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ARTICLE

Energy expenditure and muscle activity during lying, sitting, standing, and walking in people with motor-incomplete spinal cord injury

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Abstract

Study design Cross-sectional exploratory study.

Objectives To determine oxygen uptake (VO_2), energy expenditure (EE), and muscle activity (MA) during lying (rest), sitting, standing, and walking among ambulatory individuals with spinal cord Injury (SCI) and to compare VO_2, EE, and MA between individuals with different levels of ambulation.

Setting Rehabilitation institution with a spinal cord injury unit.

Methods A total of 22 adults with motor-incomplete SCI, ten in a low-ambulation group (non-functional or household walker) and 12 in a high-ambulation group (community or normal walker). VO_2 was measured using indirect calorimetry. EE was expressed in metabolic equivalent of task (MET). MA was measured using a wireless surface electromyography device.

Results Mean VO_2 was 3.19 ml/kg/min. During lying and sitting, EE was below 1.5 METs for all participants. During standing, three participants of the low-ambulation group and none in the high-ambulation group showed MET values of >1.5. In the walking condition, all participants showed MET values above 1.5. MA during stance was higher compared to the sitting condition and significantly higher in the low-ambulation group compared to the high-ambulation group.

Conclusion Lying, supported- and unsupported sitting, without moving, appear to be sedentary behaviors for ambulatory individuals with a motor-incomplete SCI (MET values of <1.5 and a lack of MA). Walking, but not standing, is a moderate physical activity (>1.5 METs), which can be used by all individuals with motor-incomplete SCI to interrupt sedentary behavior.

Introduction

Physical activity has been associated with a reduced long-term cardiovascular disease risk in the spinal cord injured (SCI) population [1–3]. In addition, studies in healthy physically active individuals show, independent from activity levels, that prolonged periods of sedentary behavior are associated with a higher risk of type 2 diabetes, obesity, cardiovascular disease, and all-cause mortality [4–6]. Sedentary behavior is defined as any waking behavior characterized by an energy expenditure (EE) of ≤1.5 metabolic equivalents of task (METs) while in a sitting, reclining, or lying posture [7]. Although all levels of physical activity, including sedentary time, in individuals with SCI has shown not to be directly associated with biomarkers of cardiometabolic health [8], it is probable that prolonged periods of sedentary behavior, in the long term, are

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associated with diseases in individuals with SCI, who spend most of their time in a sitting posture [9, 10]. Especially since they are known to have a higher risk to develop metabolic and cardiovascular diseases compared to the general population [11].

The definition of sedentary behavior encompasses both MET and posture [7]. The standard value of one MET represents a resting oxygen uptake (VO_2) of 3.5 ml/kg/min, which represents the average resting VO_2 in the general population [12]. However, the resting VO_2 in individuals with an SCI may be different from the general population due to their altered body composition [13]. Several studies reported that the resting metabolic rate in SCI individuals is overestimated by 5–35% when the standard value is used [14–16]. Therefore, most studies use the participant's own resting VO_2 to calculate EE in METs during daily activities in the SCI population [15–19]. However, these studies mainly focused on individuals with motor-complete SCI and EE values during non-sedentary activities. The EE values associated with activities considered to be sedentary (sitting) and non-sedentary (standing/walking) in motor-incomplete SCI individuals therefore remain unknown. The motor-incomplete SCI population is a very heterogeneous group with variety in the level of injury, and residual innervation. The severity of motor deficits is therefore extremely variable among people with motor-incomplete SCI. This may lead to differences in lean body mass and difficulty in performing certain activities that consequently may lead to variation in the measured VO_2 and EE. Activities that are strenuous for individuals with more severe motor deficits might not be strenuous, and therefore not useful to interrupt sedentary behavior, for individuals with less severe motor deficits. Therefore, an evaluation of EE during a range of activities that approximate sedentary behavior among participants with a range of motor-incomplete SCI would provide valuable information about the actual physiological demand. For determining patient-specific values, in this heterogeneous group, categorization functional ambulation is necessary.

Muscle inactivity has negative consequences for health. Excessive sitting time, with contractile inactivity of the postural muscle groups, is associated with suppression of skeletal muscle lipoprotein lipase, which in turn is linked to decreased levels of HDL cholesterol, increased triglycerides levels, insulin resistance, and glucose [20, 21]. Observations in the general population suggest that brief interruptions of sedentary activities that require muscle activity (MA) lead to significant reductions in postprandial glucose and insulin levels, irrespective of the activity intensity [22, 23]. Thus, promoting even brief interruptions of sedentary time could be an important clinical intervention in the SCI population who spend most of their time in a sitting position. Both EE and MA are therefore important factors related to sedentary behavior.

An evaluation of the EE and MA profiles of individuals with SCI, during postures and activities that are assumed to represent or interrupt sedentary behavior (i.e., sitting, standing, and walking), would provide valuable information about their actual physiological demand. Therefore, the purpose of this study was to determine VO_2, EE, and MA during lying, sitting, standing, and walking among ambulatory individuals with motor-incomplete SCI. Because of the heterogeneity of the motor-incomplete SCI population, we categorized the study population on functional ambulation level to compare VO_2, EE, and MA.

Methods

Study design

This cross-sectional exploratory study was conducted at De Hoogstraat Rehabilitation, a rehabilitation institution with a SCI unit in the Netherlands. The Medical Ethics Committee of the University Medical Centre Utrecht reviewed the study protocol and concluded that this study did not fall under the scope of the Dutch Medical Research Involving Human Subjects Act (WMO). The study was subsequently approved by De Hoogstraat Rehabilitation, and informed consent was obtained from all included participants.

Procedure

Individuals with SCI visiting the outpatient clinic of De Hoogstraat Rehabilitation who fitted the inclusion and exclusion criteria were invited for this study. They were contacted by telephone and received written information. Those who consented for participation were tested on the day of their appointment at the outpatient clinic. The measurements were performed during working hours, dependent on the availability of the participants. They were asked not to consume food, drinks (other than water), or smoke for at least 4 h before the measurement. Furthermore, participants were asked not to participate in any sport or other vigorous physical activities 24 h before the measurement. Information regarding demographics, medical history, use of medication, and smoking was taken from medical charts and checked during the appointment.

Measurements were done in a fixed sequence: lying, unsupported sitting, supported sitting, standing, and walking. This order was used to minimize the need for transfers between the examination table and a chair. The knee angle of the participants during the sitting conditions was held at approximate 90° by using an adjustable table and seat. Participants who used a walking aid in daily life were permitted to use one during the standing and walking conditions when necessary. All participants wore shoes during the standing and walking conditions to avoid different walking patterns compared to their normal life. The conditions lying, sitting without support, sitting with support, and standing lasted a minimum of 5 min and walking lasted a minimum of 6 min. Walking was performed at a comfortable pace back and forth on a 15-m course.

Participants

Eligible participants were older than 18 years of age on the date of the measurement, were able to understand Dutch, and had no cognitive impairment preventing them from performing simple tasks. All participants had a motor-incomplete SCI, American Spinal Injury Association Impairment Scale C or D, for at least 1 year, and were able to stand for 5 min and walk for at least 6 min, with or without the use of an aid. Participants were excluded if they had a known allergy to electromyography (EMG) electrodes, known cardiovascular disease, pulmonary problems that would interfere with the EE measurements, or if they had another disease that could influence their standing and walking performance and/or EE, like cerebrovascular or neuromuscular diseases.

Outcome measures

Height was measured using a tapeline in stance, weight was measured using an electronic scale (Seca, Hamburg, Germany) calibrated to the nearest 0.1 kg, and blood pressure was measured electronically using a sphygmomanometer (Omron Healthcare, Model M3, Kyoto).

The adapted Hoffer Functional Ambulation Scale was used by the first author to categorize the participants' level of functional walking ability [24]. This ordinal-level rating scale categorizes ambulatory status as normal ambulators, community ambulators, household ambulators, non-functional ambulators, and non-ambulators. Normal ambulators are without any mobility problems, not using any assistive devices for mobility. Community ambulators walk indoors and outdoors, and may need crutches, braces, or both. They may also use a wheelchair for longer distances. Household ambulators walk only in and around the house with walking devices. They may use a wheelchair for some indoor activities and use a wheelchair for all activities in the community. Non-functional ambulators are able to walk in a therapy session, but use a wheelchair in their everyday life. Because of the low numbers of participants per group, level of ambulation was dichotomized into two categories in the statistical analyses. The normal ambulators and community ambulators groups were merged into a high-ambulation group, and the non-functional ambulators and household ambulators groups were merged into a low-ambulation group.

Oxygen consumption was measured using indirect calorimetry. By indirect calorimetry, VO_2 was measured and sampled at 10 s intervals. Indirect calorimetry is considered the gold standard for assessing the VO_2 in the general population, as in the SCI population [15, 25]. In this study, the Cortex Metamax 3B system was used and data were analyzed with the Metasoft software (Samcon, Belgium). The Metamax is a valid and reliable system for measuring ventilatory parameters [26]. The system weighs about 1 kg and is comfortably worn on the chest. Participants wore a firm fitted facemask over mouth and nose, which was attached to a transmitting unit with gas analyzers. Prior to the measurement, or at least once a day, the volume analyzer was calibrated with a three-liter calibration pump. The gas analyzer was calibrated with two gasses of known mixture (17% O_2, 5% CO_2). Before the start of each measurement, the flow sensor was adjusted, thereby avoiding contact with breathing or draught. After installation of the Metamax and preparation of the EMG gear (which lasted about 60 min while the participant was in a lying position), the participants were asked to further acclimatize without talking in a lying position for 15 min. To minimize variation, measurements of VO_2 during each activity were maintained for at least 2 min after reaching a steady state (which means not more than 2 ml/kg/min VO_2 difference in 1 min time) [27].

During all conditions, *MA* of 12 muscle groups was measured using a wireless surface EMG device (Mega Electronics Ltd., eMotion Faros, Kuopio). Surface EMG is a valid method to measure muscle activation non-invasively [28]. Prior to electrode placement, the skin was shaved and cleaned with alcohol to optimize EMG signal transfer. The electrodes were placed parallel to the muscle fibers with a 20-mm distance between the electrodes. The placement of the electrodes was following the recommendations of the SENIAM group [29]. The 12 muscle groups measured were (left and right for all muscle groups): m. vastus lateralis, m. tibialis anterior, m. soleus, m. biceps femoris, m. gastrocnemius medialis, and m. erector spinae. The EMG signal was recorded by amplification of the signal (1000×), followed by an analog bandpass filtering (range 10–450 Hz) and an analog to digital conversion with a sampling frequency of 1000 samples per second. Measurement of MA for each posture started when the EE was stable for 1 min.

Data analysis

The EE and EMG data were processed offline with Matlab (Mathworks, Matlab 2013b, Massachusetts) and analyzed using SPSS version 24.0 (SPSS Inc., Chicago, Illinois).

Oxygen consumption

Oxygen consumption was determined as the mean VO_2 measured in lying position and during the different activities for at least 2 min after a steady state was reached.

Energy expenditure

Mean values (±SD) of VO_2 (ml/kg/min) measured during the different activities were calculated. EE was expressed in METs. We defined 1 MET for every participant as his or her own resting VO_2. The METs of each activity were calculated by dividing the mean VO_2 during each activity by the resting VO_2.

Muscle activity

Power spectra for all raw EMG signals per muscle group were calculated and plotted to check for contaminations due to movement artifacts, sensor noise (frequency median >200 Hz), ECG contamination, and power line interference (50 Hz). Thereafter, the following procedures were applied: a digital high-pass filter (2nd-order Butterworth filter) with a cut-off frequency of 30 Hz, a digital band-stop filter (2nd-order ORR notch digital filter) around 50 Hz up to 500 Hz with steps of 50 Hz (50, 100, 150,…500 Hz), and a correction for off-set of the signal by subtracting the mean and rectification of the filtered signal. In order to determine overall MA level, the left and right muscles were averaged. Because it is not feasible in persons with impaired muscle activation to perform a maximal voluntary contraction, the MA during activities was expressed as a percentage of the participant's MA during walking at a comfortable pace.

Walking velocity

Walking velocity (m/s) was calculated by dividing the walking distance (m) by the time (s) of the walking measurement.

Data were checked for normality using a Shapiro–Wilk test and by inspection of histograms and boxplots. The Unpaired sample *t*-test and Fishers test were used to check for differences between groups. As the variable VO_2 was normally distributed, the results are presented in mean±1 SD. As the MET values were not normally distributed in the unsupported sitting and walking conditions, results are shown in median and inter-quartile range (IQR) or 95% CI. Depending on normality of the data, the Unpaired sample *t*-test or the Mann–Whitney *U* test was used for comparing VO_2, EE, and MA among the high-ambulation group and the low-ambulation group, for each activity.

Results

Thirty-five eligible participants were invited and 24 agreed to participate. Subsequently, one person could not participate because of physical problems with transfers, and one person had to postpone the appointment at the outpatient clinic. For all 22 participants, the EE for each activity could be measured adequately. Because of dysfunctional EMG gear, the EMG results of three participants could not be used for analysis. The descriptive statistics of the sample are shown in Table 1. There were no significant differences between the two groups, except for walking speed and the use of a walking aids.

Oxygen consumption

The mean VO_2 uptake values during lying and all test conditions of the low-ambulation group and high-

Table 1 Descriptive characteristics of participants

		Low-ambulation group (mean; SD)	High-ambulation group (mean; SD)	Differences between groups
		N=10	*N*=12	
Age		49.7 (9.9)	45.1 (12.9)	p=0.368 (4.6, 95% CI: −5.8 to 15.0)
Gender	Male	7 (70%)	6 (50%)	p=0.420
	Female	3 (30%)	6 (50%)	
Height (cm)		176.7 (9.5)	174.0 (8.9)	p=0.505 (2.7, 95% CI: −5.5 to 10.8)
Weight (kg)		83.3 (26.8)	82.0 (24.7)	p=0.907 (1.3, 95% CI: −21.6 to 24.2)
BMI (kg/m^2)		26.6 (8.4)	27.5 (9.9)	p=0.812 (−0.95, 95% CI: −9.2 to 7.3)
Walking velocity (m/s)		0.4 (0.2)	0.8 (0.2)	p=0.000 (−0.47, 95% CI: −0.7 to −0.3)
Walking aid	Yes	9 (90%)	3 (25%)	p=0.004
	No	1 (10%)	9 (75%)	

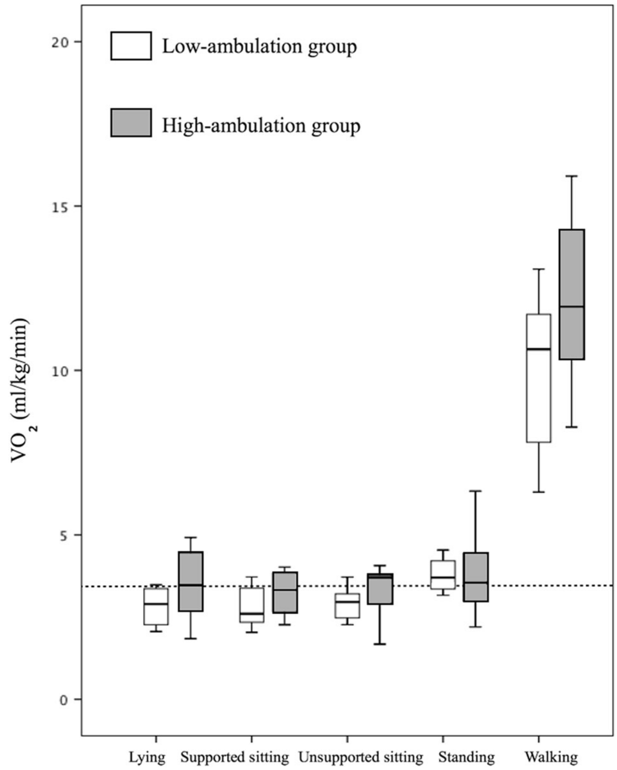

Fig. 1 Boxplot of VO_2 uptake values (ml/kg/min). The dotted line represents a VO_2 value of 3.5 ml/kg/min

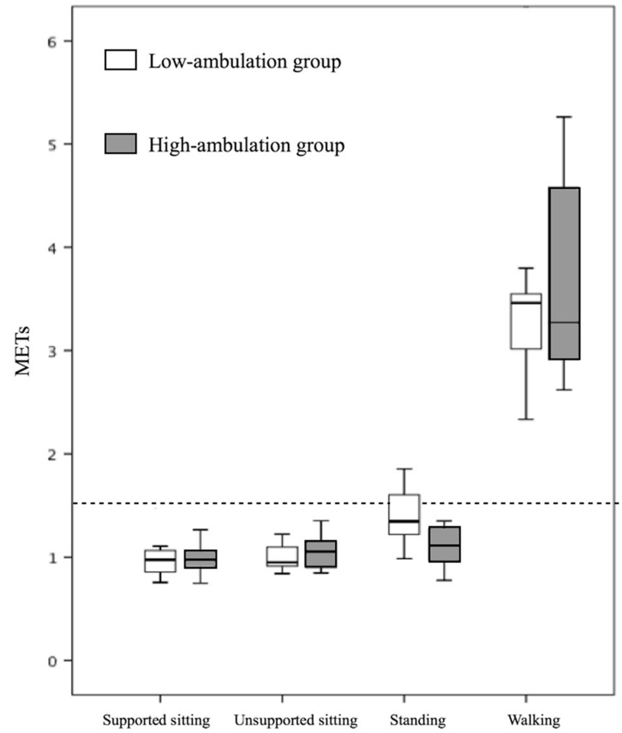

Fig. 2 Boxplot of MET values. The dotted line represents 1.5 METs

ambulation group are shown in Fig. 1 and Table 2. There is a significant difference only in the walking condition, between the groups. The mean resting VO_2 for all participants was 3.19 ml/kg/min (SD 0.87).

Energy expenditure in METs

The MET values for the low-ambulation group and the high-ambulation group are shown in Fig. 2 and Table 3. There were no significant differences in MET values between the two groups for all activities. During standing, three participants of the low-ambulation group and no participants of the high-ambulation group showed MET values >1.5 METs.

Muscle activity

MA scores among the low-ambulation group and the high-ambulation group during all test conditions are shown in Fig. 3. The total MA values of all the muscle groups (left and right) together are expressed as a percentage of the walking condition. The results are shown in median and IQR (Table 4). There were no significant differences in MA during test conditions considered sedentary (lying, unsupported sitting and supported sitting) between the low- and high-ambulation groups. During standing, the low-ambulation group had a significantly higher EMG score compared to the high-ambulation group.

Discussion

There were no differences in VO_2 in rest or during the test conditions between groups. Participants with a low-ambulation level showed significantly higher MA during standing compared to participants with a high-ambulation level, but without a significant difference in EE ($p = 0.056$).

This is the first study to estimate the resting VO_2 in a study group consisting of only people with motor-incomplete SCI. We found a mean VO_2 of 3.19 ml/kg/min (SD 0.87) in the participants of our study with motor-incomplete SCI. Studies on resting VO_2 including people with complete SCI or mixed motor-complete and -incomplete SCI groups showed VO_2 values between 2.47 and 3.2 ml/kg/min [15–18, 25]. Individuals with motor-incomplete injuries seem to have higher resting VO_2 compared to those with motor-complete injuries [13, 16, 17]. This is probably due to less atrophy of the muscles and less loss of lean body mass below the level of injury after motor-incomplete SCI [13]. These differences in lean body mass and level of injury also exist within the motor-incomplete SCI population. Therefore, a difference in VO_2 and EE is to be expected in participants with a different ambulation level. It

Table 2 VO_2 uptake values (ml/kg/min)

Test condition	Low-ambulation group (mean; SD) $n=10$	High-ambulation group (mean; SD) $n=12$	Total group (mean; SD) $n=22$	*p*-Value	Mean difference & 95% Confidence Interval
Lying	2.85 (0.53)	3.48 (1.03)	3.20 (0.87)	0.082	−0.6, CI: −1.3 to 0.1
Supported sitting	2.80 (0.63)	3.35 (0.92)	3.10 (0.83)	0.128	−0.5, CI: −1.3 to 0.2
Unsupported sitting	2.92 (0.49)	3.64 (1.17)	3.32 (0.97)	0.085	−0.7, CI: −1.5 to 0.1
Standing	3.78 (0.45)	3.79 (1.10)	3.79 (0.85)	0.970	0.0, CI: −0.8 to 0.7
Walking	9.95 (2.31)	12.14 (2.53)	11.14 (2.62)	0.049	−2.2, CI: −4.4 to 0.0

Table 3 MET values

Test condition	Low-ambulation group (median; IQR) $n=10$	High-ambulation group (median; IQR) $n=12$	Total group (median; IQR) $n=22$	Mann–Whitney *U* value/ standardized test statistic	*p*-Value	Mean difference & 95% Confidence interval
Supported sitting	0.98 (0.84–1.07)	0.98 (0.90–1.07)	0.98 (0.87–1.07)	$U=61.0$, $z=0.07$	0.947	0.01, CI: −0.15 to 0.17
Unsupported sitting	0.95 (0.91–1.13)	1.06 (0.91–1.17)	1.01 (0.91–1.14)	$U=65.0$, $z=0.33$	0.742	−0.01, CI: −0.18 to 0.17
Standing	1.35 (1.17–1.62)	1.11 (0.94–1.29)	1.24 (1.03–1.35)	$U=31.0$, $z=-1.91$	0.056	0.25, CI: 0.04 to 0.46
Walking	3.46 (3.01–3.61)	3.30 (2.90–4.67)	3.43 (3.01–3.97)	$U=61.0$, $z=0.07$	0.947	−1.12, CI: −1.01 to 0.78

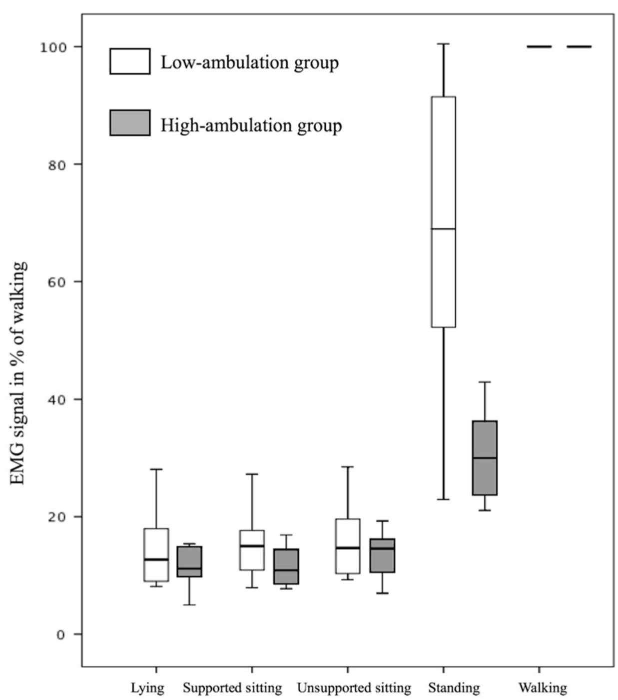

Fig. 3 Boxplot of muscle activity (all muscle groups) in % of walking condition

is probable that participants with a high-ambulation level have more lean muscle mass and more residual muscle innervation. In this study, the resting VO_2 in the low-ambulation group was lower compared to the high-ambulation group, but this difference was not significant. The small sample size and large variation in VO_2 among the high ambulatory group could explain why this difference was not significant.

The EE values during supported sitting and unsupported sitting were approximately 1.0 METs. There were no differences between the two ambulation groups. Other studies determined EE during activities considered sedentary in motor-complete SCI (or a combination with motor-incomplete) and found higher values between 1.2 and 1.6 METs [15, 17, 18]. These higher values, compared with our findings, could be explained by the involvement of active movement of the upper body, trunk, and arms (desk work, computer work, reading), in these other studies and differences in study samples. Interestingly, these other studies showed that sitting or working in a sitting position is not or hardly enough to interrupt sedentary behavior (<1.5 METs) in both people with motor-incomplete or motor-complete SCI [15, 17, 18]. Results from other studies in the general population were in line with our findings and found no significant differences in EE during supine and motionless sitting measurements [30, 31].

Only three participants in the low-ambulation group had an EE value >1.5 METs while standing. For these individuals in the low-ambulation group, standing requires more energy than described in the definition of sedentary

Table 4 Muscle activity (all the muscle groups) in % of walking condition

Test condition	Low-ambulation group (median; IQR) n=10	High-ambulation group (median; IQR) n=9	Total group (median; IQR) n=19	Mann–Whitney U value/ standardized test statistic	p-Value	Mean difference & 95% Confidence Interval
Lying	12.7 (8.94–20.50)	11.0 (7.62–14.93)	12.09 (9.01–15.37)	U=38.0, z=−0.57	0.568	4.75, CI: −16.03 to 25.54
Supported sitting	15.0 (10.74–20.06)	10.8 (8.23–15.53)	12.26 (9.40–16.82)	U=27.0, z=−1.47	0.142	7.74, CI: −11.79 to 27.27
Unsupported sitting	14.7 (10.30–21.81)	14.3 (9.43–17.44)	14.58 (10.32–19.02)	U=36.0, z=−0.74	0.462	7.04, CI: −9.55 to 23.63
Standing	69.0 (50.56–92.48)	30.3 (23.74–37.10)	43.19 (28.41 −70.06)	U=53.0, z=−3.02	0.003	38.60, CI: 20.80 to 56.39

behavior [7]. Although the difference with the high-ambulation group was non-significant ($p = 0.056$), standing seems to be more intense for individuals with a lower ambulation function. The participants in this study who used a walking aid in daily life were allowed to use a walking aid during the measurements, which could explain the low MET values during standing. Similarly, the study of Collins et al. [17] reported MET scores of only 1.17 MET in two motor-incomplete SCI during assisted standing with an walking aid.

For the walking condition, the MET values of both groups varied between 3 and 4.5 METs, which is moderate-intensity activity (3–5.9 METs). The study of Collins et al. reported a mean MET score of 4.7 METs in nine motor-incomplete male SCI individuals while walking [17]. Another interesting finding is that the EE during walking was similar in both levels of ambulation groups. This can be explained by the protocol used in this study. The walking velocity was not standardized, since participants were instructed to walk at a comfortable pace.

It is important to realize that there is no study available that studies the direct relation between the individualized MET values, which we use in this study, and cardiometabolic health biomarkers or long-term health benefits. This dimension remains to be analyzed.

MA during lying and sitting is similar in both groups. Another study found significant higher EMG activity levels in static trunk muscles in individuals with SCI relative to healthy controls during tasks like sitting [32]. The present study did not find a difference between the ambulatory groups, possibly due to the muscle groups measured (mostly leg and back muscles instead of trunk muscles per se). In future research, it will be interesting to include trunk and upper body muscles since individuals might activate these muscle groups for maintaining balance in a sitting position. The present study shows that there is a rise in MA during standing compared to sitting in both groups. Since we determine overall MA level and averaged the left and right muscles, we cannot differentiate between muscle groups. The MA during standing is the highest in the low-ambulatory group. A study of Pesola et al. [20] found that participants having low total muscle inactivity time had clinically significant better outcomes of HDL cholesterol and triglycerides than the participants having high total muscle inactivity time, independent of moderate to vigorous physical activity time. It may be possible that in people with SCI with higher MA, cardiometabolic biomarkers can be positively altered, even when having an EE of <1.5 METs. Because the mechanisms underlying the negative health consequences of prolonged sitting may be directly attributable to muscle inactivity, it is important to establish how much MA is sufficient to attenuate these consequences. A study in healthy young adults showed that a 7–8-fold increase in MA led to an attenuation of postprandional C-peptide, but not for other metabolic biomarkers [33]. At this time, we do not know how much MA is required to counteract the negative health consequences of sedentary behavior. But, activating large muscle groups is generally accepted as an interruption of sedentary behavior/time. A recent interesting study shows that low-frequency stimulation of the quadriceps and hamstrings increased EE above the resting baseline level, which might also be a feasible option to offset the negative side effects related to muscle inactivity after SCI [34].

There are some limitations to this study. It should be noted that the results from this cross-sectional study are not indicative of the cause and effect. Controlled studies are needed to determine the impact of sedentary behavior on cardiometabolic health in this study population. Second, this study is limited by the low number of participants and the great diversity of functional walking ability in the motor-incomplete SCI population. Third, we did not test all participants on the same time in the day which could have influenced the results. Fourth, we were not able to use a ventilated hood since we wanted to measure VO_2 during more activities (i.e., sitting, standing, and walking), which is not possible in the ventilated hood setup. Fifth, the majority of previous studies have used longer time periods to asses resting VO_2. This could result in an overestimation of the resting VO_2. Sixth, the results are not generalizable for the whole population of people with motor-incomplete spinal cord injury since we did not include people without ambulatory function. In this study, the level of injury was left out of the analysis since we categorized the participants on level of functional walking ability. Our study population might have been too small to detect a significant between-group difference in VO_2 and EE values. We suspect that when using a larger study group, the VO_2 in rest and during activities will be significantly lower in participants with a lower ambulation level compared to participants with a higher ambulation level. Furthermore, comparing the METs values, based on a person's own resting VO_2, we believe this will be significantly higher in participants with a lower level of ambulation. This means that the relative EE will be higher in the participants with a lower ambulation level.

Furthermore, moderate to vigorous physical activity should not be forgotten, since it not only has health benefits but also attenuates the health risks of high volumes of sedentary time [6, 35]. At last, MA was expressed as a percentage of walking MA during walking at a comfortable pace instead of expressing it as a percentage of maximal voluntary contraction, as this is not feasible in persons with impaired muscle activation. The level of MA during walking is higher in people with severe mobility limitation, and therefore the absolute difference in EMG between groups for the other activities might have been underestimated in this study.

Conclusion

Lying, supported- and unsupported sitting, without moving, are, according to the definition, sedentary behaviors for individuals with a motor-incomplete SCI (MET values of <1.5 and a lack of MA) as is the case for able-bodied individuals. Walking, but not standing, can be classed as a moderate physical activity (>3 METS) in persons with motor-incomplete SCI. While walking could be used to interrupt prolonged periods of sedentary behavior in this population, the chronic effects over time on cardiometabolic health remain unknown.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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