WILDERNESS & ENVIRONMENTAL MEDICINE (2018) ▮, ▮▮▮–▮▮▮

ORIGINAL RESEARCH

Metabolic Demand of Hiking in Wildland Firefighting

Joseph A. Sol, MS; Brent C. Ruby, PhD; Steven E. Gaskill, PhD; Charles L. Dumke, PhD; Joseph W. Domitrovich, PhD

From the United States Department of Agriculture, Forest Service, National Technology and Development Program, Missoula, MT (Mr Sol and Dr Domitrovich); the Montana Center for Work Physiology and Exercise Metabolism, University of Montana, Missoula, MT (Dr Ruby); and the Department of Health and Human Performance, University of Montana, Missoula, MT (Drs Gaskill and Dumke).

Introduction—The objective of this study was to document characteristics of hiking during wildland firefighter (WLFF) training and wildfire suppression. For the first time, the overall physical demands during wildland firefighting were evaluated in the field using global positioning systems coupled with wireless physiological monitoring and load carriage prediction models.

Methods—Male (n=116) and female (n=15) interagency hotshot crew and type II WLFFs on wildfires volunteered for this direct observation study. Participants' heart rate, internal temperature, speed, and elevation gain were monitored throughout training and during wildfire suppression. The Pandolf and Santee equations were used to predict metabolic rate to estimate oxygen consumption of uphill and downhill hiking.

Results—Equipment weight varied by crew type (type II: 24±9 kg and interagency hotshot crew: 28 ±6 kg; $P<0.05$). Grade of terrain was steepest during training hikes, and ingress hikes were statistically different from egress and training hikes (ingress: 4±9%, shift: 4±9%, egress: 1±8%, training hikes: 10±9%; $P<0.01$). Estimated oxygen consumption was highest during ingress hikes and was significantly different from all other hike types on fire assignments (ingress: 22±12, shift: 19±12, egress: 19±12 $mL \cdot kg^{-1} \cdot min^{-1}$; $P=0.01$). Oxygen consumption was higher during training hikes (34±14 $mL \cdot kg^{-1} \cdot min^{-1}$) than during job-related hikes ($P<0.01$).

Conclusions—The greatest metabolic demand during wildfire assignments occurred during ingress hikes. On average, this was close to the estimated metabolic demand of the job qualification arduous pack test. However, greater metabolic demand occurred for periods during both shift (on the job) and training hikes. These data quantify the demands associated with actual wildland performance of WLFFs and can help define future work capacity testing and training procedures.

Keywords: energy expenditure, load carriage, oxygen consumption

Introduction

Wildland firefighting (WLFF) is one of the few occupations that intrinsically requires components of strength and endurance for strenuous labor over long durations. Research on WLFFs has comprehensively evaluated the total energy expenditure (TEE) of wildfire suppression using doubly labeled water methodologies.[1–3] These data demonstrated an overall TEE averaging 17.5±4.1 $MJ \cdot d^{-1}$ and 19.1±3.9 $MJ \cdot d^{-1}$ over 5 and 3 continuous days of work, respectively.[2,4] Moreover, these studies revealed a consistent day-to-day pattern of TEE approximating nearly 3 times estimated resting metabolic rates (11.4–26.2 $MJ \cdot d^{-1}$ or 2868–6214 $kcal \cdot d^{-1}$) and demonstrated that TEE on the fireline can be a function of body size, sex, self-selected work rates, job assignments, and topography.[1–6]

Considering these energy expenditure values of these 12 to 16 h shifts, the most important and common WLFF job tasks are identified as hiking with loads, cutting and clearing trees and brush, digging containment line down to the bare mineral soil, working with aviation resources, and conducting firing operations to create breaks between burned and unburned terrain.[7–9] Comprehensive job analyses have consistently demonstrated that the average steady-state energy expenditure

Corresponding author: Joseph W. Domitrovich, PhD, National Technology and Development Program, US Forest Service, USDA, 5785 Highway 10 W, Missoula, MT 59808; e-mail: jdomitrovich@fs.fed.us.

Submitted for publication October 2017.
Accepted for publication March 2018.

of these WLFF tasks is approximately 7.5 kcal · min^{-1} (22.5 mL · kg^{-1} · min^{-1}).[9,10] Prior work suggested that workers could likely sustain 50% of their maximal aerobic capacity during day-long operations, which led to early work capacity testing in the United States and the establishment of a minimum employment standard for WLFFs—the arduous work capacity test (arduous pack test).[7] This 20.5 kg load carriage test on flat terrain for a duration of 45 min has an estimated oxygen consumption of 22.5 mL · kg^{-1} · min^{-1}, although it may vary by person, and tests the ability of an individual to sustain similar amounts of energy needed to complete job tasks, which is in accordance with Uniform Guidelines on Employee Selection Procedures.[11]

There is a strong consensus regarding the energy costs of these fireline tasks from research teams in the United States and Australia, yet the energy estimates represent averages of the many job tasks a WLFF performs. If the arduous pack test only qualifies an individual with an average physical requirement, it may miss a critical component of above-average energy expenditures required for some tasks. Petersen et al noted that while the data provide an average energy expenditure of WLFF job tasks, they may not adequately describe physiologic demands associated with successful performance on the job.[12] The definition of success, however, may differ by job and by year based on conditions and environments present during wildfires in the United States, making successful performance difficult to quantify. For that reason, Ruby et al[1,2] and Cuddy et al[3] collected data from type I interagency hotshot crews (IHCs) on wildfire assignments, representing some of the most experienced WLFFs in the United States. Fire management typically relies on IHCs to perform tasks crucial to the successful management of wildfires. Additionally, IHCs likely perform their jobs at metabolic demands that exceed that of the arduous pack test. Petersen et al suggested that to fully determine content-valid cutoff scores for the arduous pack test, global positioning system (GPS) tracking could be used to record hiking duration and speed across varied terrains on actual wildfire assignments.[12] The use of GPS on wildfires could help identify expected areas of high-intensity work, such as hiking, and enable a more comprehensive construct of successful WLFF performance.

Hiking with varied loads occurs regularly during wildland fire operations and provides the widest expected range of metabolic demands depending on the terrain, rate of travel, grade, and external load.[3,13] Givoni and Goldman[14] first developed an empirical formula to estimate metabolic rate during walking relative to the variation in speed, external load, body weight, grade, and terrain. Pandolf and others further validated this approach using a range of loads and body masses[15–17] Despite some limitations in the equations,[18,19] additional data have helped refine the original versions of the Pandolf (1979) equation.[15,17,20–24] As these revisions accommodate the metrics of hiking with a load across varied terrain, these prediction equations can be applied across a broad range of topography to better identify some of the unknown aspects of WLFF metabolic demands.

The purpose of this study was to evaluate WLFF hiking episodes using GPS tracking, direct observation, and physiologic variables to estimate metabolic demand. The amount of direct observations in this study, including several hundred miles of hiking data, is unique and provides a perspective of the physiological responses found in this occupation during actual field operations.

Methods

SUBJECTS

Male (n=116) and female (n=15) WLFFs participated in this study (see Table 1 for participant characteristics). Females typically account for about 10 to 15% of WLFF crews; thus, this was a representative sample. Metabolic data are reported as an aggregate for males and females to maintain statistical power, and additional female data are being collected for future reports. Participants were recruited on large wildfires in the western United States and a different crew was observed each day. Participants were recruited for one work shift from available resources the night before the observation period and typically had at least one day of work on the fire before their involvement in the study. Before participating in the study, participants provided written, informed consent approved by the University of Montana Institutional Review Board.

To provide a more comprehensive evaluation across crew types, both IHC and type II crews were included (68% and 32% of the total sample, respectively). However, the amount of training hike data for type II crews was limited and was therefore not included in the data analysis. On wildfire incidents, IHCs are the most common type I resource. These crews are diverse teams of career and temporary employees who uphold a tradition of excellence, advanced firefighter qualifications, and have solid reputations as multiskilled professional firefighters.[25] The US Department of Agriculture, Forest Service, US Department of Interior, Bureau of Land Management, National Park Service, and the Bureau of Indian Affairs and Tribal programs all employ IHCs. As such, these IHCs are a national resource and they may be sent anywhere in the United States and occasionally to Canada and Mexico to assist