after discharge.[4]

Motor disability raises the metabolic cost of an activity[15] and this, combined with decreased exercise capacity after TBI, may cause fatigue and decrease full participation in rehabilitation. It is therefore critical in rehabilitation after severe brain injury that exercise is intensive enough to increase not only motor skill, but also endurance and fitness. In the case of sit-to-stand, the intensity of sit-to-stand practice can be increased by such means as progressively decreasing seat height, increasing speed and by the addition of extra load.

The tests used in this study were designed to be short in duration and simple conceptually to allow individuals after TBI who have some cognitive impairment to participate, and to ensure feasibility in the clinic. The present study has limitations in the small sample size with no follow-up testing. Nevertheless, we clearly showed an improvement in the ability to stand up and sit down in the short term. A further limitation was the lack of a measure of intensity of exercise training. The findings have pointed to the importance of monitoring intensity of exercise (e.g., using a heart rate monitor) in order to ensure that exercise is intensive enough to have a fitness training effect.

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