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Ventilatory Anaerobic Thresholds of Individuals Recovering from Traumatic Brain Injury Compared to Non-Injured Controls

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Abstract

The purpose of this study was to compare the peak aerobic capacities and ventilatory anaerobic thresholds (V_{AT}) of individuals with a traumatic brain injury (TBI) to age- and gender-matched controls.

Methods—Nineteen participants that previously suffered a mild to moderate TBI and 19 apparently healthy controls (CON) volunteered as subjects. TBI and CON were matched for age and gender and were similar in weight and BMI. Volunteers performed a maximal graded treadmill test to volitional failure where oxygen consumption (VO_2), carbon dioxide production (VCO_2), ventilation (V_E), and heart rate (HR) were measured continuously. From metabolic and ventilatory data, V_{AT} was measured using a previously described method. V_{AT} and peak exercise responses of participants with a TBI were compared to CON.

Results—The VO_2 and VCO_2 at V_{AT} and peak exercise were lower for TBI compared to CON. V_E was also lower for TBI at V_{AT} and peak exercise. HR was lower for TBI at V_{AT} ; however, TBI had similar HR to CON at peak exercise.

Conclusions—The V_{AT} and peak exercise capacities of participants with a TBI were below the metabolic demands of many routine daily activities. The data suggest that therapeutic interventions for individuals with a TBI should include targeted exercise prescriptions to improve cardiorespiratory fitness.

Keywords

Exercise tolerance; fatigue; rehabilitation; exercise prescription; head injury

INTRODUCTION

Along with cardiovascular disease, cancer, and stroke, traumatic brain injury (TBI) is a leading cause of disability in the United States.¹ Each year, approximately 1.7 million people sustain a TBI.² Eighty to ninety thousand individuals suffer permanent disability and are added to the 5.4 million people currently living in the United States with a TBI. The majority of cases are children, adolescents and young adults who have the potential to live many decades with physical and/or cognitive impairments.

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There are numerous co-morbidities associated with TBI. High percentages of patients with TBI exhibit decreased cognitive and psychological functioning 10–20 years after injury.³ Although cognitive impairments resulting from TBI are the best described, physical impairments may result from injury, such as an inability to return to work or intolerance for activities of daily living.^{4,5} Fatigue and pain are near universal complaints following TBI and have been shown to negatively affect patients for up to five years post-injury.^{4,6,7} This may be particularly important to therapists because chronic fatigue is associated with poorer cognitive and motor performance outcomes.⁷

Although the mechanisms are poorly understood, some argue that fatigue likely results from an increased cognitive demand for activities. However, there is compelling evidence that decreased cardiorespiratory fitness may also contribute considerably to fatigue. It has been demonstrated that patients with a TBI have significantly lower peak aerobic work capacities than age- and gender-matched controls.⁸ Using a graded treadmill protocol, Mossberg and colleagues found that the peak aerobic capacity (VO_2 peak) of TBI patients was $8.3 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ lower than the non-injured cohort.⁸ The peak aerobic capacity of the individuals with a TBI reported by Mossberg and colleagues was below the 10th percentile.

VO_2 peak is a key descriptor of maximal aerobic fitness, but it is rare that daily activities are performed near peak. Instead, most daily activities require sustained submaximal efforts for prolonged periods of time. In addition, maximal exercise testing is dependent upon the effort of the participant and may vary significantly depending on motivation. Thus, quantification of submaximal exercise responses may be more functionally relevant and provide quantifiable measurements of aerobic fitness without the variability inherent to maximal effort-based testing.

A submaximal exercise response that has been correlated with cardiorespiratory fitness is the anaerobic threshold. The anaerobic threshold is the point in the exercise continuum at which there is a rapid decrease in cellular pH.⁹ It can be directly determined by measuring muscle pH or indirectly determined by analyzing blood lactate.¹⁰ The least invasive method of estimating anaerobic threshold is to assess systemic metabolic and ventilatory parameters.^{11–14} Estimation of anaerobic threshold using metabolic and ventilatory measurements is termed ventilatory anaerobic threshold (V_{AT}). Work rates at or below V_{AT} can be sustained for relatively long periods of time. When the hydrogen ion concentration reaches a certain threshold, muscular contractions are disrupted and work levels become unsustainable; the subjective sensation is muscle fatigue.

V_{AT} determination may be particularly useful in patients with a TBI because it does not necessitate a maximal effort, is non-invasive, and has been used in other clinical populations.^{15–18} V_{AT} has also been shown to correlate with health outcomes, including early mortality.¹⁹ The purpose of this study was to compare the V_{AT} and peak aerobic capacities of patients with a TBI with uninjured, apparently healthy controls. It was hypothesized that in participants with a TBI compared to CON there would be a difference in (i) metabolic, ventilatory, and cardiovascular responses at V_{AT} , (ii) metabolic, ventilatory, and cardiovascular responses at peak exercise, and (iii) the percentage of peak VO_2 at which V_{AT} occurred.

METHODS

Design

A case-control design was used to complete the study objectives. Participants with a TBI were matched for gender and age to apparently healthy control subjects with no known history of traumatic brain injury.

Participants

A total of 38 sedentary individuals volunteered to participate in this study (28 male, 10 female). Nineteen individuals (14 males, 5 females) recovering from a TBI were current or former residents in a comprehensive post-acute rehabilitation center. They were recruited by word of mouth through the physical therapy department at the post-acute center. The 19 healthy controls were matched for gender and age (± 5 y) to the participants with a TBI. The average age at injury for the individuals with a TBI was 24.4 ± 9.5 y. The average time post injury was 4.2 ± 4.3 y. The causes of injury for participants with a TBI were motor vehicle accidents ($n = 10$), blunt head trauma ($n = 3$), explosions ($n = 3$), falls ($n = 2$), and assaults ($n = 1$). All subjects were considered healthy by American College of Sports Medicine guidelines for exercise testing, or were medically cleared for maximum exercise by a physician.²⁰ Additionally, all participants with a TBI had high levels of motor functioning and could ambulate without assistance, follow a minimum of two-step commands, and tolerate the testing equipment. Prior to beginning the study, subjects provided written and verbal consent to all study procedures. These procedures were approved by the Committee for the Protection of Human Subjects at a nearby university and the Institutional Review Board of the rehabilitation center.

Data Collection Procedures

Four skin sites on the anterior thorax were prepped for three-lead electrocardiogram (ECG) measurements (Cardio Perfect Inc., Atlanta, GA 30339). The ECG signals were used to obtain resting and exercising heart rates and for medical safety monitoring. Additionally, blood pressure was measured in sitting and standing before treadmill walking, immediately after exercise while still standing on the treadmill, and after 10 and 20 minutes of sitting recovery. Prior to exercise a neoprene face mask was fitted to the subject and connected to an automated metabolic gas analyzer and pneumotachometer (MedGraphics Corp., St. Paul, MN 55127). After the facemask was placed on the participant, they were asked to take several deep breaths, exhaling as fast as possible. If the participant felt air leaking around the perimeter of the mask, the mask was adjusted or changed to a smaller or larger size until it was free from leaks. The metabolic cart was calibrated prior to testing using gases of known concentrations. The pneumotachometer was calibrated using a 3L syringe according to the manufacturer's specifications. Baseline heart rate, metabolic, and ventilatory data were collected for 3 minutes before exercise commenced.

A constant speed, variable incline test previously reported to be reliable in determining peak VO_2 in patients with a TBI was used in this investigation.^{21, 22} After collection of baseline data, subjects stood on the treadmill holding the hand rails as the treadmill belt velocity was slowly increased in the first two minutes until the subjects were walking at a comfortable but brisk pace. The final selected treadmill testing speed was the fastest speed a subject could safely walk, but did not exceed $5.3 \text{ km} \cdot \text{h}^{-1}$ (3.3 mph). After the first 2 minutes at 1% grade, treadmill incline was increased by 2% each minute. Subjects were encouraged to walk without holding the handrails, using fingertip touch on the handrails only as needed to correct balance. The test termination criteria suggested by the American College of Sports Medicine and used in this investigation were: 1) a respiratory exchange ratio (RER) greater than 1.10, and/or 2) a visible plateau in with increased workload, 3) and volitional fatigue.²⁰

During the testing protocol, volume of oxygen consumed (VO_2 , $\text{mL} \cdot \text{min}^{-1}$), volume of carbon dioxide produced (VCO_2 , $\text{mL} \cdot \text{min}^{-1}$), heart rate (HR, $\text{beats} \cdot \text{min}^{-1}$), and minute ventilation (V_E , $\text{L} \cdot \text{min}^{-1}$) were collected continuously. From these data, respiratory exchange ratio (RER), ventilatory equivalents for oxygen (V_E / VO_2) and carbon dioxide ($\text{V}_E / \text{VCO}_2$) were calculated. Data used for statistical analyses were 20 second averages of

the breath by breath data.^{21, 23} The values of each variable at V_{AT} and peak effort were determined.

V_{AT} was determined using the method described previously by Beaver and colleagues.¹⁴ Briefly, V_{AT} was determined by plotting the value obtained from the middle five of seven breaths for VCO_2 , V_E / VO_2 , end-tidal partial pressure of O_2 ($P_{ET}O_2$), and RER against VO_2 . V_{AT} was then found using the following criteria: 1) a change in the relationship between VCO_2 to VO_2 , 2) the nadir point of V_E / VO_2 , 3) the nadir point of end-tidal partial pressure of O_2 ($P_{ET}O_2$), and 4) an abrupt increase in RER. An example of the V_{AT} determination for a single subject is presented in Figure 1.

Statistical Analysis

All data were exported into a Microsoft Excel spreadsheet and visually inspected for anomalous values. Outlier analyses were performed on the primary dependent variables for the study (i.e. VO_2 , VCO_2 , HR, and V_E). If the data were ± 2.0 standard deviations from the mean, the subject was eliminated from analysis.²⁴ Baseline anthropometric differences between groups were determined using paired t-tests. Paired tests were used because of the subject matching technique used in the case-control design. The peak effort values and the values at V_{AT} were entered into a statistical software program (SPSS 18.0; SPSS Inc., Chicago, IL). Multivariate analysis of variance (MANOVA) tests were used to assess differences between metabolic, ventilatory, and cardiovascular variables between groups at V_{AT} and peak exercise. MANOVAs were used to control for errors due to multiple comparisons; F-ratios were calculated using Hotelling's Trace method.²⁵ Dependent variables entered into the two MANOVA models included normalized VO_2 , VO_2 , VCO_2 , HR, V_E , RER, V_E / VO_2 , V_E / VCO_2 . Differences in the percent of peak VO_2 at which V_{AT} occurred were determined using a paired t-test. The critical value for significance was set at $p = 0.05$. All data are expressed as mean $\pm$ standard deviation.

RESULTS

Group characteristics are listed in Table 1. Participants with a TBI ranged in age from 19–54 y and control subjects from 20–53 y. There were no statistical differences in age ($p = 0.59$), height ($p = 0.79$), body weight ($p = 0.41$), or body mass index ($p = 0.34$). The average peak ambulatory speed for the participants with a TBI was $4.5 \pm 1.3 \text{ km} \cdot \text{h}^{-1}$. All CON subjects walked at $5.3 \text{ km} \cdot \text{h}^{-1}$. No outliers were detected in the data set; therefore, all subjects were used in analysis.

Ventilatory Anaerobic Threshold Responses

A summary of metabolic, cardiovascular, and ventilatory variables at V_{AT} is provided in Table 2. There were significant between group differences in V_{AT} ($F = 6.64$ ($df = 8, 29$); $p < 0.001$). RER at V_{AT} was similar between TBI and CON ($p = 0.44$). Body weight normalized VO_2 (Figure 2) was significantly greater in CON at V_{AT} ($p < 0.001$). Additionally, absolute VO_2 ($p < 0.001$) and VCO_2 ($p < 0.001$) at V_{AT} were significantly greater in CON compared to TBI. CON had significantly greater V_E at V_{AT} ($p = 0.001$). Ventilatory equivalents for VO_2 at V_{AT} were not different between groups ($p = 0.06$); however, the ventilatory equivalents for VCO_2 were significantly greater in TBI ($p = 0.007$). Heart rates at V_{AT} were significantly greater in CON compared to TBI ($p = 0.05$). Most importantly, V_{AT} occurred at $53.1 \pm 8.8\%$ and $60.6 \pm 10.2\%$ of peak VO_2 for TBI and CON, respectively; the difference was statistically significant ($p = 0.02$).

Peak Exercise Responses

Group means and confidence intervals for metabolic, ventilatory, and cardiovascular variables are shown in Table 3. Similar to V_{AT} , there was a significant difference between groups for peak exercise ($F = 2.73$ ($df = 8, 29$); $p = 0.02$). No significant between group differences were observed in RER at peak exercise ($p = 0.32$). However, CON subjects had a greater peak body weight normalized VO_2 compared to TBI ($p < 0.001$; Figure 2). The peak absolute VO_2 ($p = 0.002$) and VCO_2 ($p = 0.002$) were significantly greater in CON. Likewise, V_E at peak exercise was significantly greater in CON ($p = 0.005$). Neither the ventilatory equivalents for VO_2 ($p = 0.87$) nor VCO_2 ($p = 0.56$) at peak exercise were significantly different between groups. Peak exercising heart rate was not different between groups ($p = 0.11$).

DISCUSSION

The purpose of this study was to compare the anaerobic thresholds, determined using ventilatory measurements, and peak exercise responses of participants with a TBI to apparently healthy, sedentary gender- and age-matched controls, similar in weight and BMI. These data confirm that high level motor functioning individuals with a TBI have lower peak aerobic capacities than matched, sedentary controls (10th vs. 30–40th percentile, respectively).²⁶ The significant novel finding of this study was that participants with TBI have marked reductions in the percentage of peak VO_2 at which V_{AT} occurs. These findings have important implications for functional activities of daily living and could be a significant contributor to reported levels of fatigue in this patient population.

Fatigue is a multifactorial phenomenon that involves events occurring both centrally and peripherally; it is one of the most common complaints of individuals with TBI. Under the conditions of our study, the results point strongly towards peripheral mechanisms being a significant contributor to fatigue in participants with a TBI. Objective indicators of maximal aerobic effort are a plateau in the oxygen consumption with increasing workload and a respiratory exchange ratio greater than 1.10. The RER was the same in both TBI and CON indicating peripheral metabolic events (anaerobic metabolism), and not motivation or boredom (central events), were the main limiting factors. Rapid fatigue occurs at intensities that exceed anaerobic threshold and it is evident from our results that this shift occurred at significantly lower relative work intensities and may contribute to perceptions of fatigue during activities of daily living.

In most healthy individuals, the physical exertion required for routine activities of daily living are well below V_{AT} . Thus, routine activity results in minimal fatigue. However, our data indicate that individuals with a TBI may reach or exceed V_{AT} performing even low level activities of daily living. Crouter and colleagues²⁷ used a portable metabolic system to quantify the metabolic equivalents for oxygen (METs; note that 1 MET = $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ or the basal metabolic rate) of routine activities of daily living (e.g., sweeping, yard mowing, heavy sawing, etc.). The metabolic costs of many of these activities are comparable or above the V_{AT} of most of participants with TBI we tested; some metabolic costs of these daily living activities exceed their peak working capacity (see Figure 3). The V_{AT} levels of the participants with TBI ranged from 3.2 – 5.2 METS. Peak VO_2 in the TBI group ranged from 5.3 – 12.1 METS. For 3 participants, sweeping or mopping would be a supra-threshold activity. For all 19 participants with a TBI, lawn mowing and stair ascent was a supra-threshold activity and for 3 participants these activities were at or above their VO_2 peak. Finally, the reported metabolic demand of heavy sawing exceeds the V_{AT} of all participants with a TBI and exceeds the peak VO_2 of 10 of the 19 participants tested. Although not directly measured, these data indicate that many participants with a TBI may not possess the

metabolic capacity to perform and complete daily activities considered routine for healthy individuals, which could substantially contribute to fatigue.

Along with affecting physical work tolerance, the low aerobic capacities observed for individuals with TBI may contribute to poor overall health outcomes. It has been reported that physical inactivity and poor aerobic capacity are independent risk factors for cardiovascular (CVD) and coronary artery disease (CAD).²⁸ Williams demonstrated a general linear trend between fitness level and risk for CVD. Their data indicate the risk for these diseases increases exponentially for individuals with peak aerobic fitness below the 25th percentile. In our sample, the fitness level of 17 out of 19 participants was below the 10th percentile suggesting that persons with a TBI may be at increased risk for CVD and CAD. Given this result, it is not surprising that patients with a TBI are 3 times more likely to die of cardiovascular disease.²⁹ The findings of Williams in relation to the data in our study strongly suggest young survivors of TBI should be educated on the importance of cardiorespiratory exercise as an element in the prevention of secondary disability.

Ventilatory responses were also suppressed at V_{AT} and peak VO_2 in participants with a TBI compared to CON. This was an expected finding as previous research has shown reductions in peak ventilation.⁸ At sea level, exercising ventilation is not thought to be a limiting factor at maximum exercise. In healthy individuals oxygen diffusion is considered the limiting ventilatory factor, not the volume of air inhaled.³⁰ However, in certain clinical populations, such as patients with chronic obstructed pulmonary disease or congestive heart failure, pulmonary inefficiency may restrict exercise capacity.^{31, 32} To date, there are no studies investigating the impact of reduced ventilation on exercise in individual with a TBI, nor are there data supporting mechanisms for reduced ventilation. It could be that ventilation is decreased due to physical inactivity and deconditioning. In addition to V_E , ventilatory equivalents for VCO_2 were lower in participants with a TBI compared to control at V_{AT} but not peak exercise. Likewise, HR was also lower in patients with a TBI compared to CON at V_{AT} but not peak exercise. Although the cause for these differences is unknown, it is likely the result of V_{AT} occurring at a lower percentage of peak exercise capacity.

From these data, it is not clear if the reduction in peak oxygen consumption is caused by TBI or is a result of a sedentary lifestyle adopted post-injury. Nevertheless, the results suggest that therapists should prioritize cardiorespiratory fitness training in patients with a TBI, especially those with minimal physical impairments. The Centers for Disease Control and Prevention and the American College of Sports Medicine currently recommend that all individuals engage in moderate exercise daily (<50% of maximal aerobic capacity).³³ Further, they suggest individuals should perform exercise at sufficient intensity to improve cardiovascular health (vigorous; 70% of maximal aerobic capacity) 3 days per week for at least 20 minutes per day. We believe these minimal recommendations are appropriate for most patients with TBI.

There are few intervention studies examining the effects of exercise on peak aerobic capacity in this population. However, the studies investigating exercise suggest that patients with a TBI respond positively to various modes of exercise and show improvements in submaximal and peak cardiorespiratory variables.^{34, 35, 36} However, we are unaware of data showing improvements in V_{AT} of patients with a TBI. Future prospective or experimental studies are needed to precisely define exercise prescriptions aimed to improve aerobic capacities in patients with a TBI. Furthermore, these data suggest that research should be targeted towards interventions that increase V_{AT} or result in V_{AT} occurring at higher percentages of VO_2 peak in this population.

One potential limitation of this study was that the relationship between exercise capacity, V_{AT} or peak VO_2 , and perceived fatigue in patients with a TBI is speculative. Although these data strongly suggest such an association is likely by demonstrating that the V_{AT} and peak VO_2 are lower than common ADL's, the construct of fatigue was not measured in this study. Studies are needed measuring both exercise capacity and perceived fatigue to quantify these associations. A self-report measure of fatigue such as the Fatigue Severity Scale may be appropriate.³⁷ These data may also better support the need for exercise interventions in patients with a TBI specifically targeting improvements in V_{AT} and perceived fatigue.

CONCLUSION

The V_{AT} and peak aerobic capacity of individuals with TBI was found to be lower than matched healthy sedentary controls. In most cases, the V_{AT} was below the metabolic work demands of many routine activities of daily living. This is likely a significant contributor to fatigue after TBI. Although physical therapy for patients with TBI generally involves basic locomotor training, our results suggest that specific exercise interventions targeted at improving cardiorespiratory fitness may be necessary for successful rehabilitation outcomes regarding activities of daily living. When feasible, therapists should consider implementing more vigorous exercise strategies to improve V_{AT} (e.g., high intensity interval training). Furthermore, the entire rehabilitation team should be aware of the deficits in endurance capacity that exist in patients who have few, if any, overt physical impairments and for whom cognitive and behavioral therapies are the rehabilitation emphasis. Although precise exercise recommendations have not been studied adequately in TBI patients, prescriptions based on evidence derived from apparently healthy individuals may be used as a baseline to develop individual prescriptions. Exercise interventions designed to improve overall aerobic work capacity and improve anaerobic threshold are indicated and may be necessary for optimal functional outcomes in the rehabilitation of patients with TBI.

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Figure 1.

Example plot of data used to determine ventilatory anaerobic threshold (V_{AT}). Note 1) the change in the VCO_2 to VO_2 relationship, 2) the nadir point of V_E / VO_2 , 3) the nadir point of the end-tidal partial pressure of O_2 ($P_{ET}O_2$), and 4) the abrupt increase in RER all occur almost simultaneously (i.e., the V_{AT}).

*Note that solid line centered within boxes represents the median score and dashed line indicates the group mean.

Figure 2.

Differences in oxygen consumption normalized for body weight at ventilatory anaerobic thresholds (V_{AT}) and peak exercise in TBI compared to CON.

Figure 3.

Functional significance of the ventilatory anaerobic thresholds (V_{AT}) and peak exercise capacities of participants with TBI. Metabolic equivalent (MET) data for common activities of daily living were derived from Crouter et al.²⁷ Note that one MET is equal to $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ or the basal metabolic rate.

Table 1

Subject anthropometric characteristics

	Age (y)	HT (cm)	Wt (kg)	BMI
TBI	28.2 ± 8.4	174.4 ± 9.1	85.4 ± 18.7	27.8 ± 5.0
Control	29.5 ± 7.2	173.3 ± 9.1	80.6 ± 15.9	26.4 ± 3.9

Table 2

Mean $\pm$ SD and confidence intervals for key metabolic, cardiovascular and ventilatory variables at ventilatory anaerobic threshold (V_{AT})

Dependent Variable	Group	Mean $\pm$ SD	95% Confidence Interval		p-value
			Lower	Upper	
Norm $\dot{V}O_2$ (mL $\cdot$ kg ⁻¹ $\cdot$ min ⁻¹)	TBI	14.6 $\pm$ 2.2	13.1	16.1	$p < 0.001$
	CON	22.3 $\pm$ 4.0	20.8	23.8	
$\dot{V}O_2$ (mL $\cdot$ min ⁻¹)	TBI	1207.2 $\pm$ 324.2	1024.8	1389.7	$p < 0.001$
	CON	1789.9 $\pm$ 428.9	1601.5	1966.4	
$\dot{V}CO_2$ (mL $\cdot$ min ⁻¹)	TBI	1080.2 $\pm$ 324.4	896.2	1264.4	$p < 0.001$
	CON	1639.3 $\pm$ 455.8	1455.4	1823.3	
RER	TBI	0.9 $\pm$ 0.1	0.9	1.0	$p = 0.44$
	CON	0.9 $\pm$ 0.1	0.9	1.0	
$\dot{V}_E$ (L $\cdot$ min ⁻¹)	TBI	29.4 $\pm$ 8.1	24.5	33.8	$p = 0.001$
	CON	40.3 $\pm$ 10.6	35.9	44.7	
$\dot{V}_E / \dot{V}O_2$	TBI	24.7 $\pm$ 4.1	23.2	26.3	$p = 0.06$
	CON	22.6 $\pm$ 2.3	21.1	24.2	
$\dot{V}_E / \dot{V}CO_2$	TBI	27.5 $\pm$ 3.5	26.2	28.9	$p = 0.007$
	CON	24.8 $\pm$ 2.2	23.5	26.2	
Heart Rate (beats $\cdot$ min ⁻¹)	TBI	115.5 $\pm$ 18.7	108.0	122.9	$p = 0.05$
	CON	132.9 $\pm$ 12.9	125.5	140.4	

Abbreviations: SD, standard deviation; V_{AT} ; ventilatory anaerobic threshold; $\dot{V}O_2$, volume of oxygen consumed; $\dot{V}CO_2$, volume of carbon dioxide produced; RER, respiratory exchange ratio; $\dot{V}_E$, minute ventilation, $\dot{V}_E / \dot{V}O_2$, ventilatory equivalents of oxygen consumption, $\dot{V}_E / \dot{V}CO_2$, ventilatory equivalents of carbon dioxide production.

Table 3

Mean $\pm$ SD and confidence intervals for key metabolic, cardiovascular and ventilatory variables at peak exercise

Dependent Variable	Group	Mean $\pm$ SD	95% Confidence Interval		p-value
			Lower	Upper	
Norm $\dot{V}O_2$ (mL $\cdot$ kg ⁻¹ $\cdot$ min ⁻¹)	TBI	28.2 $\pm$ 6.2	25.3	31.1	$p < 0.001$
	CON	37.2 $\pm$ 6.3	34.3	40.1	
$\dot{V}O_2$ (mL $\cdot$ min ⁻¹)	TBI	2289.5 $\pm$ 621.5	2000.2	2578.8	$p = 0.002$
	CON	2966.4 $\pm$ 622.1	2677.1	3255.7	
$\dot{V}CO_2$ (mL $\cdot$ min ⁻¹)	TBI	2727.2 $\pm$ 794.0	3261.4	4007.9	$p = 0.001$
	CON	3634.8 $\pm$ 809.9	2354.1	3100.4	
RER	TBI	1.2 $\pm$ 0.1	1.2	1.2	$p = 0.32$
	CON	1.2 $\pm$ 0.1	1.2	1.3	
$\dot{V}_E$ (mL $\cdot$ min ⁻¹)	TBI	81.6 $\pm$ 24.3	68.9	93.4	$p = 0.005$
	CON	106.2 $\pm$ 26.3	94.4	118.0	
$\dot{V}_E/\dot{V}O_2$	TBI	35.8 $\pm$ 5.8	33.0	38.5	$p = 0.87$
	CON	36.1 $\pm$ 4.0	33.3	38.8	
$\dot{V}_E/\dot{V}CO_2$	TBI	30.2 $\pm$ 4.6	28.1	32.2	$p = 0.56$
	CON	29.4 $\pm$ 4.2	27.3	31.4	
Heart Rate (beats $\cdot$ min ⁻¹)	TBI	166.7 $\pm$ 19.8	158.1	175.3	$p = 0.11$
	CON	176.4 $\pm$ 17.2	167.8	185.1	

Abbreviations: SD, standard deviation; $\dot{V}O_2$, volume of oxygen consumed; $\dot{V}CO_2$, ventilatory equivalents of carbon dioxide production; RER, respiratory exchange ratio; $\dot{V}_E$, minute ventilation, $\dot{V}_E/\dot{V}O_2$, ventilatory equivalents of oxygen consumption, $\dot{V}_E/\dot{V}CO_2$, ventilatory equivalents of carbon dioxide production.