ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2018;99:2038-44

ORIGINAL RESEARCH

Energetic Cost of Walking and Its Physiological Correlates in Persons With Multiple Sclerosis Who Have Moderate Mobility Disability

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Abstract

Objective: This study examined aerobic capacity, upper leg muscular strength, and static postural control as correlates of the energetic cost of walking (C_w) in moderate multiple sclerosis (MS) mobility disability.

Design: Cross-sectional study.

Setting: University-based laboratory.

Participants: Persons (N=44) with MS (aged 48.43±8.64 years) who have reached a benchmark of moderate mobility disability (ie, Expanded Disability Status Scale scores between 4.0 and 6.0) participated in the study.

Main Outcome Measures: C_w was based on (1) net oxygen consumption collected using a portable metabolic unit and (2) walking speed during the 6-minute walk test. Participants underwent standard assessments of peak aerobic capacity, upper leg muscular strength, and static postural control.

Results: The data were analyzed using bivariate correlation and linear regression analyses. C_w was inversely correlated with peak oxygen consumption ($r=-.308$, $P<.05$), peak power output ($r=-.548$, $P<.00$), and peak torque at 75° knee flexion ($r=-.340$, $P<.05$), whereas C_w was positively correlated center of pressure area sway ($r=.319$, $P<.05$), and mediolateral sway velocity ($r=.411$, $P<.05$). 40.3% of variance in C_w was explained by peak power output ($\beta=-.526$, $P<.01$) and mediolateral sway velocity ($\beta=.339$, $P<.05$).

Conclusion: Our findings demonstrate that aerobic power and postural sway may be important correlates of C_w in moderate MS mobility disability. Peak power output reflects a person's physiological functional reserve that is directly relevant for understanding the penalty of walking impairment on the energetic demands of walking. The association between mediolateral postural sway and C_w suggests that mechanical inefficiency controlling the trajectory of the body's center of pressure during ambulation may contribute to the elevated C_w.

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Walking impairment is one of the most prevalent and life-altering consequences of multiple sclerosis (MS),[1,2] and the onset may occur in the early stages of the disease,[3] but it becomes more prevalent and burdensome with disability progression. For example, persons with MS demonstrate worse walking performance as indicated by 6-minute walk test (6MWT) distance than healthy controls,[4] and the degree of impairment in 6MWT performance worsens as a function of increasing disability status.[5] The effect of reduced walking performance becomes particularly concerning when it co-occurs with an increase in the energetic cost of walking (C_w). C_w represents a physiological marker of walking impairment that reflects the contribution of pathologic gait abnormalities and other manifestations caused by neurologic disability.[6] C_w is defined as the amount of oxygen consumed per kilogram of body weight per unit distance traveled ($mL \cdot kg^{-1} \cdot m^{-1}$).[6] Conceptually, C_w reflects the energy required for over-ground and treadmill walking and can increase as a function of shorter distance traveled while expending the same amount of energy, or as a function of increased energy expenditure for walking the same distance.

There is evidence that C_w is higher in persons with MS than controls and is linearly associated with disability status and perhaps other disease-related consequences in persons with MS. One study reported that C_w during treadmill walking was higher in

Disclosures: none.

0003-9993/18/$36 - see front matter © 2018 by the American Congress of Rehabilitation Medicine
https://doi.org/10.1016/j.apmr.2018.06.011

persons with MS than controls.[5] The same study reported that disability status has a positive, linear association with C_w during 6-minute bouts of treadmill and over-ground walking in persons with MS.[5] C_w during treadmill walking at 54 m·min^{-1} farther has been associated with spatiotemporal parameters of gait (ie, shorter stride length and longer double limb support) measured over-ground at comfortable walking speed in persons with MS[7]; however, it should be noted that treadmill walking at a fixed speed and over-ground walking at comfortable speed may involve substantially different mechanics. Another study overcame the limitation of the aforementioned study by measuring both C_w and gait parameters over-ground and reported that C_w was moderately to strongly associated with disability status and spatiotemporal gait parameters in persons with moderate MS-related mobility disability, and cadence, in particular, explained the association between C_w and disability.[8] Collectively, the research demonstrates that C_w is elevated in MS, particularly among those who have mobility disability, and C_w is associated with cadence and other indices of gait (ie, pathologic gait abnormality).

To date, there is minimal research focusing on putative modifiable variables that are associated with elevated C_w in persons with MS who have reached a benchmark of moderate mobility disability characteristic of the second stage of MS based on Expanded Disability Status Scale (EDSS) scores (eg, EDSS between 4 and 6).[9] This is important for identifying approaches for reducing C_w and its consequences in MS; C_w has been associated with higher fatigue and interference with daily activities in MS.[7] There are a number of reasons why researchers might focus on metrics of physical fitness (eg, aerobic capacity, upper leg muscular strength, and postural control) as correlates of C_w in persons with MS who have mobility disability. There are consistent data indicating that physical fitness is compromised in persons with MS compared with controls,[10] and the magnitude of reductions in aerobic capacity, upper leg muscular strength, and postural control increase as a function of disability status.[11,12] We further note that physiological conditioning outcomes (ie, physical fitness) have been associated with 6MWT performance in MS,[10] and walking performance is one component of C_w.[5] Physical fitness outcomes have been associated with C_w in other populations including stroke,[13] healthy older adults,[14] and adults from the general population.[15] Nevertheless, there have been no direct examinations of physical fitness outcomes as correlates of C_w in persons with MS who have moderate mobility disability.

The current study examined objective measures of aerobic capacity, muscular strength of the knee flexors and extensors, and static postural control as correlates and predictors of C_w in adults with MS who have moderate mobility disability using bivariate correlation and linear regression analyses. We expected that lower levels of aerobic capacity, upper leg muscular strength, and postural control would be associated with a higher C_w. We further expected that aerobic capacity, upper leg muscular strength, and postural control would be independent predictors of C_w, but the exact nature of the associations was not specified a priori, but rather determined through the regression analysis. Such evidence would provide preliminary guidance for the design of an exercise training intervention for targeting C_w in moderate MS disability, as this group has a level of disability wherein disease-modifying medications have limited influence on the manifestations, such as walking impairments and C_w.[9] Few rehabilitation options have been established in this group; exercise, for example, is often studied in persons with mild MS.[16] To that end, identifying domains of physical fitness that might be associated with C_w in persons with moderate MS disability would provide critical information for the development of targeted exercise training interventions (ie, improving physiological conditioning) for possibly reducing C_w, and this may result secondary benefits including managing fatigue and maintaining quality of life and independence.

List of abbreviations:

6MWT	**6-Minute Walk test**
COP	**center of pressure**
C_w	**energetic cost of walking**
EDSS	**Expanded Disability Status Scale**
MS	**multiple sclerosis**
PDDS	**Patient Determined Disease Steps**
$\dot{V}O_2$	**oxygen consumption per unit time**
VO_{2peak}	**peak oxygen consumption**

Methods

Participants

Participants were recruited through newspaper, television, and radio advertisements, as well as e-mail announcements and letters distributed among persons in our research database and through the National MS Society. The inclusion criteria were (1) medical diagnosis of MS confirmed in writing by the participant's neurologist; (2) EDSS score of 4.0 through 6.0 based on clinical evaluation (ie, a benchmark of moderate mobility disability reflecting the second stage of MS)[9]; (3) no relapse over the past 30 days; (4) no symptoms of underlying cardiovascular disease based on the one or fewer affirmatives on the Physical Activity Readiness Questionnaire; (5) physician approval for undertaking exercise testing. We included persons irrespective of disease-modifying medications. There were 44 participants who satisfied the inclusion criteria and were subsequently enrolled in the study.

Experimental protocol

The study and its procedures were approved by a university institutional review board. All participants provided written informed consent and were asked to refrain from physical activity and food intake 1-3 hours prior to data collection. Data on symptomatic and disease-modifying medications were not recorded. The outcomes were administered on 2, nonconsecutive days in our laboratory. The order of assessments within and across days was intentionally designed to reduce fatigue. On day 1, participants initially reported demographic and clinical characteristics. We then measured height and weight using a standard scale stadiometer. This was followed by the 6MWT and measurement of C_w using the portable calorimetry system. Participants then underwent isometric dynamometry for measurement of muscular strength of the knee joint. On day 2, participants initially underwent measurement of static postural control, followed by the incremental exercise test for measurement of aerobic capacity. Participants received $50 remuneration for completing the outcomes.

Outcome measures

Energetic cost of walking

C_w was measured during the 6MWT using a portable, indirect calorimetry system (K4b^2).[17,a] We initially calibrated the