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Using Biomechanics and Physiology to Offer New Insight on Activity Prescription after Incomplete Spinal Cord Injury

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Abstract

Individuals living with incomplete Spinal Cord Injury (iSCI) are prone to gait impairment and highly sedentary lives. Gait impairment exacerbates the energy cost of movement activities. This case-control investigation sought to quantify the caloric expenditure and gait movement patterns of a case with a cervical seven, iSCI and an age-, sex-, and height-matched control (CON). Laboratory data were combined with free-living step activity to evaluate the appropriateness of prescribing physical activity using step metrics after iSCI. Participants completed a six-minute walk test and three, paced-walks wearing a portable metabolic cart. Step activity monitors were worn for seven days to capture daily living activity prior to participants returning for three-dimensional gait evaluation. Kilocalories per step, step count, and Lateral Deviation (LD) of the seventh cervical spinal process were compared between the iSCI and CON. Peak oxygen consumption, daily step count, and walking speed were lower while energy cost (of walking) and LD were higher in iSCI compared to CON. Though iSCI took two thirds fewer steps, they expended nearly twice as many calories per step compared to CON. A LD to walking speed index (LDI) was created to represent gait pattern relative to actual locomotion. The iSCI LDI improved by 45% and CON by 21% when walking speed increased; this improvement may represent greater efficiency of movement at faster walking speeds. Walking mechanics impact energy expenditure of walking post-iSCI and step activity recommendations should be reconsidered. Rehabilitation specialists may implement LDI as a clinical metric that represents gait pattern and efficiency.

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Introduction

Individuals post incomplete Spinal Cord Injury (iSCI) are prone to a highly sedentary lifestyles secondary to gait impairment. Musculoskeletal adaptations in an iSCI are more severe than prolonged bed rest, weightlessness (space travel), and immobilizations [1-3]. The muscles below the iSCI atrophy with concomitant decreases in metabolism [4]. Moreover, those with iSCI present with a greater concentration of anaerobic muscle fibers (i.e. IIx) relative to those without iSCI [5], making the musculature more predisposed to fatigue. Those with longstanding iSCI are slow to develop torque below the injury, thereby limiting locomotor function [6] and efficiency. The diminished gait leads to higher energy cost when completing movement activities (e.g., daily living, self-care, leisure) [7]. Despite this higher metabolic cost, there is no recommended step count value for those post-iSCI.

A lack of modified step prescriptions leaves a person with iSCI to follow the standardized recommendation of 10,000+ daily steps to be considered "active"; a recommendation which was created for able-bodied individuals [8]. Step activity criteria were designed to reflect an overall daily energy expenditure, but this objective measure is exposed to error when gait is impaired. Individuals with functional limitations, such as iSCI, are known to expend more energy during locomotion when compared to non-impaired controls (CON) [7].

The purpose of this study was to investigate the energy cost of Daily Step Physical Activity (DSPA) post-iSCI and compare that to an able-bodied CON of similar physical characteristics. The research team also examined kinematic parameters of gait between iSCI and CON walking to better understand differences noted in walking energy cost. Appraising these changes may help clinicians better prescribe treatment plans to improve quality of movement.

Table 1: Participant demographic data.

	Age	Weight	Body Fat	Total Limb Length
Case	36	196.5	28.1	31.9
Control	38	179.6	18.9	32.5

Note: Age- years; weight- pounds; body fat- percent; total limb length- in inches

Case-Control Presentation

One ambulatory male case with an iSCI was recruited. The iSCI was the result of a traumatic head and neck injury (level C5) twelve years prior to participation. There was no evidence of a traumatic brain injury resulting from the accident and the case was scored an ASIA D upon hospital discharge. Chronic repercussions to the iSCI are persistent neuropathic pain treated by non-steroidal anti-inflammatory drugs and mild clonus in the lower right limb. One age-, sex- and limb length-matched CON (± 2 years and 2 inches) was also recruited. Descriptive statistics for each participant are shown in Table 1.

Volunteers signed an IRB-approved informed consent prior to initiation of data collection. Participants' limb length (femur and shank) were measured by a licensed physical therapist with a nylon tape. Values were totaled for a summed limb length. Weight and body composition were assessed *via* bioelectrical impedance (InBody570®, In Body USA, Cerritos, CA).

Walking tasks

Session one began with an activity specific warm up followed by a familiarization and fitting of the calibrated portable metabolic cart (Cosmed K4b², Cosmed, Rome, Italy). To assess peak oxygen consumption (VO_{2peak}), each participant completed a Six-Minute Walk Test (6MWT) on an oval track while wearing the metabolic cart. Participants were asked to walk at the fastest, maintainable pace for six minutes. The case was permitted to use typical daily walking aids (cane and Bioness L300) for all study walking tasks. Heart rate, VO_{2peak} (using a 15-breath rolling average) [9], and total distance covered were collected for each participant.

Matching the paces on the Step Activity Monitor (SAM; Modus Health, Oklahoma City, Oklahoma), participants completed three-minute walk tests paced at 15 (low), 35 (moderate), and 55 (high) steps per minute, respectively. Each test was separated by a minimum of five minutes rest. Participants were fitted with a SAM on the dominant limb, immediately superior to the lateral malleolus. Participants wore the SAM for the remainder of the day and for the next seven consecutive days. The monitor was calibrated following a previously established protocol [10].

Biomechanical analyses

No sooner than seven days after session 1, participants returned to complete the biomechanical assessments during the following tasks: Self-selected and fast-10-meter walk tests (SS10MWT & F10MWT) and balancing on a flat platform (both feet, then alternating single leg attempts). Gold standard [11], three-dimensional motion analysis (Qualisys AB, Gothenburg, Sweden)was used to capture gait speed and Lateral Deviation (LD) during SS10MWT and F10MWT. LD was determined by movement of the seventh cervical spinal process (C7) reflective marker along the frontal plane (Figure 1).

Participants safely completed the walking trials without issue; however, the case was unable to maintain the 55 steps per minute cadence. Metabolic and step activity data are presented in Table 2. Visualization of C7's deviation path during the F10MWT is presented in Figure 2.

Table 2: Metabolic and step activity data.

	iSCI	CON
Laboratory Data		
Peak VO_2 during 6MWT	21.6 ± 1.3 ml/kg/min	28.2 ± 2.3 ml/kg/min
Energy cost of 6MWT	0.3 kcal/m	0.1 kcal/m
VO_2 slow pace	11.9 ± 1.0 ml/kg/min	8.5 ± 1.1 ml/kg/min
VO_2 moderate pace	17.7 ± 2.2 ml/kg/min	9.8 ± 0.6 ml/kg/min
VO_2 fast pace	Unable to complete	13.2 ± 0.9 ml/kg/min
Kcal/step slow pace	0.4 kcal/step	0.2 kcal/step
Kcal/step moderate pace	0.2 kcal/step	0.1 kcal/step
Kcal/step fast pace	Unable to complete	0.1 kcal/step
Stride rate SS10MWT	0.25 ± 0.06 m/s	1.37 ± 0.14 m/s
Stride rate F10MWT	0.32 ± 0.06 m/s	1.90 ± 0.05 m/s
Gait speed SS10MWT	0.20 ± 0.07m/s	1.37 ± 0.08m/s
Gait speed F10MWT	0.33 ± 0.07m/s	1.91 ± 0.10m/s
LD SS10MWT	0.43 ± 0.04 m	0.09 ± 0.02 m
LD F10MWT	0.39 ± 0.02 m	0.10 ± 0.04 m
Free-Living Data		
Daily step count	2,764 ± 2054	8,502 ± 5640
Steps at slow pace	920 ± 313	2,094 ± 1450
Steps at moderate pace	1,038 ± 348	5,234 ± 3754
Steps at fast pace	256 ± 187	1,180 ± 728
Extrapolated Data		
Estimated kcal/day from steps	1,262.8 ± 2237	2,309.0 ± 1880.2
Kcals from slow pace	978.5 ± 110.8	1,963.96 ±1302.8
Kcals from moderate pace	239.8 ± 80.3	230.34 ± 412.9
Kcals from fast pace	44.5 ± 32.5*	115.64 ± 71.3

Note: Means ± standard deviation (when applicable); peak VO_2 during 6-Minute Walk Test (6MWT); energy cost in kilocalories per meter; ml/kg/min: Milliliters per kilogram per minute; m/s: Meters per second; average daily step count represents both limbs (SAM output multiplied by two); slow pace - 15 steps per minute; moderate pace - 35 steps per minute; fast pace – 55 steps per minute. *VO_{2peak} was used to estimate kcals from fast pace walking.

Figure 1: Representation of the anatomical location for LD and reflective marker placement at bony landmark on cervical seven spinous process.

Discussion

Findings from this case-control investigation support data that those with neurologically impaired gait will exhibit greater caloric expenditure during walking tasks [12]. If we truly consider

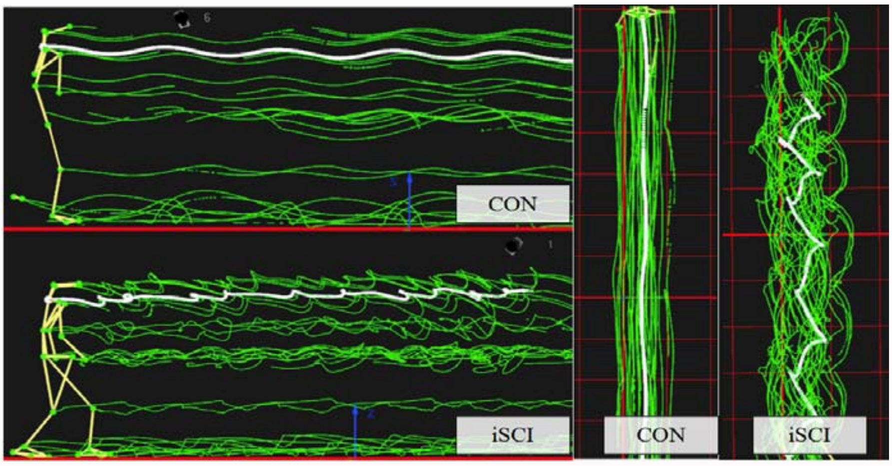

Figure 2: Trajectories of reflective markers (green lines); deviation of C7 (white line); stacked figures on the left are the lateral view and the two figures on the right are superior views.

the concept of step count, we would recognize the goal of such recommendations is about energy cost of movement; the threshold count is a helpful metric for aiming to maintain healthy weight and physiological processes (e.g., cardiorespiratory, metabolic). Tudor-Locke and Bassett (2004) recognized early that the step goal of 10,000 or more a day would likely be unattainable by many, therefore suggesting an adjustment to as low as 5000 to 7500 steps per day to avoid a sedentary classification [8]. Rather than sticking with step counts, however, Marshall et al. [13] suggested identifying step counts that relate to moderate-intensity walking (3 to 5 METs) to account for effort. Findings from this investigation were that estimating MET values from step counts was prone to considerable error and that walking at a pace greater than 100 steps per minute represented the minimum threshold for attaining moderate-intensity. Another issue with translating steps to METs is the inconsistency of using the resting energy expenditure constant of 3.5 ml/kg/min. The case in this investigation had a standing energy expenditure of 7.35 ml/kg/min (or 2.1 METs), with typical adults having a standing MET value of 1.59 ± 0.37 [14]. Therefore, it is likely inappropriate to standardize activity recommendations based on step metrics or standardized MET values for those with functional limitations without first considering their biomechanical and metabolic efficiency.

In the clinical setting, LD is often indicative of an abnormal walking pattern, but is not typically quantified for objective assessments. While both participants increased gait speed between 10MWTs, LD did not change as expected. LD decreased in the case and increased with the CON when going from SS10MWT to F10MWT, as shown in Figure 3.

Rather than looking at LD in isolation, it may be relevant for clinicians to consider evaluating a LD and walking speed index (LDI) as a clinical outcome. The case's LDI (calculated as LD/walking speed) improved from the SS10MWT (2.15) to the F10MWT (1.18). The CON's LD index also improved from 0.66 to 0.52 when walking faster. It is possible that the case adopted a gait pattern that allowed for greater weight bearing on the more impaired limb during the SS10MWT when compared to the F10MWT. Clinicians may consider a more segmental approach to fully gain insight on compensatory mechanisms adopted during self-selected and fast walking after neurological trauma. Rehabilitation specialists may also consider implementing a more objective view of C7 movement when assessing pathologic gait, as it is clearly impacted by altering walking speed.

Unrealistic expectations may heighten perceived barriers, undermine mobility related to self-efficacy, and discourage adoption or adherence of activity behaviors. Exercise prescription based on energy expenditure goals may serve as an alternative mode to individualize daily activity for those with functional limitations. Future research should attempt to establish new recommendations based on functional status for those outside the typical gait norm. Clinicians may also consider evaluating the relationship between C7, pelvic response, trunk flexion, and metabolic cost of walking speeds to better direct therapeutic attention to the component most responsible for the dysfunction.

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