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Energy Cost of Physical Activities in Persons with Spinal Cord Injury

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ABSTRACT

COLLINS, E. G., D. GATER, J. KIRATLI, J. BUTLER, K. HANSON, and W. E. LANGBEIN. Energy Cost of Physical Activities in Persons with Spinal Cord Injury. *Med. Sci. Sports Exerc.*, Vol. 42, No. 4, pp. 691–700, 2010. **Introduction**: The objectives of this descriptive study were (a) to determine the energy expenditure of activities commonly performed by individuals with a spinal cord injury (SCI) and summarize this information and (b) to measure resting energy expenditure and establish the value of 1 MET for individuals with SCI. **Methods**: One-hundred seventy adults with SCI were partitioned by gender, anatomical level of SCI, and American Spinal Injury Association designations for motor function. Twenty-seven physical activities, 12 recreational/sport and 15 daily living, were performed, while energy expenditure was measured continuously via a COSMED K4b^2 portable metabolic system. In addition, 66 adult males with SCI completed 30 min of supine resting energy testing in a quiet environment. **Results**: Results for the 27 measured activities are reported in kilocalories per minute (kcal·min^{-1}) and $\dot{V}O_2$ (mL·min^{-1} and mL·kg^{-1}·min^{-1}). One MET for a person with SCI should be adjusted using 2.7 mL·kg^{-1}·min^{-1}. Using 2.7 mL·kg^{-1}·min^{-1}, the MET range for persons in the motor incomplete SCI group was 1.17 (supported standing) to 6.22 (wheeling on grass), and 2.26 (billiards) to 16.25 (hand cycling) for activities of daily living and fitness/recreation, respectively. The MET range for activities of daily living for persons in the group with motor complete SCI was 1.27 (dusting) to 4.96 (wheeling on grass) and 1.47 (bait casting) to 7.74 (basketball game) for fitness/recreation. **Conclusions**: The foundation for a compendium of energy expenditure for physical activities for persons with SCI has been created with the completion of this study. In the future, others will update and expand the content of this compendium as has been the case with the original compendium for the able-bodied. **Key Words:** ENERGY METABOLISM, ENERGY EXPENDITURE, PHYSICAL ACTIVITY, WHEELCHAIR

BASIC SCIENCES

Individuals who sustain a spinal cord injury (SCI) become more sedentary. The loss of muscle mass and metabolically active tissue over time is associated with a chronic decrease in daily energy expenditure. In the nondisabled adult population, researchers and the lay public use a compendium of physical activities published by Ainsworth et al. (2,3) to quantify the energy expenditure for a variety of physical activities. Harrell et al. (14) published energy costs of a variety of physical activities frequently engaged in by children and adolescents, and recently, a subsequent compendium for children was developed (26). Given the unique anatomical and physiological changes that are secondary to paralysis and that most of physical activities are performed from a seated position or wheelchair, energy expenditure values presented in existing compendiums are inappropriate and cannot be used by clinicians or researchers to measure/estimate activity levels in individuals with SCI.

Previously investigators have measured the energy cost of activities completed by people with an SCI to compare the efficiency of different types of wheelchairs (4,25,28), while playing ballgames (1,27), during functional electric stimulation cycling (11), while using the Case Western Reserve standing neuroprosthesis (12), or to determine peak exercise capacity (7,16–18,21,29). Although these studies are critically important, the results are not always presented in a format that is useful to people with SCI who want to know how many calories they are using while performing activities of daily living.

Buchholz et al. (8) documented that the resting metabolic rate for individuals with SCI is overestimated by 5%–32%. This reduction in resting metabolic rate is largely explained by the reduced fat-free body mass that occurs because of atrophy of the skeletal muscle in individuals with SCI (8,20,24). Jeon et al. (19) reported similar results when

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TABLE 1. Descriptive data (mean ± SD) for male (a) and female (b) subjects partitioned by anatomical level of SCI who completed the physical activity measurements.

	Upper-Level Injury (C5–C8)	Mid-Level Injury (T1–T8)	Lower-Level Injury (T9–L4)
(a) Male participants			
Sample size (n)	45	64	47
Age (yr)	40.6 ± 12.1	42.7 ± 10.5	41.9 ± 13.0
Height (cm)	178.0 ± 7.3	180.4 ± 6.5	178.3 ± 7.5
Body weight (kg)	81.1 ± 15.4	83.6 ± 13.7	78.0 ± 13.6
Body mass index (kg·m^{-2})	25.6 ± 4.9	25.7 ± 4.2	24.7 ± 4.2
Subjects with complete injury (%)	24 (53.3)	52(81.3)	22 (46.8)
Months since injury	135 ± 108	165 ± 110	155 ± 149
(b) Female participants			
Sample size (n)	2	8	4
Age (yr)	53.0 ± 11.3	39.4 ± 8.4	41.3 ± 10.2
Height (cm)	167.5 ± 3.5	163.1 ± 9.5	170.0 ± 3.9
Body weight (kg)	98.5 ± 53.0	64.6 ± 19.7	73.0 ± 19.6
Body mass index (kg·m^{-2})	34.5 ± 17.7	24.0 ± 6.6	25.5 ± 7.6
Subjects with complete injury (%)	0	7 (87.5)	3 (75.0)
Months since injury	122 ± 116	166 ± 117	103 ± 70

Statistical comparisons between groups were not significant ($P > 0.05$).

comparing resting metabolic rate in individuals with chronic SCI with age-matched controls. Buchholz et al. (9) determined that physical activity levels in free-living adults with chronic paraplegia were low and concluded that individuals with chronic paraplegia need to engage in increased physical activity. Indeed, it has been documented that individuals with SCI are physically unfit, and those with paraplegia are only slightly more fit than those with tetraplegia (7). With the prevalence of obesity in the SCI population higher than the able-bodied (13,30), it is important to make available, to people with SCI, a usable resource that provides a valid measure of the energy costs of activities of daily living in which they are likely to engage.

The objective of this descriptive study was twofold: (i) to determine the metabolic requirement of commonly performed self-care, household, occupational, and recreation/fitness activities for individuals with complete and incomplete SCI and to use this information in the creation of the foundation for a compendium of energy cost of physical activities for persons with SCI; and (ii) to establish the resting energy expenditure (REE) for people with SCI and to ascertain the appropriate value of the MET for persons with SCI. In the compendium for the nondisabled, activity intensity is quantified and categorized in METs. One MET is the ratio of energy expended during a physical activity compared with the energy expended during rest (3). The commonly accepted value in the able-bodied population for 1 MET is 3.5 mL·kg^{-1}·min^{-1}.

METHODS

Ethical Conduct

The studies presented here were reviewed and approved by the institutional review boards at the participating sites. Research participants were provided with a verbal overview of the study and an opportunity to have all of their study-related questions answered by trained personnel before consent. All individuals who participated in this research were volunteers older than 18 yr and gave written consent.

Subjects/Settings

Participants with SCI were recruited to perform various physical activities and/or during quiet resting; some individuals participated in both. This was a convenience sample recruited via on-site flyers, newspaper articles, mailings, and word-of-mouth. One-hundred seventy apparently healthy adults with SCI participated in the activity portion of the study (Table 1, a and b). Participants were categorized by gender and neurological level of SCI, specifically low tetraplegia (C5–C8), high paraplegia (T1–T8), and low paraplegia (T9–L4) and whether the injury was motor complete or incomplete, determined as American Spinal Injury Association Impairment Scale (AIS) classification A or B (complete) and C or D (incomplete) (5). Participants completed only the activities that were familiar to them. Depending on the activity, testing was conducted at various locations on-site, including laboratory and hospital rooms, and off-site (e.g., at a local grocery store or city park). As part of a separate investigation, 66 apparently healthy adults with SCI participated in the REE portion of the research and were categorized as low tetraplegia (C5–C8) or paraplegia (T1–L4; Table 2).

Exclusions

Individuals were excluded from the study if they had known unstable coronary artery disease, angina, chronic congestive heart failure, resting hypertension, chronic obstructive pulmonary disease, shoulder problems, or other problems known to limit exercise ability. Tests were not performed on any individual experiencing an acute episode of urinary tract infection, pulmonary infection, skin breakdown (decubitus ulcers), or cardiac symptoms or who was febrile (self-report).

Instruments

Activity testing. Energy expenditure during various activities was measured via open-circuit, indirect calorimetry

TABLE 2. Descriptive data and REE measurements (mean ± SD) for 66 study participants with SCI who successfully completed the testing.

	Upper-Level Injury (C5–C8)	Lower-Level Injury (T1–L4)
Sample size (n)	32	34
Age (yr)	53.0 ± 14.3	51.6 ± 12.3
Height (cm)	178.7 ± 6.8	177.3 ± 7.1
Weight (kg)	78.2 ± 18.0	74.9 ± 17.6
Body mass index (kg·m^{-2})	24.4 ± 5.4	23.9 ± 5.5
Complete injury (%)	30	52
Time since injury (months)	126 ± 138	190 ± 172
Oxygen consumption		
mL·min^{-1}	193 ± 43	201 ± 38
mL·kg^{-1}·min^{-1}	2.52 ± 0.50	2.77 ± 0.47
Kilocalories per minute	0.980 ± 0.219	0.995 ± 0.162

with the lightweight (~1.5 kg) COSMED K4b^2 portable telemetry system (COSMED, Rome, Italy). The COSMED K4b^2 system has been reported to be a valid and reliable measure of oxygen uptake in field studies (22).

Gas exchange was measured breath by breath. The COSMED K4b^2 software was used to establish summary estimates of energy expenditure which included oxygen uptake in milliliters per minute (mL·min^{-1}), milliliters per kilogram of body weight per minute (mL·kg^{-1}·min^{-1}), and kilocalories per minute (kcal·min^{-1}). The system analyzers were calibrated before each test and verified with reference gases and room air immediately after calibration.

Before testing, the instrumentation and procedures were reviewed for the subject, and proper tire inflation was checked. The COSMED K4b^2 was calibrated, and then the apparatus was fitted to the individual. Participants were allowed a minimum of 3 min to acclimatize to wearing the COSMED K4b^2 while verbal instructions and a demonstration of how the activity was to be performed were given by the investigator. Opportunity to practice/warm up, where appropriate (e.g., during a sport activity), was given before the beginning of testing. It was repeatedly emphasized that an activity was to be completed at the person's "usual" pace. A minimum of 3 min of resting gas exchange data were collected both before beginning each activity and after completion of the activity. The assessment goal was to achieve steady state for each activity; the time required for this to occur varied among individuals. All activities were performed for a minimum of 5 min. If another activity was to be completed during the same visit, the investigator waited for return-to-baseline values before beginning the subsequent activity.

Minute ventilation, tidal volume, and respiration frequency were measured by a low-resistance (<0.7 cm $H_2O·L^{-1}·s^{-1}$ at 12 L·s^{-1}) bidirectional digital turbine flow meter. The flow meter was calibrated before each exercise test. Electronic barometer and temperature sensors resident in the K4b^2 provided automatic real-time correction for variations in ambient pressure and temperature during testing.

Resting. REE was measured using open-circuit indirect calorimetry with the SensorMedics 2900 Metabolic System (Yorba Linda, CA) in a thermoneutral environment. Before testing, subjects fasted for 12 h. All REE measurements were scheduled between 06:30 and 08:00 a.m. Before each test, the system analyzers were calibrated, and immediately after the calibration, these were verified with reference gases and room air. Expired gases were collected using a ventilated hood for 30 min. During the measurement period, subjects were lying down and remained still. They were instructed not to talk and not to fall asleep.

Procedures

Minimization of risks. All efforts were made to minimize risks to participants during performance of physical activities. To prevent hypotensive episodes, participants were queried at intervals during testing sessions regarding the presence of dizziness and/or lightheadedness. To avoid the onset of autonomic dysreflexia, each participant received verbal and written instructions to drink plenty of fluids, empty their bladder before testing, and inform the investigator if they had any recent urinary tract infections or problems with their schedule of bowel care. Testing sessions were composed of normal activities in which each participant might engage; that is, no unfamiliar or excessively strenuous activities were assessed.

Participants only completed energy expenditure studies on activities that were familiar to them. Activities were performed in as uniform a manner as possible. Although participants were instructed to perform each activity as they normally would, scenarios were also prescribed to control, as much as possible, for variability in each activity. A brief description of how each activity was completed is provided in Supplemental Digital Content 1 for this article, http://links.lww.com/MSS/A12. It should be noted that arm cranking involved an exception to the "5-min minimum rule" because participants were instructed to complete two exercise sessions of 3 min in duration at two different arm crank workloads (W). Instructions for two activities are provided below as examples of how testing was directed.

Instructions to participant. Activity: Wheeling on tile—After all the measurement equipment is in place, you will sit quietly for approximately 3 min. You will then push your wheelchair in a tiled hallway area that has been designated for this activity. Push your wheelchair at a pace that is comfortable and "normal" for you. Continue to push your wheelchair for approximately 5 min. When the 5-min exercise time has elapsed, the investigator will tell you to stop. You will then be asked to rest quietly for 3 min.

Instructions to participant. Activity: Billiards—After all the measurement equipment is in place, you will sit quietly for approximately 3 min. Choose a cue and rack the balls. Begin playing a game of 8-ball. You will play for a minimum of 5 min. When enough time has elapsed, the investigator will ask you to stop. You will then be asked to rest quietly for 3 min.

Data Analysis

Data for activity measurements were analyzed by using the COSMED K4b^2 software and Excel spreadsheet (Microsoft Excel, Microsoft Corp., Seattle, WA). Energy expenditure values for each activity were determined by averaging breath-by-breath measures across 30-s periods. Only values collected during the interval when the subject performed the activity were analyzed to determine a steady state. The selection of a steady-state or near steady-state period proceeded in the following steps: (i) caloric expenditure (kcal·min^{-1}) values were plotted on time for the duration of the exercise; every selection of steady-state included as many consecutive and data points as possible; (ii) a moving average trend line function was used to assist in the visual inspection and

TABLE 3. Energy expenditure (mean ± SD) for activities in males with a motor complete SCI.

Activity/Group	*n*	$\dot{V}O_2$ (mL·min^{-1})	kcal·min^{-1}	mL·kg^{-1}·min^{-1}	SCI MET
Fitness					
Aerobics					
C5–C8	4	516.9 ± 233.7	2.59 ± 1.15	5.70 ± 1.02	2.11
T1–T8	7	462.1 ± 88.8	2.31 ± 0.41	5.43 ± 0.89	2.01
T9–L4	3	497.5 ± 231.3	2.58 ± 1.10	6.53 ± 2.67	2.42
Arm cranking (16 W)					
C5–C8	7	560.4 ± 121.3	2.75 ± 0.51	7.01 ± 1.56	2.60
T1–T8	11	589.7 ± 59.9	2.89 ± 0.28	7.66 ± 1.43	2.84
T9–L4	5	628.8 ± 99.7	3.26 ± 0.74	8.23 ± 1.21	3.05
Arm cranking (32 W)					
C5–C8	5	753.9 ± 188.9	3.69 ± 0.84	9.41 ± 1.77	3.49
T1–T8	14	709.3 ± 171.4	3.62 ± 0.90	9.22 ± 2.46	3.41
T9–L4	9	733.9 ± 80.6	3.64 ± 0.43	9.93 ± 1.69	3.68
Arm cranking (48 W)					
C5–C8	4	855.9 ± 189.8	4.38 ± 1.06	11.86 ± 3.84	4.39
T1–T8	13	918.6 ± 191.1	4.75 ± 1.14	11.00 ± 2.51	4.07
T9–L4	8	894.3 ± 81.5	4.52 ± 0.43	11.88 ± 2.21	4.40
Arm cranking (64 W)					
T1–T8	11	1125.6 ± 279.2	5.92 ± 1.57	12.96 ± 2.63	4.80
T9–L4	9	1111.4 ± 73.4	5.67 ± 0.37	15.08 ± 2.57	5.59
Arm cranking (80 W)					
T1–T8*	4	1136.5 ± 253.0	5.35 ± 0.85	14.41 ± 4.18	5.34
T9–L4	7	1111.4 ± 73.4	6.82 ± 0.45	16.59 ± 2.39	6.14
Arm cranking (96 W)					
T1–T8	4	1355.3 ± 276.2	7.14 ± 1.42	17.09 ± 4.02	6.33
T9–L4	4	1553.8 ± 160.8	8.11 ± 0.80	20.55 ± 2.95	7.61
Circuit training					
C5–C8	3	454.7 ± 219.3	2.31 ± 1.06	4.94 ± 0.66	1.83
T1–T8	7	704.3 ± 233.6	3.53 ± 1.12	7.69 ± 2.90	2.85
T9–L4	5	591.3 ± 120.9	3.19 ± 0.59	8.34 ± 2.12	3.09
Weight training					
C5–C8	4	477.7 ± 119.7	2.46 ± 0.59	5.85 ± 1.15	2.17
T1–T8	14	719.0 ± 228.6	3.65 ± 1.11	8.07 ± 2.36	2.99
T9–L4	2	636.4 ± 59.3	3.23 ± 0.49	9.21 ± 0.29	3.41
Recreation					
Basketball					
T1–T8	2	1554.0 ± 339.4	7.70 ± 1.71	20.91 ± 5.53	7.74
Billiards					
T1–T8	12	548.3 ± 179.2	2.74 ± 0.95	5.98 ± 1.69	2.21
T9–L4	4	586.9 ± 117.5	2.79 ± 0.55	7.53 ± 2.04	2.79
Bowling					
C5–C8	2	490.7 ± 282.3	2.43 ± 1.28	5.48 ± 1.21	2.03
T1–T8	15	551.2 ± 146.9	2.73 ± 0.72	6.25 ± 1.65	2.31
T9–L4	2	568.8 ± 54.6	2.85 ± 0.28	7.65 ± 1.45	2.83
Darts					
T1–T8	3	431.3 ± 53.3	2.12 ± 0.42	4.97 ± 1.52	1.84
T9–L4	2	391.0 ± 1.4	1.92 ± 0.02	5.28 ± 0.12	1.96
Fishing/casting					
T1–T8	3	370.3 ± 60.4	1.83 ± 0.24	3.98 ± 0.59	1.47
T9–L4	2	323.3 ± 51.4	1.67 ± 0.32	4.30 ± 0.28	1.59
Shooting baskets					
T1–T8	3	783.0 ± 149.1	3.80 ± 0.77	10.50 ± 2.30	3.89
T9–L4	2	849.2 ± 84.3	4.10 ± 0.64	11.88 ± 0.11	4.40
Table tennis					
T1–T8	3	564.6 ± 185.6	2.77 ± 0.95	6.11 ± 1.48	2.26
T9–L4	4	710.1 ± 227.7	3.45 ± 1.08	9.99 ± 3.38	3.70
Activities of daily living					
Bed making					
C5–C8	4	562.7 ± 269.0	2.80 ± 1.28	6.69 ± 1.74	2.48
T1–T8	14	673.1 ± 167.4	3.26 ± 0.79	8.30 ± 2.27	3.07
T9–L4	3	690.4 ± 190.5	3.31 ± 0.90	9.92 ± 1.74	3.67
Deskwork					
C5–C8	9	340.4 ± 129.4	1.69 ± 0.61	3.96 ± 1.23	1.47
T1–T8	16	341.7 ± 78.1	1.66 ± 0.34	4.35 ± 1.29	1.61
Dressing/undressing					
T9–L4	2	751.0 ± 280.0	3.63 ± 1.31	10.77 ± 1.75	3.99
Driving					
T1–T8	2	488.0 ± 67.9	2.32 ± 0.29	6.83 ± 0.06	2.53
Dusting					
C5–C8	2	268.5 ± 30.4	1.30 ± 0.09	3.44 ± 0.59	1.27
T1–T8	6	571.8 ± 138.4	2.79 ± 0.64	6.78 ± 2.17	2.51
T9–L4	4	541.8 ± 209.0	2.61 ± 1.05	7.68 ± 2.88	2.84
Grocery shopping					
T1–T8	4	492.4 ± 77.3	2.45 ± 0.37	6.18 ± 1.35	2.29
T9–L4	3	524.1 ± 62.7	2.59 ± 0.32	7.08 ± 0.66	2.62

(continued on next page)

TABLE 3. *(Continued)*

Activity/Group	n	$\dot{V}O_2$ (mL·min^{-1})	kcal·min^{-1}	mL·kg^{-1}·min^{-1}	SCI MET
Laundry					
C5–C8	11	475.3 ± 125.4	2.32 ± 0.61	5.73 ± 1.06	2.12
T1–T8	15	600.7 ± 146.8	2.92 ± 0.70	7.44 ± 1.46	2.76
T9–L4	3	651.1 ± 214.8	3.17 ± 0.98	8.39 ± 2.24	3.11
Moving items					
C5–C8	7	498.0 ± 142.0	2.51 ± 0.70	6.58 ± 1.72	2.44
T1–T8	9	614.0 ± 95.7	3.02 ± 0.41	7.52 ± 1.49	2.79
Vacuuming					
T1–T8	4	725.0 ± 158.1	3.44 ± 0.73	8.93 ± 3.38	3.31
T9–L4	2	745.0 ± 333.8	3.64 ± 1.67	11.03 ± 3.41	4.09
Washing dishes					
T1–T8	9	492.4 ± 146.1	2.39 ± 0.72	6.00 ± 1.93	2.22
T9–L4	2	485.4 ± 133.0	2.28 ± 0.73	6.58 ± 1.62	2.44
Wheeling on tile					
C5–C8	8	523.4 ± 141.5	2.61 ± 0.71	6.29 ± 1.73	2.33
T1–T8	20	616.6 ± 122.0	3.04 ± 0.62	7.45 ± 1.62	2.76
T9–L4	7	553.5 ± 134.8	2.63 ± 0.59	7.39 ± 1.90	2.74
Wheeling on carpet					
C5–C8	6	695.1 ± 225.9	3.48 ± 1.10	8.23 ± 2.43	3.05
T1–T8	14	693.4 ± 203.6	3.47 ± 1.00	8.42 ± 2.31	3.12
T9–L4	3	621.8 ± 51.1	3.01 ± 0.22	8.16 ± 1.42	3.02
Wheeling on grass					
T1–T8	3	1122.0 ± 71.4	5.41 ± 0.33	13.40 ± 1.60	4.96
Wheeling outside					
C5–C8	3	575.8 ± 151.8	2.90 ± 0.63	7.67 ± 1.38	2.84
T1–T8	14	689.1 ± 172.6**	3.40 ± 0.89	8.01 ± 1.68	2.97
T9–L4	4	797.5 ± 269.3	3.98 ± 1.36	11.34 ± 4.43	4.20

*Difference in oxygen uptake between lower tetraplegia and paraplegia, $P < 0.05$.
**Difference between complete and incomplete injury, $P < 0.05$.
C, cervical spine; L, lumbar spine; SCI MET, where 1 MET equals 2.7 mL·kg^{-1}·min^{-1}; T, thoracic spine.

selection of the data points that best represented steady state; and (iii) mean and SD for selected data points were calculated. The average of the steady-state measures (<5% in variation) was then accepted as representing energy expenditure for that individual's activity.

In the case of two activities, "weight training" and "circuit training," it was not feasible to follow this procedure for selecting a steady state. For these two activities, all data points from start to finish of the activity were used. In this way, the energy expended while the subject moved from one weight station to another, set up the weights, and got into position to perform the subsequent lift was captured.

Data for REE were collected for a minimum of 30 min and averaged during 5-min intervals. The SensorMedics 2900 indicated when a person's gas exchange measurement reached a steady state, frequently in less than 20 min. The average of the steady-state measures (<3% in variation) was then accepted as representing REE for that individual.

Final data were transferred into SPSS 15.0 for Windows (SPSS, Inc., Chicago, IL) for analysis. Means (±SD) and frequency distributions were used to characterize the sample and determine average energy expenditures. Because data were not normally distributed, nonparametric statistics (Mann–Whitney *U* and Kruskal–Wallis *H*) were used to determine whether there were differences in sample characteristics and energy expenditure values between categories of injury levels.

RESULTS

Activity testing. Oxygen uptake (mL·min^{-1}, mL·kg^{-1}·min^{-1}), energy expenditure (kcal·min^{-1}), and MET values for each activity are presented for men with complete injury (Table 3) and men with incomplete injury (Table 4) and for women with complete and incomplete injuries (Table 5). Figure 1 presents a comparison of selected physical activity METS using the SCI-adjusted MET value for measured activities and the value listed in the compendium of Ainsworth et al. (3).

We report the energy expenditure data on 676 activities. Additional 71 activity tests are not reported because only one participant from a particular category completed the activity.

For all activities, energy expenditure for persons with motor complete injuries was compared with those with motor incomplete injuries. For individuals with lower-level tetraplegia, those with incomplete injury had higher energy expenditure while wheeling outside (on sidewalk) than those with complete injury ($P = 0.04$; Tables 3 and 4). Energy expenditure was also higher in arm cranking at 80 W in those with a higher-level paraplegia and lower-level paraplegia ($P = 0.04$; Table 3).

REE. Differences in age, body mass index, oxygen consumption (mL·min^{-1}), and resting oxygen consumption adjusted for body weight (mL·kg^{-1}·min^{-1}) between the subjects with lower-level tetraplegia (C5–C8) and paraplegia (T1–L4; Table 2) were not significant ($P > 0.05$). The mean oxygen uptake (±SD) for 64 participants was 2.66 ± 0.50 mL·kg^{-1}·min^{-1} and REE was 0.99 ± 0.19 kcal·min^{-1}.

DISCUSSION

The purposes of this descriptive study were (a) to determine the energy expenditure of activities commonly performed by individuals with SCI and establish the foundation

TABLE 4. Energy expenditure (mean ± SD) for activities in males with a motor incomplete SCI.

Activity/Group	*n*	$\dot{V}O_2$ (mL·min^{-1})	kcal·min^{-1}	mL·kg^{-1}·min^{-1}	SCI MET
Fitness					
Arm cranking (16 W)					
C5–C8	3	586.3 ± 45.1	2.89 ± 0.21	7.92 ± 1.70	2.93
T1–T8	2	687.0 ± 227.7	3.47 ± 1.20	7.86 ± 0.51	2.91
Arm cranking (32 W)					
C5–C8	3	675.0 ± 68.4	3.39 ± 0.31	9.11 ± 2.16	3.37
T1–T8	2	804.5 ± 241.1	4.12 ± 1.29	9.27 ± 0.90	3.43
T9–L4	2	807.0 ± 96.2	4.08 ± 0.53	10.35 ± 0.73	3.83
Arm cranking (48 W)					
C5–C8	3	842.7 ± 66.0	4.29 ± 0.28	11.27 ± 2.01	4.17
T1–T8	2	979.5 ± 292.0	5.08 ± 1.60	11.29 ± 1.12	4.18
T9–L4	2	969.5 ± 112.4	4.98 ± 0.63	12.44 ± 0.92	4.61
Arm cranking (64 W)					
C5–C8	3	1006.7 ± 36.5	5.23 ± 0.14	13.12 ± 2.27	4.86
T9–L4	2	1192.0 ± 135.8	6.23 ± 0.76	15.29 ± 1.16	5.66
Arm cranking (80 W)					
C5–C8	2	1055.5 ± 6.4	5.70 ± 0.14	13.63 ± 2.77	5.05
T9–L4	2	1192.0 ± 135.8	7.40 ± 0.87	17.69 ± 1.26	6.55
Circuit training					
C5–C8	6	619.7 ± 144.2	3.11 ± 0.73	7.45 ± 1.27	2.76
T1–T8	5	676.6 ± 417.7	3.41 ± 1.99	8.68 ± 5.89	3.21
T9–L4	5	800.2 ± 342.7	3.97 ± 1.60	9.68 ± 4.00	3.59
Weight training					
C5–C8	9	672.2 ± 284.5	3.28 ± 1.17	8.23 ± 3.66	3.05
T1–T8	5	671.0 ± 365.0	3.33 ± 1.72	8.18 ± 5.30	3.03
T9–L4	6	697.3 ± 293.6	3.54 ± 1.50	7.24 ± 1.60	2.68
Recreation					
Basketball					
T9–L4	3	1375.3 ± 460.5	6.74 ± 2.27	17.87 ± 5.71	6.62
Billiards					
C5–C8	2	593.3 ± 92.4	2.93 ± 0.46	6.81 ± 1.46	2.52
T1–T8	4	516.8 ± 170.9	2.51 ± 0.77	6.10 ± 2.57	2.26
T9–L4	5	495.6 ± 74.8	2.42 ± 0.35	6.77 ± 2.15	2.51
Bowling					
C5–C8	2	604.0 ± 321.0	2.89 ± 1.63	6.37 ± 2.19	2.36
Darts					
T1–T8	2	442.0 ± 89.1	2.12 ± 0.43	6.57 ± 1.53	2.43
Table tennis					
T1–T8	2	533.0 ± 48.1	2.48 ± 0.25	6.77 ± 2.18	2.51
T9–L4	2	752.5 ± 381.1	3.53 ± 1.60	7.20 ± 0.42	2.67
Activities of daily living					
Assisted standing					
T9–L4	2	238.0 ± 5.7	1.23 ± 0.03	3.15 ± 0.43	1.17
Bed making					
C5–C8	4	633.8 ± 173.6	3.05 ± 0.80	6.90 ± 0.68	2.56
T1–T8	3	616.0 ± 14.2	2.94 ± 0.09	7.92 ± 0.84	2.93
T9–L4	3	535.3 ± 58.6	2.51 ± 0.21	7.76 ± 1.43	2.87
Deskwork					
C5–C8	2	312.5 ± 36.1	1.57 ± 0.23	3.50 ± 0.39	1.30
Driving					
T9–L4	4	472.1 ± 75.3	2.34 ± 0.31	6.05 ± 1.36	2.24
Dusting					
C5–C8	2	559.0 ± 89.1	2.78 ± 0.61	4.89 ± 0.74	1.81
T1–T8	3	484.3 ± 39.1	2.34 ± 0.11	6.66 ± 0.38	2.47
T9–L4	3	626.7 ± 316.3	3.02 ± 1.52	7.07 ± 3.28	2.62
Hand-cycling					
T9–L4 (5 m·h^{-1})	2	1153.5 ± 446.2	5.67 ± 2.17	15.55 ± 6.40	5.76
T9–L4 (10 m·h^{-1})	2	1938.5 ± 623.0	9.64 ± 2.89	26.15 ± 9.11	9.69
T9–L4 (all-out)	2	3245.5 ± 1523.8	17.75 ± 9.06	43.87 ± 21.70	16.25
Laundry					
C5–C8	4	501.2 ± 62.3	2.38 ± 0.22	5.85 ± 0.83	2.17
T1–T8	2	493.9 ± 28.0	2.41 ± 0.13	7.31 ± 0.19	2.71
T9–L4	4	547.2 ± 144.3	2.59 ± 0.74	6.16 ± 1.23	2.28
Moving items					
C5–C8	4	702.9 ± 83.3	3.54 ± 0.41	8.43 ± 2.27	3.12
T1–T8	2	870.8 ± 582.0	4.32 ± 2.93	9.65 ± 4.49	3.57
T9–L4	3	585.4 ± 232.7	2.83 ± 1.11	8.27 ± 3.39	3.06
Showering					
T9–L4	2	650.0 ± 370.5	3.10 ± 1.79	6.77 ± 2.26	2.51
Stair climbing					
C5–C8	2	1117.1 ± 265.6	5.15 ± 0.97	16.14 ± 3.54	5.98
Vacuuming					
C5–C8	4	542.0 ± 118.2	2.58 ± 0.55	6.62 ± 0.37	2.45
T1–T8	3	586.7 ± 131.8	2.83 ± 0.62	7.57 ± 1.26	2.80
T9–L4	3	665.3 ± 366.7	3.1 ± 1.69	7.21 ± 2.39	2.67

(continued on next page)

TABLE 4. *(Continued)*

Activity/Group	n	$\dot{V}O_2$ (mL·min^{-1})	kcal·min^{-1}	mL·kg^{-1}·min^{-1}	SCI MET
Walking					
C5–C8	2	877.3 ± 556.9	4.20 ± 2.66	12.87 ± 8.17	4.77
T9–L4	9	959.9 ± 334.8	4.70 ± 1.71	12.70 ± 3.16	4.70
Washing dishes					
C5–C8	4	418.3 ± 119.0	2.03 ± 0.66	4.55 ± 0.71	1.69
T1–T8	2	535.5 ± 70.0	2.60 ± 0.24	8.09 ± 1.03	3.00
T9–L4	2	414.5 ± 96.9	1.91 ± 0.41	5.10 ± 0.04	1.89
Wheeling on tile					
C5–C8	7	598.0 ± 129.6	2.96 ± 0.62	7.55 ± 1.49	2.80
T1–T8	3	496.4 ± 212.0	2.41 ± 1.02	6.30 ± 2.50	2.33
T9–L4	9	689.5 ± 345.0	3.37 ± 1.74	8.95 ± 3.81	3.31
Wheeling on carpet					
C5–C8	3	671.4 ± 258.9	3.38 ± 1.29	7.47 ± 0.95	2.77
T1–T8	2	890.5 ± 39.7	4.48 ± 0.23	11.50 ± 3.42	4.26
T9–L4	7	687.2 ± 148.0	3.30 ± 0.73	9.04 ± 2.50	3.35
Wheeling on grass					
C5–C8	2	982.5 ± 293.4	4.96 ± 1.27	11.95 ± 0.82	4.43
T9–L4	2	1537.0 ± 247.5	7.81 ± 0.92	16.79 ± 3.25	6.22
Wheeling outside					
C5–C8	2	645.1 ± 30.9	3.33 ± 0.49	9.63 ± 0.26	3.57
T1–T8	2	861.3 ± 123.4	4.25 ± 0.82	11.44 ± 2.06	4.24
T9–L4	3	1049.8 ± 163.3	5.10 ± 0.61	11.33 ± 0.97	4.20

for a compendium and (b) to measure REE and establish the value of 1 MET for individuals with SCI.

Resting oxygen uptake for participants in our study was 23% lower than that reported for nondisabled adults. Although resting values were lower for those with an upper-level injury (2.52 ± 0.50 mL·kg^{-1}·min^{-1}) when compared with a lower-level injury (2.77 ± 0.47 mL·kg^{-1}·min^{-1}), the difference was not statistically significant ($P > 0.05$). The mean oxygen uptake (±SD) for the 66 subjects was 2.66 ± 0.50 mL·kg^{-1}·min^{-1}, and the 95% confidence interval was 2.54–2.78 mL·kg^{-1}·min^{-1}. Monroe et al. (23) reported that the resting metabolic rate in 10 male SCI participants was 27% lower when compared with 59 age-matched control participants. Bauman et al. (6) reported data on 13 pairs of monozygotic twins discordant for SCI, with the SCI twin having a 10% lower REE. Jeon et al. (19) found the measured resting metabolic rate to be 27% lower in seven males with complete tetraplegia when compared with seven nondisabled control males. In a similar study of males and females with paraplegia, Buchholz et al. (8) reported that the resting metabolic rate was 14% less in those with SCI when compared with the nondisabled. Both Jeon et al. (19) and Buchholz et al. (8) reported that the difference in resting metabolic rate decreased to 3% and less than 2%, respectively, when adjusted for fat-free mass. In the present study, we did not measure body composition.

We determined that 1 MET was equivalent to 2.7 mL·kg^{-1}·min^{-1} for persons with SCI compared with 3.5 mL·kg^{-1}·min^{-1} for nondisabled adults. By using a value of 3.5 mL·kg^{-1}·min^{-1}, researchers may underestimate the

TABLE 5. Energy expenditure (mean ± SD) for activities in females with motor complete and incomplete injuries.

Activity/Group	n	$\dot{V}O_2$ (mL·min^{-1})	kcal·min^{-1}	mL·kg^{-1}·min^{-1}	SCI MET
Fitness					
Arm cranking (32 W)					
T1–T8	2	756.0 ± 339.5	3.77 ± 1.52	11.09 ± 6.68	4.1
Circuit training					
T1–T8	2	474.5 ± 129.5	2.58 ± 0.87	7.25 ± 0.37	2.7
Weight training					
T1–T8	2	479.1 ± 76.9	2.44 ± 0.39	7.46 ± 1.23	2.8
Activities of daily living					
Dusting					
T1–T8	2	422.0 ± 108.9	1.96 ± 0.55	5.44 ± 0.56	2.0
Moving items					
T9–L4	2	582.0 ± 18.4	2.81 ± 0.13	9.26 ± 2.78	3.4
Vacuuming					
T1–T8	2	481.5 ± 116.7	2.24 ± 0.59	6.22 ± 0.75	2.3
Washing dishes					
C5–C8[a]	2	235.7 ± 101.9	1.26 ± 0.73	2.47 ± 0.30	0.9
T1–T8	3	303.7 ± 44.0	1.45 ± 0.15	4.02 ± 0.65	1.5
T9–L4	2	388.3 ± 39.5	1.89 ± 0.18	6.24 ± 2.29	2.3
Wheeling on carpet					
T1–T8	2	573.0 ± 361.0	2.92 ± 1.82	8.42 ± 2.55	3.1
Wheeling on sidewalk					
T1–T8	2	515.4 ± 315.4	2.62 ± 1.66	8.11 ± 2.70	3.0
Wheeling on tile					
T1–T8	3	362.1 ± 100.6	1.74 ± 0.42	5.80 ± 0.93	2.1
T9–L4	2	603.5 ± 46.7	3.05 ± 0.111	10.53 ± 2.09	3.9

[a] Incomplete.

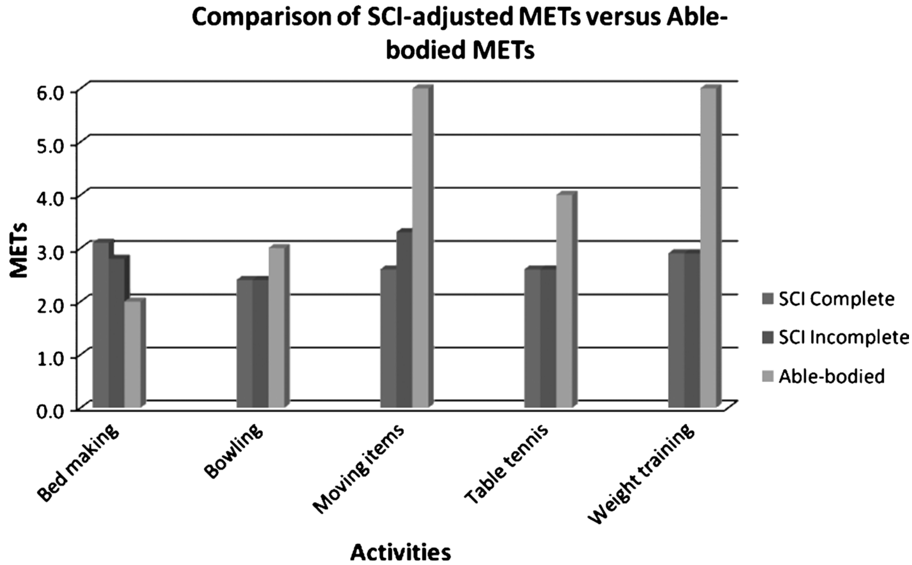

FIGURE 1—Comparison of MET values for five activities using SCI-adjusted METs and tabled values for the able-bodied.

stress and strain of a particular activity in a person with SCI. For example, oxygen uptake for arm cranking at 96 W for participants with a T9–L4 injury was 20.55 ± 2.95 $mL \cdot kg^{-1} \cdot min^{-1}$. Using the 2.7 $mL \cdot kg^{-1} \cdot min^{-1}$ designation for 1 MET, that activity had a MET value of 7.6 METs, whereas using the 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ value, that activity had a MET value of 5.9 METs, thus underestimating the level of intensity of the activity in a person with SCI. This ratio of work metabolism to rest metabolism also holds true for absolute oxygen uptake values. In this case, the work-to-rest ratio for arm cranking at 96 W using the absolute oxygen uptake values ($mL \cdot min^{-1}$) was 7.7.

This is the first study to report energy expenditure data for a comprehensive number of activities of daily living, fitness activities, and recreation activities. Clinicians, researchers, and individuals with SCI can use these tabled energy cost values to quantify energy expenditure. These tabled values can be used for a program of weight maintenance or weight loss or to track daily energy expenditure. For example, to use 150 kcal beyond what is commonly expended by a person with SCI during his/her daily activities, a person with a C7 complete injury would need to arm crank at 16 W for 6 min (16.5 kcal), circuit train for 15 min (34.7 kcal), and wheel outside for 35 min (101.5 kcal) (total time = 52 min and 153 kcal). Likewise, a person with a T10-level complete injury would need to arm crank at 16 W for 6 min (19.6 kcal), circuit train for 12 min (38.3 kcal), and wheel outside for 25 min (99.5 kcal) (total time = 37 min and 157 kcal). Similarly, researchers and clinicians wishing to quantify physical activity patterns of individuals with SCI can use measured energy costs as estimates instead of relying on the compendium for able-bodied adults.

Peak oxygen uptake in untrained individuals with tetraplegia (13.9 $mL \cdot kg^{-1} \cdot min^{-1}$) and paraplegia (22.0 $mL \cdot kg^{-1} \cdot min^{-1}$) (10) was similar to arm cranking data measures at higher power outputs in our data. Although not cranking at the same absolute power, our energy expenditure results are also similar to submaximal arm cranking values reported by Schneider et al. (29) and Hjeltnes and Wallberg-Henriksson (15). Algood et al. (4) reported energy expenditure while wheeling at various levels of resistance. Interestingly, oxygen uptake while wheeling at 12 W of resistance was similar to wheeling on carpeting for individuals with tetraplegia (664 ± 261 vs 695 ± 226 $mL \cdot min^{-1}$, respectively).

It is important to recognize that the outcomes for this study are not the traditional outcome measures. Conditions under which data were collected were a close approximation to real-life situations. We did not push the subjects to peak performance levels. Instead, participants were told to complete activities in a manner that they would perform the activity in everyday life or under ordinary exercise circumstances. With the exception of the third condition for handcycling, i.e., "all-out effort," data are submaximal. Therefore, it is not surprising that an appreciable number of measures presented in the tables do not match those presented by other investigators who reported peak oxygen uptake for a given activity (7,16–18,21,29).

We recognize that for subjects within an injury category, active muscle mass may differ on the basis of the level and completeness of the injury. We concluded that dividing levels of injury in the manner used in this study was consistent with the published literature. In addition, the division among C5–C8, T1–T8, and T9–L4 was theoretically sound physiologically because of the active muscle available at each level. Likewise, activities were designed to approximate real-life situation and thus left several factors free to vary. As a result, because of higher variability, we may not have found statistical significance when clinically important differences within the data exist. Likewise, the number of participants at each level of injury is less than if we decided to group participants by tetraplegia and paraplegia or simply group all participants into one SCI category.

The activities that were measured in this study are commonly performed by individuals with SCI as part of their activities of daily living or for recreational/sport or exercise. To make the energy costs more generalizable for the SCI population, we did not limit participants to trained athletes, as has been the case in previous studies (2,11,28). Individuals were able to use assistive devices when needed. For example, while bowling, some people used assistive devices and others did not. When we measured grocery shopping, some individuals shopped at large stores and others at smaller stores. Although they were given a list of groceries to "buy," the location of the items in different stores varied. Such variations occur in daily life, and in building a comprehensive list of this nature, we believed it was important to capture the variability of the activity. Although we view this as a strength of the study, others may view this variability as a limitation.

Our study was limited by several factors. First, because several activities were completed out-of-doors, weather limited some data collection. In addition, two of the data collection sites were in places with harsh winters. Thus, if there was snow on a data collection day, often participants did not test. Second, we attempted to obtain data while participants were engaged in winter activities such as skiing. Because of the excessive condensation in the mask, these data were unusable. Third, some activities that were initially tested (e.g., transferring) were too short in duration to provide meaningful steady-state data and, ultimately, were not used. Energy expenditure data on 71 tests were not included because we were unable to enroll participants of a similar injury level and completeness of injury. Lastly, the number of females enrolled in this study was small, and no women participated in the REE portion of this study. This could limit the generalizability of this compendium to women.

In conclusion, energy expenditure data on 27 activities were measured, and steady-state values were reported. Second, REE in persons with an SCI is lower than that reported for the nondisabled, and in the future, adjustments in calculating MET levels should be made accordingly. Moreover, it is proposed that a more precise value for the MET when applied to people with SCI is 2.7 $mL \cdot kg^{-1} \cdot min^{-1}$. Further research is needed to determine the influence of physical activity on the (a) general health and well-being of the individual with SCI, (b) incidence/prevalence and potential prevention of secondary complications of SCI, (c) cardiovascular and pulmonary health, and (d) general health-promoting behaviors in the SCI population.

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