Eur J Appl Physiol (1990) 61:237-245

European Journal of Applied Physiology and Occupational Physiology

Physiological strain due to load carrying

Michael Holewijn

TNO Institute for Perception, Thermal Physiology Research Group, Kampweg 5, NL-3769 DE Soesterberg, The Netherlands

Accepted February 19, 1990

Summary. In an experimental study of load carrying the effects of mass (0, 5.4, 10.4 kg) and the type of support (on the shoulder or on waist) on parameters of physiological strain were quantified to determine the factor(s) which limit carrying time. Four categories of strain were investigated: metabolic (in terms of oxygen uptake), cardiovascular (in terms of heart rate), muscular (in terms of EMG activity) and skin pressure under the shoulder straps. Four young male subjects were tested on a treadmill using different combinations of load and speed. While standing, oxygen uptake was not influenced by the type or mass of the backpack, and averaged 10% maximal oxygen uptake. The heart rate increased significantly by 9 beats per min while standing wearing a backpack, independent of type of support or mass of backpack. While walking both the heart rate and the oxygen uptake were significantly influenced by the mass carried, but both types of strain remained below the tolerance limits for prolonged wear. Standing supporting a load did not significantly increase the root mean square value of the EMG signal of the trapezius pars descendens muscle. While walking, load carrying significantly increased the root mean square value, and, converted to force, the largest increase amounted to 2.7% of the maximal force for a load of 10.4 kg suspended from the shoulders. This was below levels of force producing fatigue, which was also indicated by an absence of changes in the median power frequency of the EMG signal. The pressure on the skin under the shoulder straps during load carrying on the shoulders was more than a factor of three times higher than the threshold value for skin and tissue irritation. Load transfer to the waist with a flexible frame reduced the pressures on the skin of the shoulder to far below the threshold value. On basis of these results it was concluded that even with relatively low loads the limiting factor was the pressure on the skin, if a waist belt did not relieve such pressure on the shoulders.

Key words: Electromyography – Load Carrying – Backpack – Exertion – Shoulder

Introduction

During leisure or military activities, load-carrying with a backpack is frequently practised. In most of the studies concerning backpacking, the main goal has been to determine the energy cost of walking taking into account a variety of terrains (grade and surface), velocities, and external loads (Datta and Ramanathan 1971; Goldman and Iampietro 1962; Legg and Mahanty 1986; Myles and Saunders 1979; Pandolf et al. 1976) or to determine the level of metabolism, expressed as a percentage of maximal oxygen uptake ($\dot{V}O_{2\,max}$), which could be maintained without physical fatigue (Epstein et al. 1988; Shoenfield et al. 1977; Evans et al. 1980). A few studies have examined the effects of load-carrying on muscle activity (Cook and Neumann 1987; Bobet and Norman 1982), walking kinematics (Bloom and Woodhull-McNeal 1987; Martin and Nelson 1986), or the effects of load distribution on loss of mobility (Holewijn and Lotens 1987).

In this paper the effects of the mode of carrying and the load mass were investigated by simultaneous measurement of several physiological strain parameters. Firstly, from a study of the literature different types of strain were identified which could limit the endurance time of walking with a back pack (Holewijn 1986). It was found that in addition to a reduction in physical performance, effects on the metabolic, musculo-skeletal, and cardiovascular systems, and the skin underneath the shoulder straps are important. The aim of this study was to quantify all the resulting strains to assess the limiting factor in the endurance time of walking with a normally loaded backpack. It was hypothesized that local strain of the shoulder muscles or pressure on the skin under the shoulder straps could be the cause of electromyographic techniques (EMG) and the pressure on the skin of the shoulder region was measured at several locations under the right shoulder strap to assess the distribution of pressure. The oxygen uptake ($\dot{V}O_2$) and the heart rate were also monitored to exclude the possibility that these strains were above the limits of tolerance.

Methods

Subjects. Four healthy young male students participated in this study. They all participated regularly in physical activities but were not used to carrying backpacks. The subjects were informed of the purpose and procedures of the study and consented to participate. The subjects had a mean age of 24 years (range 23–26), mass of 75.1 kg (range 69–81.5) and $\dot{V}O_{2\,max}$ of 3.4 l·min^{-1} (range 3.3–3.8).

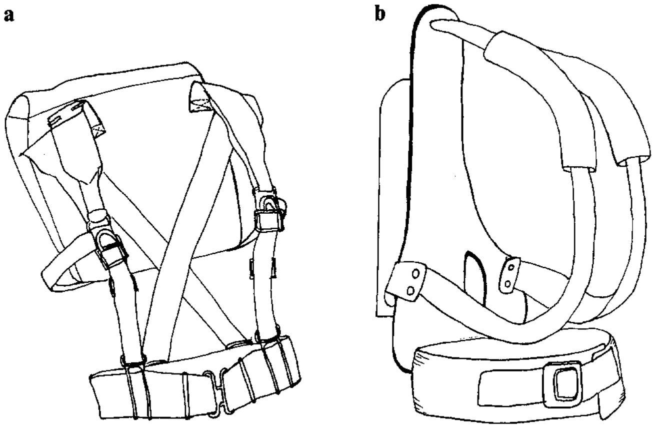
Types of backpack. Two packs were used in this study. One was the backpack in use in the Royal Netherlands Army (Mil), as pack mounted high on the back by straps. The straps ran from the front of the waist belt to the back being attached to the pack on the same side and crossing between the shoulder blades to reach the waist belt on the opposite side. On the shoulders the straps had a width of 5 cm and were of heavy canvas (Fig. 1a). This type of backpack puts the load mainly on the shoulders. The second backpack was a custom-made pack (Cust) where most of the load was supported on the hips by means of a flexible frame connected to a padded 10-cm wide waist belt (Fig. 1b). The padded shoulder straps were 8 cm wide on the shoulders.

Load. Loads of 5.4 kg and 10.4 kg were chosen, representing the fighting and marching order of a Royal Netherlands Army soldier, respectively. Measurements without a pack served as control. These loads were applied both while standing and walking on a treadmill at a moderate walking speed of 1.33 m·s^{-1}.

Physiological measurements and apparatus. The EMG activity of the descending part of the right trapezius muscle was measured with two surface silver-silver chloride electrodes (PPG, Hellige, FRG), positioned on the distal third of the muscle with an inter-electrode distance of 2 cm parallel to the muscle fibres. The electrodes were attached after thoroughly cleaning the skin with alcohol. The reference electrode was attached on the acromion. The EMG recordings started 1 h after application of the electrodes because by that time the skin impedance had almost stabilised (Zipp et al. 1977).

a

b



The EMG signals were first passed through a small battery fed pre-amplifier (100×), mounted on a waist belt, and then through an amplifier with a gain of 2×–50× and a bandfilter of 5–1,000 Hz (slopes: low pass filter 6 dB·octave^{-1}, high pass filter 12 dB·octave^{-1}). The EMG was then sampled over 1-min periods by an microcomputer (IBM, USA) using a 12 bit A/D board (DT2821, Data Translation, USA) set at a sample frequency of 2,048 Hz, and stored on a hard disk. The root mean square value (rms) of the amplitude was determined on line with a custom built rms detector (AD 637, time constant = 55 ms) and sampled with the same equipment.

Post experimental analysis of the EMG consisted of dc-correction and a fast Fourier transform (FFT) with a data analysis software package (Asystant, Macmillan Software Company, USA). From every EMG recording four samples of 1-s duration, equally distributed over the 1-min sample period, were taken for a 2,048 point FFT analysis. The resulting power spectra were averaged and from this averaged power spectrum the median power frequency (MPF), i.e. the frequency above and below which the integrated power is equal, was calculated. The rms data of the same four samples were transformed to force values using a previously determined rms versus force relationship. This calibration curve between rms of the EMG of the trapezius muscle and the force produced by this muscle was determined for each subject with two adjustable slings running over the shoulders, one of which was connected to a floor mounted force transducer (Z 2H6, Hottinger Baldwin Messtechnik, FRG). The shoulder was positioned directly above the force transducer. The subject performed three isometric maximal voluntary contractions (MVC), with a 10-min rest period between each contraction, by lifting the shoulders, while sitting with a straight back and with the feet not touching the floor. This posture was chosen to ensure that the force could only be produced by lifting the shoulders and not by other means (leg muscles, leaning forward). The highest force level maintained for 3 s was taken as the MVC. After 30-min rest the rms value was measured for 1 s at force levels of 5%, 10%, 20%, 30%, 50%, and 100% MVC. Between each measurement there was a 10-min rest. By power regression a curve was fitted to the data.

The pressure under the shoulder strap on the skin of the right shoulder was measured with a miniature pressure transducer (model 156, Precision Measurement Company, USA) measuring 8.5×4 mm and 1 mm thick. The small dimensions made it possible to measure the pressure with a minimal change to the curvature of the shoulder strap thereby introducing a negligible artefact in the recordings.

The pressure signal was amplified (MG 3150, Hottinger Baldwin Messtechnik, FRG) and sampled by an IBM microcomputer with a sample frequency of 2,048 Hz and stored on disk.

While the subjects were standing the pressure on the skin was measured at five positions under the right shoulder strap and for each position at three locations, i.e. the lateral and the medial edge of the strap and in the middle. The five positions were spaced out equally over the shoulder strap at intervals of 5 cm, position 3 being just on top of the shoulder. During walking the skin pressure was measured only at position 3 on the medial edge of the shoulder strap.

The $\dot{V}O_2$ (l·min^{-1}) was measured with an Oxylog portable system (Morgan Ltd, England) which was mounted on a fixed frame above a treadmill. The $\dot{V}O_2$ (l·min^{-1}) was normalised with respect to each subject's $\dot{V}O_{2\,max}$, and with respect to the total load (mass of the subject + load). The $\dot{V}O_{2\,max}$ was estimated during a submaximal treadmill running test, by increasing the running speed at 3% gradient until a heart rate of 160 beats·min^{-1} was reached. The $\dot{V}O_{2\,max}$ was calculated by extrapolating the subject's heart rate versus $\dot{V}O_2$ relationship to his maximal estimated heart rate (Åstrand and Rodahl 1986). This method had the advantage that the subjects were not stressed to their limits, but the accuracy was 10%–15% less than a direct measurement of $\dot{V}O_{2\,max}$ (Davies 1968).

The heart rate was monitored continuously by a custom built

Experimental procedure. Prior to the load-carrying sessions, each subject's $\dot{V}O_{2max}$ was estimated, followed by the measurement of the force versus rms calibration curve. After a rest period of 30 min the load carrying sessions started.

Each carrying session consisted consecutively of 20-min standing, 10-min rest and 20-min walking on the treadmill at a velocity of 1.33 $m \cdot s^{-1}$.

While standing and walking $\dot{V}O_2$ and heart rate were recorded continuously on a chart recorder. Both while standing and walking the pressure, the EMG and the rms were measured at the 1st, 10th, and 20th min. Off-line, the average EMG and rms values were calculated for each 1-min measurement period. This cycle was repeated five times, with a 20-min rest between each cycle. The five carrying conditions (no backpack, Mil and Cust backpacks, each with a 5.4- and 10.4-kg load) were administered according to a balanced design.

Statistics. The data were assessed by analysis of variance (ANOVA) with the Systat computer programme (Systat Inc, USA) after checking normality of the data (Kolmogorov-Smirnov test) and the homogeneity of variance. If significant F values were found ($P<0.05$) the differences between levels within an effect were analysed for significance by a Newman Keuls post hoc test ($P<0.05$).

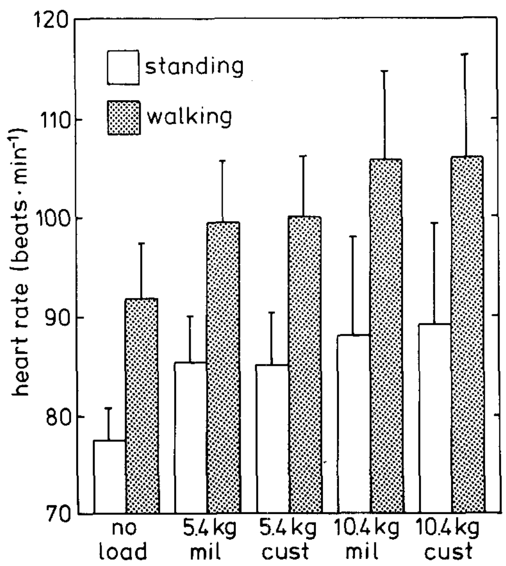


Fig. 3. The effect of different combinations of load and backpack type on the heart rate (mean and SD) while standing and walking (speed = 1.33 $m \cdot s^{-1}$). *Mil*, Military backpack; *Cust*, custom built backpack

Results

Oxygen uptake

There was no significant difference in metabolism between the 1st, 10th, and 20th min in any of the carrying sessions. Therefore, the data were averaged over the three measuring points. In Fig. 2 the effect of the type of backpack on the relative metabolic strain (% $\dot{V}O_{2max}$) is shown. While standing the relative metabolic strain was not significantly influenced by the load and averaged 10% $\dot{V}O_{2max}$. However, while walking differences between loads were evident.

Walking with the 5.4-kg load caused a significant increase of 1.5% $\dot{V}O_{2max}$, and with the 10.4-kg load the increase was 4.8% $\dot{V}O_{2max}$, resulting in absolute $\dot{V}O_2$ of 0.96 $l \cdot min^{-1}$ and 1.08 $l \cdot min^{-1}$ respectively. No significant difference was found between the two types of backpack.

Comparing $\dot{V}O_2$ for the two loads, the energy cost necessary for displacement of body mass and load separately can be calculated. The average energy cost during walking without a load amounted 4.2 $W \cdot kg^{-1}$ of body mass. However, the average energy cost per kg load at first decreased (1.1 $W \cdot kg^{-1}$ for the first 5.4 kg) but then increased (6.3 $W \cdot kg^{-1}$ for the next 5 kg) with increasing loads. The average energy cost per kg load for the first 5 kg was thus lower than for a kg of body mass, but increased steeply with increasing loads.

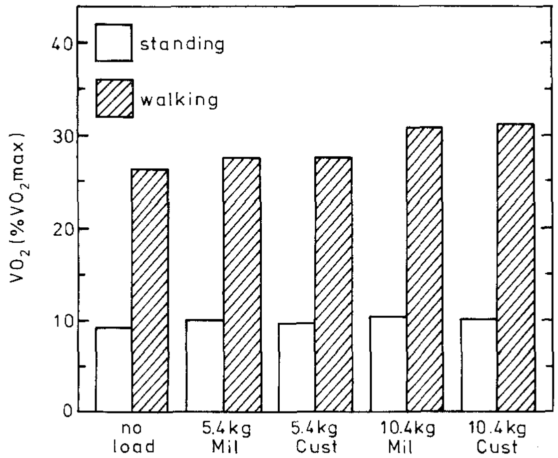


Fig. 2. The effect of different combinations of load and backpack type on the relative metabolic strain [%maximal O_2 uptake

Heart rate

While standing the average heart rate increased significantly by 9 beats $\cdot min^{-1}$ with load carrying. There was no significant difference between the four load carrying conditions (Fig. 3).

While walking the heart rates during control measurements remained significantly lower than the heart rates during the load-carrying conditions (Fig. 3). The 5.4-kg load caused a significant increase of 8 beats $\cdot min^{-1}$ and the 10.4-kg load added a further significant increase of 6 beats $\cdot min^{-1}$. The type of backpack had no significant effect on the heart rate.

Electromyographic activity of the trapezius muscle

Amplitude. The relationship between rms and the lifting force of the descending part of the trapezius muscle,

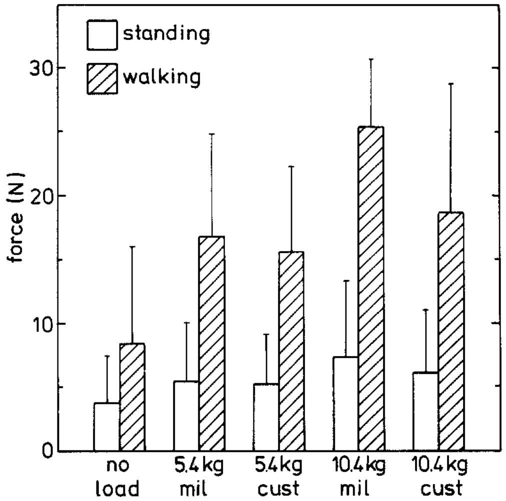


Fig. 4. The force level (mean and SD) of the descending part of the trapezius muscle while standing and walking without a load and using two types of backpack carrying 5.4- and 10.4-kg loads. *Mil*, Military backpack; *Cust*, custom built backpack

inear line, having an average correlation coefficient of 0.99. The ANOVA revealed that there was no significant change in rms over time. In further analyses the three measurements were averaged. Converting rms of the EMG of the trapezius muscle to force resulted in the force levels shown in Fig. 4.

Although the force level while standing increased when a load was carried, the effect was not significant. The force averaged 5.4 N. While walking the force levels increased significantly during load carrying, but not in the control situation.

The Cust with a 5.4- and 10.4-kg load and Mil with the 5.4-kg load resulted in similar force levels of 15 N (1.6% MVC), 17 N (1.7% MVC), and 19 N (1.9% MVC), respectively. The Mil, however, containing a 10.4-kg load resulted in a force level of 27 N (2.7% MVC), which was significantly higher than in the other three load conditions.

The force level was significantly dependent on the subject, in particular for the heavy load. This explains in part the variation in force level.

With Mil the increase in force, comparing standing and walking, was significantly higher than with Cust.

Mean power frequency

The MPF did not decrease significantly with time while standing or walking with a backpack. The average MPF

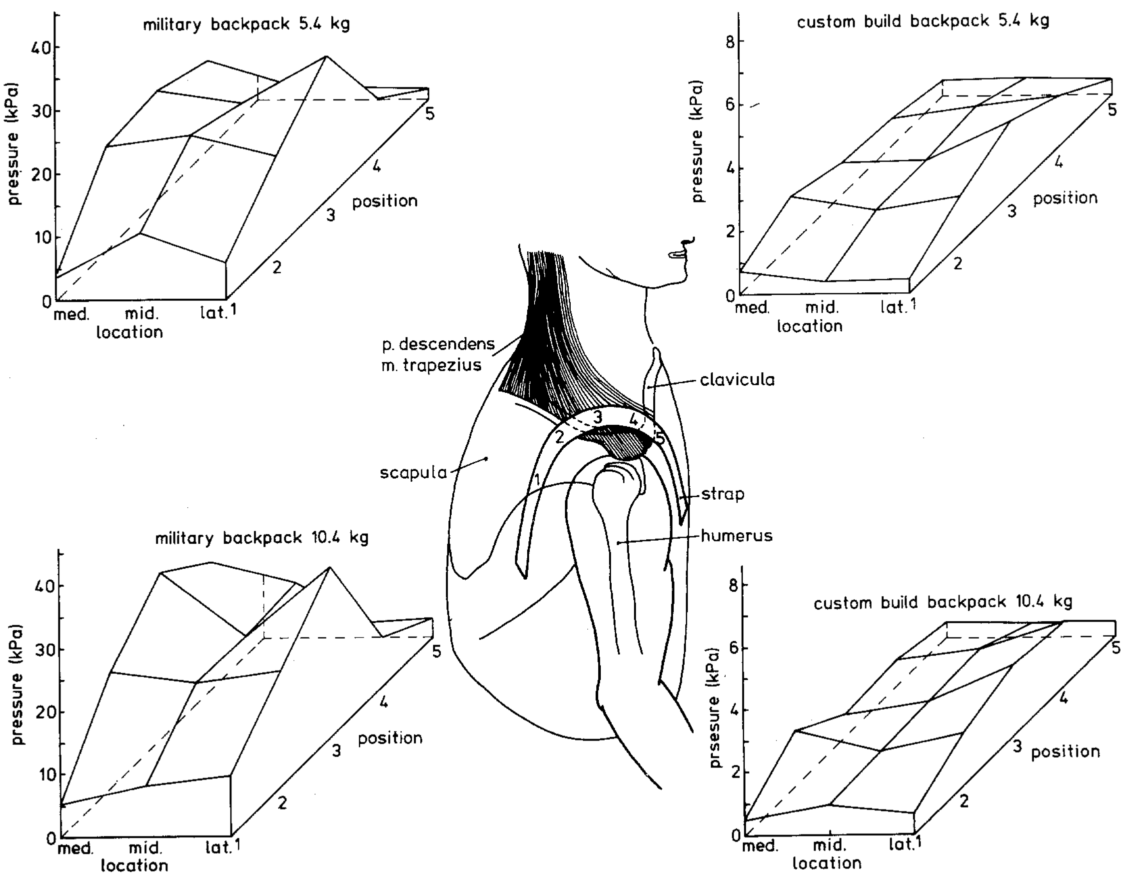


Fig. 5. The distribution of average skin pressure of the right shoulder measured at five positions under the shoulder strap while standing

while standing (35 Hz) was not significantly different from the MPF while walking (34 Hz). Neither the type of backpack nor the mass of the load significantly influenced the MPF while standing and walking.

Pressure of the shoulder straps on the skin

While standing the pressure distribution on the skin under the right shoulder strap measured in each of the 15 sites is graphically represented in Fig. 5, showing the differences between the two backpacks and the effect of increasing the load.

The two backpacks showed pressure increasing from the back at the lower edge of the scapula to the top of the shoulder and a sharp decrease on the front side of the shoulder. Carrying the loads using Mil caused a peak pressure on the acromion (location = 3, position = lateral) and another on the upper edge of trapezius muscle (location = 3, position = medial). The former peak was also found using Cust, but smaller in amplitude. The peak pressure on the medial side was not present with Cust. The peak skin pressures using Mil were significantly higher than the skin pressures using Cust. The maximal pressures amounted to 20 kPa (150 mm Hg) (Mil, 5.4 kg), 27 kPa (203 mm Hg) (Mil, 10.4 kg), 2 kPa (15 mm Hg) (Cust, 5.4 kg and 10.4 kg). At most positions the pressure on the edges of the shoulder strap was higher than in the middle of the strap.

The statistical analysis showed further that increasing the load from 5.4 to 10.4 kg in Mil caused a significant increase in the skin pressure of 36%, whereas no significant effect was found with Cust. The form of the pressure distribution did not appear to be significantly influenced by the load level.

While walking the pressure showed sinusoidal fluctuations about 0.2 s out of phase with rms of the EMG of the trapezius muscle (Fig. 6). Similar to measurements made while standing, the skin pressure while walking was significantly dependent on mass and the type of backpack (Fig. 7). The post hoc test showed that Cust had a significantly lower skin pressure on the top of the shoulder than Mil. Further, the skin pressure using Mil increased significantly with increase in the load from 5.4 kg to 10.4 kg.

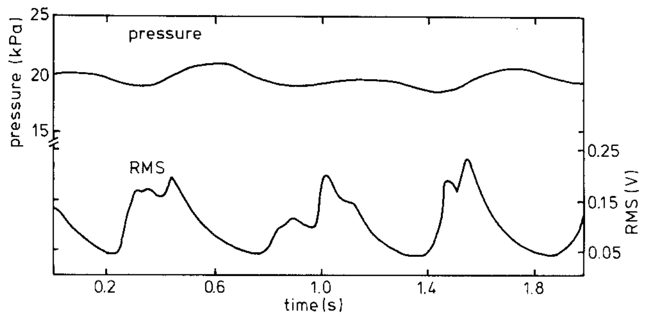


Fig. 6. A typical example of the sinusoidal variations of the skin pressure and root mean square (RMS) of the electromyogram of the trapezius pars descendens muscle while walking (speed = 1.33 $m \cdot s^{-1}$) using the military backpack with a load of 5.4 kg

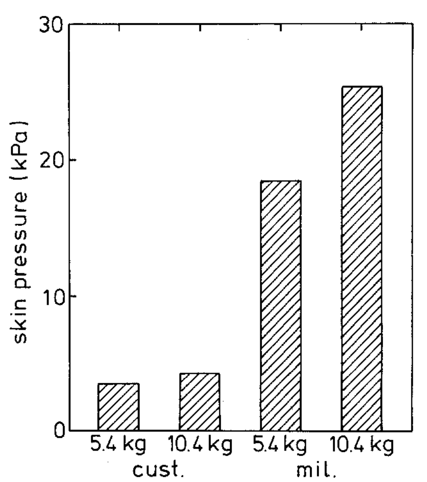


Fig. 7. The average skin pressure on the top of the shoulder while

Discussion

Metabolic and cardiovascular strain

In this study, in contrast to other studies, it was found that carrying a backpack had a significant effect on the heart rate while standing (Borghols et al. 1978; Pierrynowski et al. 1981; Pimental and Pandolf 1979). A possible explanation may be that in this study the time taken standing was more than a factor of two longer than in other studies and in combination with a different type of backpack this may have resulted in significant effects on the cardiovascular system. This increase in heart rate has been commonly observed during static muscular exercise. Kilbom (1976) has concluded in his review that the resulting increase in cardiac output during static contractions is mainly directed towards the peripheral parts of the body and only a small part is supplied to the myocardium. In this study standing while carrying a backpack, however, required no significant extra metabolic energy which is in agreement with other studies (Borghols et al. 1978; Pierrynowski et al. 1981). Thus, the relationship normally found between heart rate and $\dot{V}O_2$ during dynamic exercise was disrupted during static contractions.

Pandolf et al. (1977) and Pimental and Pandolf (1979) formulated an empirical energy prediction equation relating metabolic weight, body mass and load mass, walking velocity, grade and terrain:

$$MR = 1.5m + 2(m+L)(L \cdot m^{-1})^2 + n(m+L)(1.5v^2 + 0.35v \cdot G) \quad (1)$$

where MR is metabolic rate (W), m is subject mass (kg),

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase® Smarter legal research.