ORIGINAL ARTICLE

Energy expenditure in people with motor-complete paraplegia

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Study design: The present descriptive clinical and laboratory study is cross-sectional in design.

Objectives: The primary aim is to describe and compare resting energy expenditure (REE) and energy expenditure (EE) during different standardized sedentary, non-exercise and exercise activities in people with motor-complete paraplegia (Th7 to Th12.). A secondary aim was to compare men and women.

Methods: Thirty-eight adults (10 women) with SCI, T7–T12 AIS A–B, were recruited. All the data were collected through indirect calorimetry. REE was measured in supine for 30 min after 8 h of overnight fasting. Activity energy expenditure (AEE) for activities was measured for seven minutes during sedentary, non-exercise physical activity (NEPA) and exercise activities.

Results: AEE increased four to eight times when engaging in NEPA compared to that in sedentary activities. Men had significantly higher resting oxygen uptake compared to women, 0.19 vs 0.15 l min⁻¹ ($P=0.005$), REE per 24 h, 1286 vs 1030 kcal ($P=0.003$) and EE during weight-bearing activities. However, these became nonsignificant after adjustment for body weight and speed of movement, with a mean resting oxygen uptake of 2.47 ml O₂ per kg min⁻¹ for the whole group (women 2.43 and men 2.57 ml O₂ kg⁻¹ min⁻¹, $P=0.49$).

Conclusions: NEPA increases AEE up to eight times compared to sedentary activities. Gender differences in oxygen uptake during both rest and weight-bearing activities were diminished after adjustment for body weight. The mean resting oxygen uptake for the whole group was 2.47 ml O₂ kg⁻¹ min⁻¹. These results highlight the importance, especially of NEPA, for increasing total daily EE in the target population.

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INTRODUCTION

Improvement in rehabilitation and medical care for people with a spinal-cord injury (SCI) has increased their long-term survival, resulting in lifestyle- and age-related health issues such as a higher risk of cardiovascular disease (CVD).^{1,2} After a motor-complete SCI, the muscles below the level of injury start to atrophy and resting energy expenditure (REE) decreases during the first 6 months.^{3,4} Previous studies showed that paraplegics gained body weight during early rehabilitation, and another study showed that 3 years after the injury 44% were obese and 23% overweight.^{5,6} Also, the combination of low physical activity and a sedentary lifestyle may in the long-term increase the prevalence of overweight and obesity and other lifestyle-related chronic diseases such as CVD.^{2,6–9}

The first method of choice for CVD prevention in the general population is lifestyle changes, such as smoking cessation, increase in energy expenditure (EE) through regular physical activity, weight management and dietary control.^{10,11} Because of changed conditions after a motor-complete SCI, these recommendations are not fully applicable on the SCI population, and evidence-based adapted CVD prevention programs for physical activity and weight control for the SCI population are scarce. However, some recent studies have included recommendations about how

physical activity can improve muscle strength and cardiovascular endurance.¹²

One underlying key factor in most prevention programs is adapted information regarding EE, expressed in kcal, during rest and activities. The gold standard for measuring EE is doubly labeled water or direct calorimetry; but these methods are not suitable for clinical settings. The most common method for clinical research is indirect calorimetry.¹³ However, this method is too resource-intensive for clinical practice. Instead, practitioners estimate REE using validated equations.¹⁴ Further, EE and activity intensities are often described as multiples of REE (expressed in metabolic equivalents, METs).¹⁵ However, the use of these formulas for the SCI population is questioned, as they seem to overestimate both REE and EE during activity.^{16–22}

There are a small number of studies that have assessed EE in rest and during activities for persons with SCI, describing REE to be 14–27% lower compared to the general population.²³ Further, EE during activities calculated as METs are reported to be lower in the SCI population compared to the general population.^{17,21} However, these studies have only included small numbers of participants when assessing EE during activity^{17,21} and participants with a wide range of injury level, hence a wide range in available muscle mass.

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Moreover, studies including women are scarce;²¹ that is, women with SCI are understudied. Studies with strict inclusion criteria and larger homogenous subsamples from the SCI population are needed.^{24,25} Also, there is a need for studies including both men and women, as there are conflicting results concerning sex differences in energy metabolism and REE even after adjustment for body weight, reported in the general population.^{16,26–29}

The primary aim of the present study is therefore to describe and compare REE and EE during different standardized sedentary, non-exercise and exercise activities in people with motor-complete paraplegia (Th7 to Th12.). A secondary aim is to compare men and women.

MATERIALS AND METHODS

Thirty-eight participants (10 women) were included (Table 1). They were partly recruited through a convenience sample from a database at a regional SCI unit in Stockholm. Other methods were advertisements at SCI-specific websites, and word-of-mouth. Initially the participants were contacted and informed about the study by telephone, and if interested to participate, written information was by mail. Inclusion criteria were individuals with SCI AIS A and B, injury level T7–T12, ≥ 1 year post injury, age ≥ 18 years, with absent or minimal spasticity, as reported with the spasm frequency scale (Penn).³⁰ Exclusion criteria were known coronary artery disease, angina pectoris, chronic congestive heart failure, chronic obstructive pulmonary disease, hormone replacement therapy or shoulder pain.

Data were collected in Stockholm between May 2012 and September 2014. The REE data were collected in a laboratory and activity data in a clinical setting. All participants attended both the REE and activities. The study was approved by the Stockholm regional ethics committee, reference number 2011/1989-31/1. All the participants gave their informed written consent to participate.

Assessment of oxygen consumption at rest

REE was determined with indirect calorimetry in a thermoneutral environment, using a computerized metabolic system with ventilated hood and controlled airflow (Jaeger Oxycon Pro, Hoechberg, Germany). The system was switched on 30 min prior to data collection and calibrated with high-precision gas from a tank before each test using built-in automated procedures. All the tests were scheduled between 0730 and 1000 hours. The participants fasted overnight (>8 h) and were asked to refrain from nicotine and caffeine, and to avoid vigorous activity 24 h before testing. On arrival, the subjects

were instructed to lie down and rest for 30 min on a bed in the quiet laboratory with the ventilated hood placed over the head and shoulders. The lowest steady VO_2 recorded for at least 10 min was used to calculate REE.

Assessment of oxygen consumption for the different activities

Fifteen standardized activities were selected to represent a wide range of intensities. The activities included two sedentary ones (defined as, behavior while sitting or lying down, ≤ 1.5 METs³¹), four NEPA, which are the predominant component of daily activity, and spontaneous physical activities, 1.5–6 METs.³² Seven exercise activities, defined as 'planned, structured and repetitive bodily movement done to improve or maintain one or more components of physical fitness' 3–18 METs.³³ The sedentary activities included watching television and desk-based computer work. The NEPA included setting a table following a standardized procedure, wheeling a manual wheelchair indoors at preferred 'walking pace', wheeling the wheelchair outside on asphalt at 'walking pace' or perceived as 10 to 11 (light exertion) on the Borg RPE scale,^{34,35} cycling outdoors at 'walking pace' or perceived as 10 to 11 on the Borg RPE scale. The exercise activities included hand bike outdoors at 'exercise pace', Borg 'somewhat hard' 13–14, ski ergometer work at 'exercise pace' perceived as 13 to 14 'somewhat hard', arm ergometer work at 18, 24, 36 or 42 Watts at 60 r.p.m. (Ergonomic 891E Monark, Sweden), weight training at 10 repetitions at each station and circuit-resistance training modified from Nash *et al.* (2001).³⁶

The participants were asked to refrain from smoking and vigorous activity 12 h before testing. They performed each activity for seven minutes. The Jaeger Oxycon Mobile system (Hoechberg, Germany) was used to measure VO_2 and VCO_2 breath-by-breath, and the mean VO_2 during the activity. Values for the last 3 min of each activity were used to calculate EE. The system was calibrated and verified with reference gases and room air before the start of each test. A variation $<3\%$ for each steady-state measurement was accepted. The Jaeger system is valid down to 1.0 l/min compared to the gold standard—that is, the Douglas Bag method.³⁷ As our SCI population presented even lower VO_2 values during pilot testing, we performed a small validation study for lower VO_2 measurements. Ten men and women were asked to sit quietly for 10 min and, in random order, VO_2 was measured using the Oxycon Mobile system and the Douglas bag method. The last eight minutes were analyzed. Mean (s.d.) for the Oxycon Mobile was 0.281 (0.043) and for the Douglas Bag method was 0.270 (0.042), showing a nonsignificant difference with a mean of 0.011, 95% confidence interval; -0.007 to 0.029 .

Before each test, the participants were given verbal standardized information regarding the activity and a demonstration of how to perform it. The test gear was then fitted and wheelchair tire pressure checked. For the activities involving instruction about pace, the investigator used the standardized instruction and Borg RPE scale.^{34,35} For weight training, the instruction was to select a weight that the participant was able to lift ten times during a specific exercise in a calm and controlled tempo. The participants were also asked to perform the circuit-resistance training with one second for concentric phase and two seconds for the eccentric phase. Body weight was measured using a scale calibrated to the nearest 0.1 kg. Height was self-reported to the nearest centimeter. Regarding missing data, eighteen men and three women could not perform one or several activities (wheeling outdoors, hand biking outdoors, weight training, ski ergometer and circuit-resistance training) owing to weather conditions or technical problems. Twenty-two men and seven women did not perform hand biking outdoors at 'walking pace' and hand bike outdoors at 'exercise pace' because these activities were introduced at the second phase of the data collection. One subject could not manage the ski ergometer activity due to poor sitting balance.

Data analysis

The indirect calorimetry measurements were recorded and analyzed using the JLAB software (Carefusion, Hoechberg, Germany). All the data were then entered and further analyzed using SPSS version 22.0. Steady-state VO_2 -data (l/min) was used to calculate EE (kcal) during rest and for the different activities, using the thermal equivalents of oxygen for the non-protein respiratory exchange ratio ($\text{VCO}_2 / \text{VO}_2$). The MET values were obtained by dividing VO_2 (ml O_2 per kg min^{-1}) at steady state for each activity by the individually assessed VO_2 at rest. Energy expenditure during activities was also

Table 1 Characteristics of participants, resting oxygen consumption and resting energy expenditure (mean $\pm$ s.d.)

	All	Women	Men
<i>n</i>	38	10	28
Age (years)	43.11 $\pm$ 11.5	38.8 $\pm$ 10.84	44.6 $\pm$ 11.7
Height (cm)	1.74 ^a $\pm$ 0.98	165 $\pm$ 0.05	181 $\pm$ 0.07
Weight (kg)	73.7 ^a $\pm$ 15.1	59.7 $\pm$ 8.5	78.7 $\pm$ 13.8
BMI	23.4 $\pm$ 3.7	21.9 $\pm$ 3.28	23.9 $\pm$ 3.71
Years since injury	15.8 $\pm$ 11.3	14.6 $\pm$ 10.8	16.2 $\pm$ 11.7
0–15 years <i>n</i>	20	6	14
16–30 years <i>n</i>	15	3	12
31–45 years <i>n</i>	3	1	2
Resting VO_2 (l min^{-1})	0.18 ^a $\pm$ 0.04	0.15 $\pm$ 0.03	0.19 $\pm$ 0.03
Resting VO_2 (ml kg^{-1} min^{-1})	2.47 $\pm$ 0.51	2.57 $\pm$ 0.57	2.43 $\pm$ 0.49
REE (kcal min^{-1})	0.846 ^a $\pm$ 0.17	0.715 $\pm$ 0.143	0.893 $\pm$ 0.155

Abbreviations: BMI, body mass index cm, centimeters; Kg, kilograms; Min, minutes; REE, resting energy expenditure; VO_2 , volumetric oxygen consumption.

^aSignificant difference between women and men $P < 0.05$.

expressed as total energy expenditure (TEE) and activity energy expenditure (AEE), calculated from each participant's individual $TEE - REE = AEE$.

The VO_2 ($l \min^{-1}$) measurement variables assessed during rest and during the standardized activities were analyzed for normal distribution using the Shapiro-Wilk test to be able to compare with previous data.¹⁷ As all the variables were normally distributed, the data are presented as mean (s.d.).

RESULTS

In the total study population, mean resting absolute oxygen uptake was $0.18 l \min^{-1}$ and $2.47 ml O_2$ per $kg \min^{-1}$ when related to body weight (Table 1). Men had a significant higher resting oxygen uptake compared to women, $0.19 l \min^{-1}$ vs $0.15 l \min^{-1}$ ($P=0.005$), with a corresponding higher mean daily REE, 1286 kcal vs 1030 kcal ($P=0.003$). Men were significantly taller and heavier than were women, resulting in a between-gender comparable resting oxygen consumption related to body weight—women 2.43 and men $2.57 ml O_2$ per $kg \min^{-1}$, $P=0.49$. Men had somewhat higher body mass index (BMI) than women had.

Total oxygen consumption and TEE as well as activity oxygen consumption and AEE for the thirteen standardized activities are presented for all participants and separately for women and men in Tables 2 and 3, respectively. As the pace or rate for some of the activities were chosen according to relative intensity (Borg-scale), rather than absolute levels, there were large intra-individual variations. Subsequently, these values are presented per $km h^{-1}$ or watt. Table 3 also presents the mean MET values for each activity based on the individually assessed VO_2 at rest. The lowest total oxygen consumption and TEE were obtained for sedentary activities, increasing two- to threefold while engaging in the different NEPA activities. The highest values were obtained during the exercise activity wheeling wheelchair outdoors for men and hand bike outdoors for women. Men had in general higher total oxygen consumption and TEE, except for the sedentary activities and the arm-cranking exercises, the latter standardized to specific work rates for both men and women. However, when relating the oxygen uptake and EE to body weight, the gender differences became nonsignificant (except for weight training). Removing the influence of REE from the EE values obtained during activity (expressed as AEE, Table 3), indicated even greater relative increases in oxygen consumption and EE between sedentary and NEPA activities. Compared to watching TV, setting the table induced a more than fourfold AEE, with up to an eightfold increase while hand biking outdoors in walking pace. The highest AEE value was measured during wheelchair wheeling outdoors at 'exercise pace' for men, 14 times higher AEE compared to watching TV, and hand bike 'exercise pace' for women, > 11 times higher AEE than watching TV. Men had higher activity oxygen consumption and AEE for the same activities as for the total values, and only weight training remained significantly different between genders after adjustment for body weight.

DISCUSSION

The main findings in this study were that EE above resting values, AEE, increased between four- and eightfold only by engaging in non-exercise activities of daily life compared to watching TV. Engaging in exercise activities increased the AEE even further, up to between 11- to 14-fold while wheeling outdoors in exercise pace (men) and hand bike outdoors (women). Moreover, resting oxygen consumption equaled $2.47 (ml O_2 \text{ per } kg \min^{-1})$ in the total population, which is ~30% lower than that reported for the general population.¹⁵ Some gender differences in oxygen consumption and EE were seen in both

in rest and during the activities; however, these became nonsignificant after adjustments for body weight.

The present resting oxygen uptake is similar or lower to previous studies on motor-complete and incomplete women and men, between 2.28 and $3.0 ml O_2$ per $kg \min^{-1}$.^{21,23,38-40} Lee *et al.*²¹ reported a 25% higher resting oxygen uptake in motor-complete and incomplete paraplegic men and women with a mixed levels and completeness of lesion, $3.1 ml O_2$ per $kg \min^{-1}$, compared to $2.47 ml O_2$ per $kg \min^{-1}$ in the present study. Collins *et al.* included only men with complete (52%) or incomplete T1- L4 SCI, and reported a resting oxygen consumption of $2.77 O_2$ per $kg \min^{-1}$, which is slightly higher than that for men in the present study. The mean BMI for the participants (T1 to L4) in the study by Collins *et al.*¹⁷ was similar as for men in this study (23.9), and the remaining difference in resting oxygen consumption between the two samples probably are explained by the inclusion of both motor-complete/incomplete low-level injuries in the Collins study. This research field is still to be considered in an exploratory phase, as studies with injury-level homogenous samples including both genders are limited. As the resting values seem to vary according to injury completeness and level, a single accepted value for resting oxygen uptake may not be feasible to be obtained in the SCI population (as $3.5 O_2$ per $kg \min^{-1}$ is in the general population). In the present study, we included a large sample of men and women with motor-complete paraplegia between T7 to T12, an injury level span which is homogenous. Thus, for example, motor-complete injury above T7 might be influenced by impaired innervation of the sympathetic nervous system, which will reduce the cardiovascular function⁴¹ and the amount of available muscle mass. Injuries below T12 on the other hand, affect the supply of motor innervation for hip and leg muscles.⁴² Lower-body muscles have a higher EE because of their size and would most likely influence the REE. Further, it is still unclear whether regional adaptations in body composition may influence parameters of REE and AEE in persons with SCI.^{43,44} Hence, we believe that the values obtained in the present study may be representative of oxygen uptake and EE in men and in women within this homogenous group.

There is growing interest in research into how non-exercise activity can reduce risk factors and improve health in the general population.^{32,45} As demonstrated in the present study, the increase in AEE from sedentary activities to engaging in NEPA of daily life, such as setting the table or wheeling indoors, is highly clinically relevant and may be an important factor to consider when trying to increase total EE in everyday life and improve health for the target group. For example, a person weighing 80 kg who adds thirty minutes of wheelchair wheeling indoors ($4 km h^{-1}$) in bursts, and also performs household work for one hour, increases his or her AEE by about 150 kcal/day compared to watching TV during the period of time. This is comparable with one hour of wheeling outdoors at exercise pace ($8 km h^{-1}$). As a high proportion of the SCI population is reportedly physically inactive,²⁴ it might be a shorter step to go from being mainly sedentary to perform non-exercise activities of daily life rather than to start with exercise activities. Therefore, knowledge about AEE and how NEPA can contribute to an increase in total daily energy expenditure may act as motivation for people with a SCI, and may provide an evidence-based foundation for SCI personnel developing and working with prevention programs. For example, in the general population NEPA has been associated with lower insulin resistance in type 2 diabetic patients.⁴⁶ Further, that paraplegics who are physically active during leisure time at mild-to-moderate intensity for more than 25 min per day have been reported to have lower BMI, smaller waist circumference, less insulin resistance and lower systolic

Table 2 Total oxygen consumption and total energy expenditure for standardized physical activities in people with T7-12 motor-complete SCI

Activities	n (W/M)	Total oxygen consumption $\dot{V}O_2$ ml kg min ⁻¹ / (km h ⁻¹ or Watt)						TEE kcal min ⁻¹ / (km h ⁻¹ or Watt)					
		Total oxygen consumption $\dot{V}O_2$ l min ⁻¹			Total oxygen consumption $\dot{V}O_2$ ml kg min ⁻¹ / (km h ⁻¹ or Watt)			TEE kcal min			TEE kcal kg min ⁻¹ / (km h ⁻¹ or Watt)		
		Mean ± s.d.			Mean ± s.d.			Mean ± s.d.			Mean ± s.d.		
		All	Women	Men	All	Women	Men	All	Women	Men	All	Women	Men
Sedentary													
Watch TV	38 (10/28)	0.26 ± 0.05	0.22 ± 0.04	0.27 ± 0.04	3.51 ± 0.65	3.58 ± 0.72	3.48 ± 0.63	1.23 ± 0.24	1.03 ± 0.19	1.3 ± 0.22	0.017 ± 0.003	0.017 ± 0.003	0.017 ± 0.003
Computer desk work	38 (10/28)	0.27 ± 0.06	0.22 ± 0.04	0.28 ± 0.05	3.69 ± 0.67	3.79 ± 0.73	3.65 ± 0.66	1.30 ± 0.26	1.09 ± 0.17	1.37 ± 0.25	0.017 ± 0.003	0.017 ± 0.003	0.017 ± 0.003
NEPA													
Setting a table	38 (10/28)	0.52 ± 0.19	0.39 ± 0.06	0.56 ± 0.09	7.09 ± 1.25 ^a	6.53 ± 1.06	7.29 ± 1.27	2.46 ± 0.53 ^a	1.84 ± 0.29	2.68 ± 0.41	0.034 ± 0.006	0.031 ± 0.005	0.035 ± 0.006
Wheeling the wheel-chair indoors (km h ⁻¹)	38 (10/28)	0.62 ± 0.17 ^a	0.42 ± 0.10	0.68 ± 0.17	1.88 ± 0.26 ^b	1.87 ± 0.27 ^b	1.88 ± 0.27 ^b	2.95 ± 0.92 ^{a,b}	1.9 ± 0.06	3.28 ± 0.8	0.009 ± 0.001 ^b	0.009 ± 0.001 ^b	0.009 ± 0.001 ^b
Wheeling the wheel-chair outdoors 'Borg 10 to 11' (km h ⁻¹)	37 (10/27)	0.74 ± 0.21 ^a	0.52 ± 0.11	0.82 ± 0.18	1.55 ± 0.26 ^b	1.56 ± 0.24 ^b	1.55 ± 0.28 ^b	3.55 ± 1.0 ^a	2.46 ± 0.5	3.95 ± 0.9	0.007 ± 0.001 ^b	0.007 ± 0.001 ^b	0.007 ± 0.001 ^b
Hand bike outdoors 'Borg 10 to 11' (km h ⁻¹)	18 (3/15)	0.81 ± 0.16	0.69 ± 0.07	0.83 ± 0.17	1.13 ± 0.28 ^b	1.53 ± 0.027 ^b	1.06 ± 0.25 ^b	3.87 ± 0.80	3.49 ± 0.09	3.94 ± 0.83	0.005 ± 0.002 ^b	0.008 ± 0.0002 ^b	0.005 ± 0.001 ^b
Exercise													
Weight training	37 (10/27)	0.79 ± 0.21 ^a	0.54 ± 0.11	0.89 ± 0.16	10.92 ± 2.31	9.01 ± 1.28	11.63 ± 2.22	4.21 ± 1.25 ^a	2.72 ± 0.60	4.76 ± 0.93	0.058 ± 0.014 ^a	0.045 ± 0.007	0.062 ± 0.013
Arm cranking 18 W 'low'	11 (9/2)	0.57 ± 0.07	0.56 ± 0.06	0.89 ± 0.16	9.06 ± 1.5	9.42 ± 1.37	11.63 ± 2.22	2.8 ± 0.34	2.73 ± 0.29	4.76 ± 0.93	0.044 ± 0.008	0.046 ± 0.007	0.037 ± 0.007
Arm cranking 24 W 'low'	28 (2/26)	0.71 ± 0.09	0.54 ± 0.07	0.73 ± 0.07	9.59 ± 1.47	10.65 ± 2.84	9.51 ± 1.46	3.49 ± 0.4	2.73 ± 0.41	3.55 ± 0.34	0.047 ± 0.007	0.054 ± 0.01	0.046 ± 0.007
Arm cranking 36 W 'high'	12 (8/4)	0.75 ± 0.12	0.70 ± 0.11	0.86 ± 0.05	11.22 ± 1.53	11.30 ± 1.08	11.06 ± 2.41	3.76 ± 0.62	3.47 ± 0.54	4.34 ± 0.26	0.056 ± 0.008	0.056 ± 0.006	0.056 ± 0.01
Arm cranking 42 W 'high'	24 (1/24)	0.92 ± 0.10	0.72	0.93 ± 0.09	12.04 ± 1.88	12.67	12.0 ± 1.92	4.58 ± 0.43	3.93	4.61 ± 0.42	0.06 ± 0.01	0.69	0.06 ± 0.009
Ski ergometer (Watt)	37 (10/27)	0.95 ± 0.26 ^a	0.71 ± 0.18	1.04 ± 0.23	0.48 ± 0.18 ^c	0.66 ± 0.19 ^c	0.42 ± 0.12 ^d	4.81 ± 1.37 ^a	3.59 ± 0.87	5.27 ± 1.24	0.002 ± 0.0009 ^c	0.003 ± 0.001 ^c	0.002 ± 0.0006 ^c
Circuit training	37 (10/27)	0.96 ± 0.28 ^a	0.73 ± 0.14	1.05 ± 0.27	13.26 ± 3.10	12.29 ± 2.22	13.62 ± 3.3	4.96 ± 1.58 ^a	3.69 ± 0.74	5.43 ± 1.56	0.068 ± 0.018	0.062 ± 0.012	0.07 ± 0.019
Wheeling the wheel-chair outdoors 'Borg 13 to 14' (km h ⁻¹)	37 (10/27)	1.17 ± 0.37 ^a	0.78 ± 0.19	1.32 ± 0.30	1.79 ± 0.29 ^d	1.72 ± 0.26 ^b	1.82 ± 0.30 ^d	5.85 ± 1.88 ^a	3.86 ± 0.97	6.6 ± 1.55	0.009 ± 0.002 ^d	0.009 ± 0.001 ^d	0.009 ± 0.002 ^d
Hand bike outdoors 'Borg 13 to 14' (km h ⁻¹)	17 (3/14)	1.12 ± 0.27	0.83 ± 0.04	1.18 ± 0.26	1.12 ± 0.23 ^e	1.40 ± 0.36 ^e	1.07 ± 0.15 ^e	5.56 ± 1.53	4.2 ± 0.22	5.81 ± 1.55	0.005 ± 0.001	0.007 ± 0.002 ^e	0.005 ± 0.0009

Table 3 Activity oxygen consumption and activity energy expenditure for standardized physical activity in people with T7-12 motor-complete SCI

Activities	Activity oxygen consumption						AEE kcal min ⁻¹						AEE kcal min ⁻¹ / (km h ⁻¹ or Watt)						SCI MET
	Activity oxygen consumption			VO ₂ ml kg min ⁻¹ / (km h ⁻¹ or Watt)			AEE kcal min ⁻¹			AEE kcal min ⁻¹ / (km h ⁻¹ or Watt)			AEE kcal min ⁻¹ / (km h ⁻¹ or Watt)						
	Mean ± s.d.			Mean ± s.d.			Mean ± s.d.			Mean ± s.d.			Mean ± s.d.						
	All	Women	Men	All	Women	Men	All	Women	Men	All	Women	Men	All	Women	Men	All			
Sedentary																			
Watch TV	0.08±0.04	0.06±0.04	0.08±0.04	1.04 ± 0.57	1.01±0.79	1.05±0.49	0.38±0.19	0.31±0.18	0.40±0.19	0.006±0.002	0.006±0.002	0.005±0.002	0.006±0.002	0.006±0.002	0.005±0.002	1.47			
Computer desk work	0.09±0.004	0.07±0.04	0.09±0.04	1.22±0.53	1.22±0.72	1.22±0.46	0.45±0.19	0.37±0.16	0.48±0.19	0.006±0.002	0.005±0.005	0.006±0.002	0.006±0.002	0.005±0.005	0.006±0.002	1.55			
NEPA																			
Setting a table	0.34±0.06 ^a	0.23±0.05	0.38±0.07	4.62±1.02	3.96±0.9	4.86±0.97	1.61±0.43 ^a	1.13±0.23	1.79±0.33	0.022±0.005	0.019±0.004	0.023±0.005	0.022±0.005	0.019±0.004	0.023±0.005	2.93			
Wheeling the wheelchair indoors (km h ⁻¹)	0.44±0.17 ^a	0.27±0.09	0.5±0.15	1.30±0.23 ^b	1.19±0.25 ^b	1.34±0.21 ^b	2.10±0.81 ^a	1.30±0.42	2.38±0.72	0.006±0.001 ^b	0.006±0.001 ^b	0.006±0.001 ^b	0.006±0.001 ^b	0.006±0.001 ^b	0.006±0.001 ^b	3.48			
Wheeling the wheelchair outdoors 'Borg 10 to 11' (km h ⁻¹)	0.56±0.19 ^a	0.37±0.10	0.64±0.16	1.17±0.24 ^b	1.11±0.27 ^b	1.19±0.24 ^b	2.70±0.94 ^a	1.75±0.47	3.06±0.82	0.006±0.001 ^b	0.005±0.001 ^b	0.006±0.001 ^b	0.006±0.001 ^b	0.005±0.001 ^b	0.006±0.001 ^b	4.19			
Hand bike outdoors 'Borg 10 to 11' (km h ⁻¹)	0.64±0.24	0.54±0.1	0.65±0.16	0.88±0.21 ^c	1.18±0.13 ^c	0.83±0.21 ^c	3.05±0.76	2.77±0.52	3.1±0.8	0.004±0.0001 ^c	0.006±0.0007 ^c	0.004±0.0001 ^c	0.004±0.0001 ^c	0.006±0.0007 ^c	0.004±0.0001 ^c	4.78			
Exercise																			
Weight training	0.62±0.19 ^a	0.39±0.1	0.70±0.14	8.43±2.15 ^a	6.44±1.09	9.17±1.98	3.37±1.15 ^a	2.0±0.53	3.87±0.87	0.046±0.013 ^a	0.033±0.007 ^a	0.05±0.01 ^a	0.046±0.013 ^a	0.033±0.007 ^a	0.05±0.01 ^a	5.0			
Arm cranking 18 W 'low'	0.41±0.05	0.40±0.05	0.46±0.001	6.49±1.18	6.77±1.05	5.22±1.1	2.06±0.27	1.99±0.26	2.33±0.05	0.032±0.06	0.034±0.006	0.027±0.05	0.032±0.06	0.034±0.006	0.027±0.05	3.73			
Arm cranking 24 W 'low'	0.53±0.08	0.41±0.03	0.54±0.07	7.12±1.2	8.0±1.67	7.06±1.2	2.62±0.35	2.10±0.23	2.66±0.33	0.035±0.06	0.041±0.01	0.035±0.06	0.035±0.06	0.041±0.01	0.035±0.06	4.11			
Arm cranking 36W 'high'	0.59±0.10	0.54±0.09	0.68±0.06	8.77±1.30	8.76±0.90	8.79±2.07	2.99±0.55	2.74±0.47	3.49±0.27	0.044±0.007	0.044±0.005	0.045±0.01	0.044±0.007	0.044±0.005	0.045±0.01	4.90			
Arm cranking 42 W 'high'	0.74±0.09	0.61	0.75±0.08	9.67±1.69	10.87	9.61±1.70	3.70±0.38	3.43	3.71±0.38	0.049±0.009	0.06	0.049±0.009	0.049±0.009	0.06	0.049±0.009	5.36			
Ski ergometer (Watt)	0.77±0.24 ^a	0.56±0.16	0.85±0.22	0.38±0.13 ^{a,d}	0.51±0.14 ^d	0.34±0.10 ^d	3.97±1.26	2.87±0.79	4.37±1.16	0.002±0.0007 ^d	0.003±0.0008 ^d	0.002±0.0005 ^d	0.002±0.0008 ^d	0.003±0.0008 ^d	0.002±0.0005 ^d	5.71			
Circuit training	0.78±0.25 ^a	0.58±0.13	0.86±0.25	10.77±2.86	9.72±2.01	11.16±3.06	4.12±1.47 ^a	2.98±0.68	4.54±1.47	0.056±0.017	0.05±0.011	0.059±0.018	0.056±0.017	0.05±0.011	0.059±0.018	5.87			
Wheeling the wheelchair outdoors 'Borg 13 to 14' (km h ⁻¹)	0.99±0.33 ^a	0.62±0.17	1.13±0.29	1.51±0.29 ^e	1.39±0.26 ^e	1.55±0.28 ^e	5.01±1.79 ^a	3.15±0.89	5.72±1.52	0.004±0.001 ^e	0.004±0.0001 ^e	0.004±0.001 ^e	0.004±0.001 ^e	0.004±0.0001 ^e	0.004±0.001 ^e	6.99			
Hand bike outdoors 'Borg 13 to 14' (km h ⁻¹)	0.95±0.26	0.68±0.08	1.00±0.25	0.94±0.20 ^c	1.14±0.33 ^c	0.90±1.49 ^c	4.74±0.39 ^c	3.54±1.51 ^c	4.97±1.51 ^c	0.005±0.001 ^c	0.006±0.002 ^c	0.004±0.001 ^c	0.005±0.001 ^c	0.006±0.002 ^c	0.004±0.001 ^c	6.91			

Abbreviations: AEE, activity energy expenditure, that is, total energy expenditure (–) resting energy expenditure. NEPA, non-exercise physical activity.

^aSignificant difference between men and women $P<0.01$.

^bper km h⁻¹. Mean (range)—wheelchair indoors; women 3.8 km h⁻¹ (2.9–4.8). Men 4.7 km h⁻¹ (2.9–5.8). Outdoors 'Borg 10 to 11' women 5.9 km h⁻¹ (4.7–6.9). Men 6.9 km h⁻¹ (4.9–8.5).

^cper km h⁻¹. Mean (range)—hand bike outdoors 'Borg 10 to 11' women 8.3 km h⁻¹ (6.6–11.6); men 10.1 km h⁻¹ (7.3–13). Hand bike outdoors 'Borg 13 to 14' women 10.1 km h⁻¹ (6.4–12.3); six men 14.3 km h⁻¹ (10.9–17.3).

^dper Watt. Mean (range)—women 19.2 (12–31); men 34.2 (15–69).

^eper km h⁻¹. Mean (range)—wheelchair outdoors 'Borg 13 to 14' women 7.5 km h⁻¹ (6.7–8.9); men 9.4 km h⁻¹ (6.7–12).

blood pressure, compared to inactive/sedentary people.⁴⁷ Moreover, persons who wheeled 2.1 km or more during a day had a lower BMI,⁶ and paraplegics fat oxidation appears to be highest during low-level intensity Borg (RPE < 9).⁴⁸ However, engaging in more intense exercise activities increases EE even further and with even greater effects on metabolic profiles, muscle strength and endurance capacity.^{49–51}

Regarding weight training, which may not be an activity with primary focus on EE, even though it had a moderately high EE. However, it is still important for preventing shoulder pain⁵² and increasing muscle strength so as to be able to be as independent as possible in activities of daily life.⁵³ Further, AEE increased by 20% in circuit-resistance training than in weight training. This suggests that circuit-resistance training could be an effective exercise activity for both cardiorespiratory endurance and muscle strength. Additional muscle mass tissue increases both the AEE and REE.³⁶

This study also calculated SCI-specific MET values from the individual REE assessed in the present study. It is challenging to compare the MET values between studies of the SCI population, because of methodological differences such as how to cluster injury levels and completeness, and whether they measure wheeling speed when wheeling the wheelchair.^{17,21,40,54} However, interestingly, the SCI-specific MET values for sedentary and NEPA activities in the present study are similar when comparing with values reported for the general population.¹⁵ This indicates that a person with SCI is able to increase his/hers EE with similar relative intensity as an ambulatory person does for activities of daily life. However, as absolute REE is lower in the SCI population, absolute and total EE for the activity performed during a specific time period will be lower for the person with SCI.

Men had significant higher absolute oxygen uptake and EE compared to women in rest and when engaging in both non-exercise and exercise 'weight-bearing' activities (except for hand bike outdoors, where only 3 women participated). However, these differences were diminished after adjusting for body weight and speed of movement. This is in line with previous research.²¹ This may indicate that the differences seen for absolute levels in both rest and during weight-bearing activities probably were explained by a higher lean body mass and active muscle tissue mass among men. This is further strengthened by the nonsignificant differences between men and women for the arm-cranking with standardized work rates. Unfortunately, only BMI and no further measure of body composition are available, and this cannot be concluded in the present sample. Studies conducted in the general population report some differences between genders for resting values after adjustments for body weight.¹⁶ However, these differences become nonsignificant after adjustment for lean body mass.²⁷ However, men in general tend to have higher maximum oxygen uptake, which may influence EE, and the exercise muscle metabolism is reported to differ between genders.²⁹ We believe that the intra-individual variation in EE is explained by other factors beyond gender differences. Approximately 70–80% of the variation in daily EE can be explained by fat-free mass in both the general and SCI population.^{27,55,56} However, there is a large unexplained variability in EE between persons with similar lean body mass. More recent research suggests intra-individual variations in mitochondrial oxygen affinity ($p50_{mito}$)—that is, efficiency of the mitochondria.⁵⁷ This influences both EE in rest and during exercise. Moreover, variation in thermogenic brown adipose tissue is another recently highlighted factor to explain intra-individual variations in EE beyond variation in lean body mass.⁵⁷ Brown adipose tissue has initially been considered as only present as heat generator in new born babies to preserve core

temperature, but it has now been detected also in adults.⁵⁸ Brown adipose tissue possesses a large numbers of mitochondria, in which substrate metabolism consists of mainly free fatty acids (up to 90%) released as heat.⁵⁹ Neither variation in $p50_{mito}$ nor brown adipose tissue have been demonstrated to vary significantly between gender, but rather depending on other intra-individual factors.

There is little research on weight management and EE calculations from activities in the SCI population. One previous study suggested an education program for weight loss with a combination of energy-calculated diet, PA and behavior changes.⁶⁰ The study was based on the time-calorie displacement dietary approach; once a week for 12 weeks the participants attended a 90-min group class. The intention of the classes was to increase the knowledge of nutrition and exercise on weight control. The study resulted in significant weight loss for the group. The results from this study and similar ones might add information regarding SCI-specific AEE that could be useful when designing therapeutic lifestyle-based intervention programs.

Strengths and limitations

This study is limited by the low number of participants, few of whom were women, compared to studies in the general population. This may limit the possibility to find differences between men and women. Further, there was no control group for comparing REE and EE during activities. In the present study, we only measured weight and height of the participants, with subsequent calculation of BMI. We are aware that BMI has its limitation in describing body composition in the SCI population.⁶¹ However, when dividing VO_2 (l/min) in rest and for the different activities with body weight, only small differences between men and women are left, indicating small variation in body composition between men and women. Other measurements that better reflect body composition, such as DEXA, would have been preferable to further elucidate and explore intra-individual differences in REE and EE. This might have added further information that could have deepened the understanding of the results. Last, the results are not generalizable to the whole SCI population. Strengths are that all the data were collected in close approximation with real-life conditions, with a homogeneous group regarding injury level, and ~25% women. Further, all the participants got the possibility to carry out both the REE and all the activities. The study also provides information on energy expenditure without resting energy expenditure, which is useful for calculating total daily energy expenditure.

CONCLUSION

The main findings in this study of people with motor-complete SCI are that non-exercise activities of daily life, such as setting a table and propelling a wheelchair indoors/outdoors, increase AEE up to eight times compared to sedentary activities. AEE during exercise increased even more, up to 14 times during hand bike outdoors in men. REE equaled 2.47 ml O_2 per $kg\ min^{-1}$, which is similar or lower to previously reported values in the SCI population. This may be due to larger variation in completeness and level of injury in other studies compared to the present. No or small differences in REE or AEE were seen between women and men after adjustment for body weight and speed. These results are highly clinically relevant and highlight the importance of engaging in both non-exercise activities of daily life as well as exercise to increase total daily EE in the target population. More research is needed and should include people with tetraplegia and incomplete injuries.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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- Myers J, Lee M, Kiratli J. Cardiovascular disease in spinal cord injury: an overview of prevalence, risk, evaluation, and management. *Am J Phys Med Rehabil* 2007; **86**: 142–152.
- Wahman K, Nash MS, Lewis JE, Seiger A, Levi R. Increased cardiovascular disease risk in Swedish persons with paraplegia: The Stockholm spinal cord injury study. *J Rehabil Med* 2010; **42**: 489–492.
- Gorgey AS, Dudley GA. Skeletal muscle atrophy and increased intramuscular fat after incomplete spinal cord injury. *Spinal cord* 2007; **45**: 304–309.
- Castro MJ, Apple DF Jr, Hilleagass EA, Dudley GA. Influence of complete spinal cord injury on skeletal muscle cross-sectional area within the first 6 months of injury. *Eur J Appl Physiol Occup Physiol* 1999; **80**: 373–378.
- Cox SAR et al. ENERGY-EXPENDITURE AFTER SPINAL-CORD INJURY-AN EVALUATION OF STABLE REHABILITATING PATIENTS. *J Trauma* 1985; **25**: 419–423.
- Hatchett PE, Mulroy SJ, Eberly VJ, Haubert LL, Requejo PS. Body mass index changes over 3 years and effect of obesity on community mobility for persons with chronic spinal cord injury. *J Spinal Cord Med* 2016; **39**: 421–432.
- Holtz A, L R. Ryggmärgsskador—Behandling och Rehabilitering. Studentlitteratur: Sweden, 2006.
- Wahman K, Nash MS, Westgren N, Lewis JE, Seiger A, Levi R. Cardiovascular disease risk factors in persons with paraplegia: the Stockholm spinal cord injury study. *J Rehabil Med* 2010; **42**: 272–278.
- Crane DA, Little JW, Burns SP. Weight gain following spinal cord injury: a pilot study. *J Spinal Cord Med* 2011; **34**: 227–232.
- National Guidelines for Methods of Preventing Disease. <http://www.socialstyrelsen.se/nationalguidelines/nationalguidelinesformethodsofpreventingdisease>. Accessed on 12 May 2016.
- Expert Panel On Detection, E., And Treatment Of High Blood Cholesterol In Adults. Executive Summary of the Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III. *JAMA* 2001; **285**: 2468–2497.
- Ginis KAH, Latimer AL, Warburton AE, Bourne DE, Ditor C, Goodwin DS et al. The development of evidence-informed physical activity guidelines for adults with spinal cord injury. *Spinal cord* 2011; **49**: 1088–1096.
- Ainslie P, Reilly T, Westerterp K. Estimating human energy expenditure: a review of techniques with particular reference to doubly labelled water. *Sports Med* 2003; **33**: 683–698.
- Harris JA, Benedict FG. A biometric study of human basal metabolism. *Proc Natl Acad Sci USA* 1918; **4**: 370–373.
- Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF et al. Compendium of physical activities: classification of energy costs of human physical activities. *Med Science Sports Exerc* 1993; **25**: 71–80.
- Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. *J Appl Physiol* 2005; **99**: 1112–1119.
- Collins EG, Gater D, Kiratli J, Butler J, Hanson K, Langbein WE. Energy cost of physical activities in persons with spinal cord injury. *Med Science Sports Exerc* 2010; **42**: 691–700.
- Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. *Am J Clin Nutr* 1998; **68**: 1223–1227.
- Bauman WA, Spungen AM, Wang J, Pierson RN. The relationship between energy expenditure and lean tissue in monozygotic twins discordant for spinal cord injury. *J Rehabil Res Dev* 2004; **41**: 1–8.
- Buchholz AC, McGillivray CF, Pencharz PB. Differences in resting metabolic rate between paraplegic and able-bodied subjects are explained by differences in body composition. *Am J Clin Nutr* 2003; **77**: 371–378.
- Lee MZ, Hedrick W, Fernhall B. Determining metabolic equivalent values of physical activities for persons with paraplegia. *Disabil Rehabil* 2010; **32**: 336–343.
- Price M. Energy expenditure and metabolism during exercise in persons with a spinal cord injury. *Sports Med* 2010; **40**: 681–696.
- Nevin AN, Steenson J, Vivanti A, Hickman IJ. Investigation of measured and predicted resting energy needs in adults after spinal cord injury: a systematic review. *Spinal cord* 2015; **54**: 248–253.
- Buchholz AC, McGillivray CF, Pencharz PB. Physical activity levels are low in free-living adults with chronic paraplegia. *Obes Res* 2003; **11**: 563–570.
- Buchholz AC, Pencharz PB. Energy expenditure in chronic spinal cord injury. *Curr Opin Clin Nutr Metab Care* 2004; **7**: 635–639.
- Tarnopolsky LJ, MacDougall JD, Atkinson SA, Tarnopolsky MA, Sutton JR. Gender differences in substrate for endurance exercise. *J Appl Physiol* (1985) 1990; **68**: 302–308.
- Buchholz AC, Rafii M, Pencharz PB. Is resting metabolic rate different between men and women? *Br J Nutr* 2001; **86**: 641–646.
- Wu BN, O'Sullivan AJ. Sex differences in energy metabolism need to be considered with lifestyle modifications in humans. *J Nutr Metab* 2011; **2011**: 391809.
- Devries MC. Sex-based differences in endurance exercise muscle metabolism: impact on exercise and nutritional strategies to optimize health and performance in women. *Exp Physiol* 2016; **101**: 243–249.
- Penn RD. Intrathecal baclofen for severe spasticity. *Ann N Y Acad Sci* 1988; **153**: 157–166.
- Pate RR, O'Neill JR, Lobelo F. The evolving definition of 'sedentary'. *Exerc Sport Sci Rev* 2008; **36**: 173–178.
- Levine JA. Nonexercise activity thermogenesis - liberating the life-force. *J Intern Med* 2007; **262**: 273–287.
- Caspersen CJ, Powell KE, Christenson GM. Physical-activity, exercise, and physical-fitness-definitions and distinctions for health-related research. *Public Health Reports* 1985; **100**: 126–131.
- Borg BG. Borg-RPE-skalan. *En Enkel Metod for Bestamning av Upplevd Anstrangning*. Borg Perception: Stockholm, 1994.
- Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982; **14**: 377–381.
- Jacobs PL, Nash MS, Rusinowski JW. Circuit training provides cardiorespiratory and strength benefits in persons with paraplegia. *Med Sci Sports Exerc* 2001; **33**: 711–717.
- Rosdahl H, Gullstrand L, Salier-Eriksson J, Johansson P, Schantz P. Evaluation of the Oxycon Mobile metabolic system against the Douglas bag method. *Eur J Appl Physiol* 2010; **109**: 159–171.
- Gorgey AS, Chiodo AE, Zemper ED, Hornyak JE, Rodriguez GM, Gater DR. Relationship of spasticity to soft tissue body composition and the metabolic profile in persons with chronic motor complete spinal cord injury. *J Spinal Cord Med* 2010; **33**: 6–15.
- Bauman WA, La Fontaine MF, Cirmigliaro CM, Kirshblum SC, Spungen AM. Lean tissue mass and energy expenditure are retained in hypogonadal men with spinal cord injury after discontinuation of testosterone replacement therapy. *J Spinal Cord Med* 2015; **38**: 38–47.
- Lynch MM, McCormick Z, Liem B, Jacobs G, Hwang P, Hornby TG et al. Energy cost of lower body dressing, pop-over transfers, and manual wheelchair propulsion in people with paraplegia due to motor-complete spinal cord injury. *Top Spinal Cord Injury Rehabil* 2015; **21**: 140–148.
- Garstang SV, Miller-Smith SA. Autonomic nervous system dysfunction after spinal cord injury. *Phys Med Rehabil Clin N Am* 2007; **18**: 275–296 vi-vii.
- Schmid A, Huonker M, Stahl F, Barturen JM, König D, Heim M et al. Free plasma catecholamines in spinal cord injured persons with different injury levels at rest and during exercise. *J Auton Nerv Syst* 1998; **68**: 96–100.
- Gorgey AS, Gater DR. Regional and relative adiposity patterns in relation to carbohydrate and lipid metabolism in men with spinal cord injury. *Appl Physiol Nutr Metab* 2011; **36**: 107–114.
- Maggioni M et al. Body composition assessment in spinal cord injury subjects. *Acta Diabetol* 2003; **40**(Suppl 1): S183–S186.
- Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes* 2007; **56**: 2655–2667.
- Hamasaki H et al. Correlations of non-exercise activity thermogenesis to metabolic parameters in Japanese patients with type 2 diabetes. *Diabetol Metab Syndr* 2013; **5**: 26.
- Buchholz AC, Martin Ginis KA, Bray SR, Craven BC, Hicks AL, Hayes KC et al. Greater daily leisure time physical activity is associated with lower chronic disease risk in adults with spinal cord injury. *Appl Physiol Nutr Metab* 2009; **34**: 640–647.
- Kressler J, Cowan RE, Ginnity K, Nash MS. Subjective measures of exercise intensity to gauge substrate partitioning in persons with paraplegia. *Top Spinal Cord Inj Rehabil* 2012; **18**: 205–211.
- Kressler J, Cowan RE, Bigford GE, Nash MS. Reducing Cardiometabolic Disease in Spinal Cord Injury. *Phys Med Rehabil Clin N Am* 2014; **25**: 573.
- de Groot PC, Hjeltne N, Heijboer AC, Stal W, Birkeland K. Effect of training intensity on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord injured individuals. *Spinal Cord* 2003; **41**: 673–679.
- Hooker SP, Wells CL. Effects of low- and moderate-intensity training in spinal cord-injured persons. *Med Sci Sports Exerc* 1989; **21**: 18–22.
- Kemp BJ, Bateham AL, Mulroy SJ, Thompson L, Adkins RH, Kahan JS. Effects of reduction in shoulder pain on quality of life and community activities among people living long-term with SCI paraplegia: a randomized control trial. *J Spinal Cord Med* 2011; **34**: 278–284.
- Devillard X, Rimaud D, Roche F, Calmels P. Effects of training programs for spinal cord injury. *Ann Readapt Med Phys* 2007; **50**: 490–498.
- Ainsworth BE, Haskell WL, Irwin MC, Swartz ML, Strath AM, O'Brien SJ et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000; **32**: S498–S504.
- Sedlock DA, Lavature SJ. Body-composition and resting energy-expenditure in long-term spinal-cord injury. *Paraplegia* 1990; **28**: 448–454.
- Ravussin E, Lillioja S, Anderson TE, Christin L, Bogardus C. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. *J Clin Invest* 1986; **78**: 1568–1578.
- Larsen FJ, Schiffer TA, Sahlin K, Ekblom B, Weitzberg E, Lundberg JO. Mitochondrial oxygen affinity predicts basal metabolic rate in humans. *FASEB J* 2011; **25**: 2843–2852.

- 58 Sacks H, Symonds ME. Anatomical locations of human brown adipose tissue: functional relevance and implications in obesity and type 2 diabetes. *Diabetes* 2013; **62**: 1783–1790.
- 59 Nicholls DG, Locke RM. Thermogenic mechanisms in brown fat. *Physiol Rev* 1984; **64**: 1–64.
- 60 Chen Y, Henson S, Jackson AB, Richards JS. Obesity intervention in persons with spinal cord injury. *Spinal Cord* 2006; **44**: 82–91.
- 61 Jones LM, Goulding A, Gerrard DF. DEXA: a practical and accurate tool to demonstrate total and regional bone loss, lean tissue loss and fat mass gain in paraplegia. *Spinal cord* 1998; **36**: 637–640.