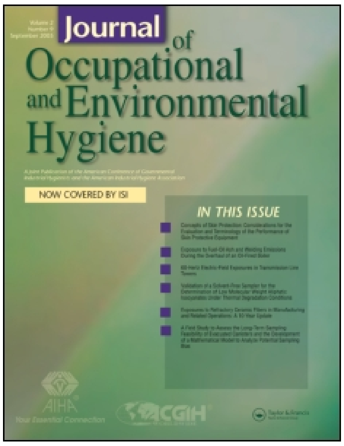

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Physiological Effects of Boot Weight and Design on Men and Women Firefighters

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The purpose of this study was to determine the effects of two leather (L1, L2) and two rubber (R1, R2) boots on firefighters' metabolic and respiratory variables during simulated firefighting tasks. Twenty-five men and 25 women, while wearing full turnout clothing, a 10.5-kg backpack, gloves, helmet, and one of four randomly assigned pairs of firefighter boots, walked for 6 min at 3 mph (4.8 km/hr) on a level treadmill while carrying a 9.5-kg hose and climbed a stair ergometer for 6 min at 45 steps per min without the hose. Minute ventilation ($\dot{V}E$), absolute and relative oxygen consumption ($\dot{V}O_2$ and $\dot{V}O_2$ ml·kg·min^{-1}, respectively), CO_2 production ($\dot{V}CO_2$), heart rate (HR), and peak inspiratory (PIF) and expiratory (PEF) flow rates were measured, and an average of the breath-by-breath data from minute 6 was used for analysis. During treadmill exercise, a 1-kg increase in boot weight caused significant ($p < 0.05$) increases in $\dot{V}E$ (9%), $\dot{V}O_2$ (5 – 6%), $\dot{V}CO_2$ (8%), and HR (6%) for men, whereas a 1-kg increase caused significant increases in $\dot{V}O_2$ (3 – 4.5%) and $\dot{V}CO_2$ (4%) for women. During stair ergometry, a 1-kg increase in boot weight caused significant increases in $\dot{V}E$(∼3%), relative $\dot{V}O_2$(∼2%), $\dot{V}CO_2$ (3%), and PIF (∼4%) in men and women ($p < 0.05$) and a significant increase in absolute$\dot{V}O_2$ (∼3.5%) in men only. Mean increases in metabolic and respiratory variables per 1-kg increase in boot weight were in the 5 to 12% range observed previously for men during treadmill walking but were considerably smaller for women. Mean increases in oxygen consumption during stair ergometry were statistically significant but were smaller in the current study than previously observed and may not be practically significant. There was no significant effect of boot design in addition to boot weight for either mode of exercise.

Keywords boots, female, firefighting tasks, oxygen uptake, firefighting tasks

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INTRODUCTION

The intensity of energy expended by firefighters performing firefighting tasks is generally agreed to be in the heavy to very heavy range (23–42 ml·kg·min^{-1}$\dot{V}O_2$).[1] From 1994 to 2004, 32% of firefighter deaths from coronary heart disease were associated with fire suppression.[2] The authors suggest that the most likely explanation for this finding is the high cardiovascular demand of suppressing a fire. Firefighters wear approximately 22.7 kg (50 lbs) of protective clothing and gear, including boots, which significantly increases energy expenditure for a given task.[1] There are two general types of National Fire Protection Association (NFPA)-certified structural fire fighting boots in use today: 33–40 cm high rubber bunker boots and 20–40 cm high leather boots.[3] Rubber boots are roughly 0.9–1.4 kg heavier than leather boots, and leather boots generally offer better support and ankle stability.[4]

A number of studies have investigated the effects on energy expenditure of additional shoe or boot weight. Increases of from 5–12% in oxygen consumption per kg of weight added to the feet have been observed; however, the magnitude of the increase may depend on task, gender, and whether subjects are wearing additional protective clothing or equipment.[5] In an early study where weighted rubber boots were compared with combat boots, increases in relative $\dot{V}O_2$ per kg increase in boot weight of 6.9%, 9.5%, and 10.3% were observed in men walking at 2.5, 3.0, and 3.5 mph (4.0, 4.8, and 5.6 km/hr), respectively.[6] Several subsequent studies examined the effect on oxygen consumption of walking vs. running in shoes and boots. Jones et al.[7] observed increases in relative $\dot{V}O_2$ of 4.9 to 6.6% per kg added to the feet in trained and untrained men walking at 2.5 to 4.5 mph (4.0 to 7.3 km/hr) and increases of 6.7% to 8.5% during running at 3.5 to 4.8 mph (5.6 to 7.6 km/hr) in leather military boots vs. athletic shoes. A 4.2 to 5.3% increase in relative $\dot{V}O_2$ was also observed during running at 3.5 to 4.8 mph (5.6 to 7.6 km/hr) in weighted shoes vs. shoes, leading the authors to conclude that weight alone accounted for 48–70% of the added energy cost of wearing boots. Martin[8] found a 7.2% increase in relative $\dot{V}O_2$ per kg weight added to running shoes in men running at 7.5 mph (12 km/hr). All walking and running bouts in these studies were performed on treadmills.

The effect on energy cost of weight added to the feet of women walking and running has been investigated in several studies. Jones et al.[9] found increases in relative $\dot{V}O_2$ of 6.5 to 13.0% per kg added to the feet in women walking at 2.5 to 4.5 mph (4.0 to 7.3 km/hr), and increases of 9.9 to 7.3% in women running at 3.5 to 4.8 mph (5.6 to 7.6 km/hr) in leather military boots vs. athletic shoes. Miller et al.[10] observed no difference in the effect on relative $\dot{V}O_2$ between men and women walking and running with weight added to the ankles; however, the sample size of this study was small (four men, three women).

In addition to task and gender, the effects of carried loads combined with weight added to the feet have been studied. Legg and Mahanty[11] investigated the effects of wearing heavy boots on the energy cost of walking with a backpack. Five men walked on a treadmill at 2.8 mph (4.5 km/hr) with a pack weighing 30% of subjects' body weight. Increases of 9.6% for absolute $\dot{V}O_2$, 7.2% for $\dot{V}E$, and 4.5% for HR per kg weight added to the feet were observed. These results are in line with the body of literature suggesting that for each kg added to the feet during walking, the increases in relative and absolute $\dot{V}O_2$ are on average 7 to 10%.[5]

In a study focused specifically on firefighter boots, Neeves et al.[4] investigated the physiological and biomechanical effects of rubber vs. leather boots in 11 male firefighters during stair climbing on a stair ergometer at 50 to 80% of their maximum oxygen consumption.[4] A mean 4% increase in relative $\dot{V}O_2$ per kg increase in boot weight was observed, and there were no significant differences in HR due to increased boot weight. Subjects wore t-shirts and shorts, and results may not be generalizable to firefighters wearing turnout gear and carrying additional equipment. Walking while carrying a hose and stair climbing are two generally accepted simulated firefighting tasks.[1] It was the purpose of the current study to investigate the effects of boot weight, boot design (leather vs. rubber), and gender on the metabolic and respiratory variables of men and women firefighters walking on a treadmill and performing simulated stair climbing while wearing full turnout gear and equipment.

TABLE I. Boot Characteristics by Model

Characteristic	Boot Model L1	L2	R1	R2
Material	Leather	Leather	Rubber	Rubber
Mean size				
Men (n=25)	10.3	10.5	10.1	9.9
Women (n=25)	8.6	8.5	8.0	7.9
Boot weight (kg)				
Men (n = 25)	2.6 (0.1)	2.9 (0.1)	3.3 (0.1)	3.9 (0.1)
Women (n = 25)	2.4 (0.1)	2.5 (0.1)	3.0 (0.1)	3.4 (0.1)
Boot height (cm)^A	36.8	36.6	40.6	39.4
Heel area (cm^2)^A	81.3	83.2	71.0	71.6

Notes: Values are presented as mean (SD). Models represent those commonly available/worn.
^{A}Boot height and heel area are for size 10 boot.

METHODS

Boot models and characteristics are shown in Table I. Boot models were selected based on sales and market share information provided by several boot manufacturers. All boots were certified by the NFPA. Subjects selected the boots they wore by trying on several sizes and arriving at a best fit.

This study was approved by the National Institute for Occupational Safety and Health Human Subjects Review Board. A sample size calculation showed that a sample of 25 was required to detect a 5% change in $\dot{V}O_2$ with a power of 0.80. Twenty-five professional men and 25 women (22 professional, 3 volunteer) firefighters between the ages of 18 and 40 were recruited, passed a medical screening, and provided written, informed consent for this study. Men (mean = 9.0 years experience) were recruited from the Morgantown, West Virginia, area, while women (mean = 7.2 years experience) were recruited from West Virginia, western Maryland, northern Virginia, and eastern Ohio.

Subjects participated in eight exercise bouts (four boot models by two exercise tasks) while wearing full turnout clothing, a 10.5-kg backpack (representing a 45-min self-contained breathing apparatus, SCBA), gloves, helmet, and a pair of firefighter boots. The two tasks consisted of walking for 6 min at 4.8 km/hr on a treadmill at 0% incline while carrying a 9.5-kg hose and climbing a stair ergometer for 6 min at 45 steps per minute (15.2 cm step height) without the hose.

Exercise intensities for both tasks were selected to elicit a heart rate of between 65 and 80% of age-predicted maximum. Boot order was randomized for each subject, and task order was then randomized for each pair of boots. All eight exercise tests were performed on the same day for each subject, with approximately 10 min of rest between bouts 1–4 and 5–8; a 1-hr break was given between bouts 4 and 5. Minute ventilation ($\dot{V}E$), oxygen consumption ($\dot{V}O_2$ and $\dot{V}O_2 ml \cdot kg \cdot min^{-1}$),

CO_2 production ($\dot{V}CO_2$), respiratory exchange ratio (R), heart rate (HR), and peak inspiratory (PIF) and expiratory (PEF) flow rates were measured using a portable metabolic measurement system (COSMED, Rome, Italy), which was calibrated before bouts 1 and 5 per manufacturer's instructions, and an average of the breath-by-breath data from minute 6 was used for analysis.

Comparisons of gender (relative $\dot{V}O_2$, $\dot{V}E$, PIF, PEF, and HR only), boot design, and boot weight were made using a MIXED analysis of variance with repeated measures ($p < 0.05$) with SAS software (Cary, N.C.). Predicted percent change per kg increase in boot weight was calculated by dividing the boot weight effects estimated by the MIXED statistical model by the means for leather Boot 2 (L2) observed for each gender.

RESULTS

Participants

Table II presents the characteristics of study participants. Men had a mean age 31.1 yrs, mean body weight of 93.4 kg, and mean height of 178.2 cm. Women had a mean age of 31.6 yrs, a mean body weight of 72.8 kg, and a mean height of 166.8 cm. Turnout clothing, a 10.5-kg backpack, gloves, and helmet made up an additional 23% of body weight for men and 29% for women. The weight of the hose carried during treadmill walking was the equivalent of 10% of body weight for men and 13% for women. For the results to have real-world applicability, relative additional weight (clothing and equipment) was not matched for men and women.

Treadmill Walking

Table III shows the mean metabolic and respiratory results by gender and boot model during treadmill walking at 4.8 km/hr. A significant difference ($p < 0.05$) was observed between men and women for relative $\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$). In addition, significant effects ($p < 0.05$) of boot weight on absolute $\dot{V}O_2$, relative $\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$), and $\dot{V}CO_2$ were observed. Significant interactions ($p < 0.05$) between boot weight and gender were observed for $\dot{V}E$ and HR.

TABLE II. Subject Characteristics

	Men n = 25	Women n = 25
Age (yrs)	31.1 (5.7)	31.6 (5.8)
Body weight (kg)	93.4 (14.1)	72.8 (10.7)
% Body weight		
Turnout gear + backpack	23%	29%
hose	10%	13%
Height (cm)	178.2 (3.9)	166.8 (5.2)
% Professional	100%	88%

Note: Values are presented as mean (SD).

Interactions were further analyzed with a separate analysis of variance for each gender, and these results, along with the boot weight main effect results from the analysis of variance (ANOVA) with no interaction, are shown in Table IV. Significant effects of boot weight ($p < 0.05$) were seen on $\dot{V}E$ and HR in men only.

In addition to effects estimates for boot weight, 95% confidence intervals (CI) for the estimates and the predicted percent change per kg increase in boot weight are also provided for the ANOVA's performed on treadmill walking data in Table IV. In men, significant 5 to 6% increases in absolute and relative $\dot{V}O_2$, a significant 8% increase in $\dot{V}CO_2$, a significant 9% increase in $\dot{V}E$, and a significant 6% increase in HR were observed ($p < 0.05$). In women, significant 3 to 4.5% increases in absolute and relative $\dot{V}O_2$ ($p < 0.05$), a significant 4% increase in $\dot{V}CO_2$ ($p < 0.05$), a 1.6% increase in VE, and a 1% increase in HR were observed.

Stair Climbing

Table V shows the mean metabolic and respiratory results by gender and boot model during simulated stair climbing at a rate of 45 steps/min. A significant gender difference ($p < 0.05$) was observed for relative $\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$). In addition, a significant effect of boot weight was observed for absolute $\dot{V}O_2$ in men only, and in relative $\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$), $\dot{V}CO_2$, $\dot{V}E$, and PIF for men and women ($p < 0.05$).

Table VI provides the effect estimates for boot weight, their 95% CIs, and the predicted percent change per kg increase in boot weight for ANOVAs performed on stair ergometry data. In men and women, significant 2.5% increases in relative $\dot{V}O_2$ ($p < 0.05$), significant 3–3.3% increases in $\dot{V}CO_2$ ($p < 0.05$), significant 3–3.3% increases in $\dot{V}E$ ($p < 0.05$), and significant 4% increases in PIF ($p < 0.05$) were observed. A significant 3.8% increase in absolute $\dot{V}O_2$ was observed in men only.

DISCUSSION

There were no significant effects of boot design (leather vs. rubber) on any variables during either mode of exercise. In addition to leather boots being lighter, leather boots differed from rubber boots in that the leather boots tested were slightly shorter and had larger heel areas and different types of soles, which may independently affect physiological responses. It is a potential limitation of the current study that due to a lack of previous data on their potential physiological effects, these multiple differences were combined into one factor, "boot design," for analyses.

The percent increases in metabolic and respiratory variables per 1-kg increase in boot weight observed in men during treadmill walking were in line with the 5 to 12% increases seen in previous research, while the increases seen in women were smaller than previously observed. This interaction observed between boot weight and gender during treadmill exercise is quite pronounced for $\dot{V}E$ (9.2% for men vs. 1.6% for women) and HR (5.7% for men vs. 0.7% for women).

TABLE III. Physiological Variables during Treadmill Walking at 3 mph (4.8 km/hr), by Boot Model and Gender

	Men (n = 25)				Women (n = 24)			
Variable	L1	L2	R1	R2	L1	L2	R1	R2
$\dot{V}O_2$ (L·min^{-1})^A	2.00	2.08	2.08	2.15	1.81	1.82	1.84	1.88
	(0.25)	(0.28)	(0.24)	(0.27)	(0.22)	(0.24)	(0.25)	(0.19)
$\dot{V}O_2$ (ml·kg·min^{-1})^{A,B}	21.5	22.4	22.5	23.3	24.8	24.9	25.5	25.9
	(2.1)	(3.1)	(2.7)	(2.5)	(3.1)	(3.2)	(3.7)	(3.3)
$\dot{V}CO_2$ (L·min^{-1})^A	1.68	1.75	1.77	1.84	1.55	1.57	1.60	1.62
	(0.25)	(0.25)	(0.23)	(0.26)	(0.24)	(0.22)	(0.24)	(0.18)
R	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.86
	(0.06)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)	(0.04)	(0.04)
$\dot{V}E$ (L·min^{-1})^C	50.0	52.1	54.1	55.4	52.1	52.6	52.0	53.2
	(8.0)	(8.9)	(7.9)	(8.0)	(10.4)	(10.6)	(8.9)	(7.8)
PIF (L·min^{-1})	131	132	132	136	130	127	124	135
(8 men, 10 women)	(24)	(25)	(18)	(21)	(23)	(19)	(24)	(20)
PEF (L·min^{-1})	126	123	126	124	120	114	120	125
(8 men, 10 women)	(26)	(24)	(28)	(24)	(28)	(18)	(28)	(18)
HR (bpm)^C	142	146	149	152	159	161	160	161
	(17)	(17)	(17)	(15)	(12)	(14)	(16)	(14)

Note: Values are presented as mean (SD).
^{A}Significant effect of boot weight ($P < 0.05$).
^{B}Significant difference between genders ($P < 0.05$).
^{C}Significant interaction between gender and boot weight ($P < 0.05$).

As a practical consideration, the 9.2% increase in $\dot{V}E$ observed in men is a particularly significant finding of this study, as it would result in an estimated 3-to 4-min decrease in service time for a 45-min SCBA cylinder. The interaction may be due to the prior observation that as the weight of a carried load increases during walking, women shorten their stride length while men do not,[(12)] thus reducing the displacement of the women's center of mass during the energetically costly double support phase of walking. This energy-saving strategy has been observed in older vs. younger subjects;[(13)] older adults had a 4% shorter stride length than younger adults while walking at 3.3 mph (5.3 km·hr^{-1}). If stride-shortening occurred in women in the present study, it could have resulted in the reduced physiological effect of additional boot weight as compared to men.

Another possible explanation for the interaction is the difference in relative load weight between men and women. Boot weight equaled approximately 3.5% of body weight for

TABLE IV. Effect of Boot Weight (Effect Estimates, 95% CI, and Predicted Percent Change per kg Increase in Boot Weight) on Physiological Variables During Treadmill Walking at 4.8 km/hr, by Gender

	Men (n = 25)			Women (n = 24)		
Variable	Estimate	95% CI	% Change	Estimate	95% CI	%Change
$\dot{V}O_2$ (L·min^{-1})	0.12^A	0.09–0.16	5.8%	0.06^A	0.03–0.09	3.0%
$\dot{V}O_2$ (ml·kg·min^{-1})	1.1^A	0.7–1.5	4.9%	1.1^A	0.7–1.5	4.4%
$\dot{V}CO_2$ (L·min^{-1})	0.14^A	0.10–0.18	8.0%	0.06^A	0.01–0.11	3.8%
R	0.01	0.00–0.02	1.2%	0.01	0.00–0.02	1.9%
$\dot{V}E$ (L·min^{-1})^B	4.8^A	3.2–6.4	9.2%	0.9	–1.6–3.3	1.6%
PIF (L·min^{-1}) (8 men, 10 women)	3.1	–1.4–7.6	2.3%	3.1	–1.4–7.6	2.5%
PEF (L·min^{-1}) (8 men, 10 women)	2.1	–3.0–8.2	1.7%	2.1	–3.0–8.2	1.8%
HR (bpm)^B	8.3^A	3.5–13.8	5.7 %	1.1	–3.4–5.6	0.7%

^{A}Significant effect of boot weight ($P < 0.05$).
^{B}Significant interaction between gender and boot weight ($P < 0.05$); boot weight analyzed for each gender separately.

TABLE V. Physiological Variables During Stair Climbing at 45 Steps/Min, by Boot Model and Gender

	Men (n = 25)				Women (n = 25)			
Variable	L1	L2	R1	R2	L1	L2	R1	R2
$\dot{V}O_2$ ($L \cdot min^{-1}$)^A	2.20	2.20	2.30	2.26	1.85	1.86	1.85	1.87
	(0.25)	(0.28)	(0.24)	(0.27)	(0.22)	(0.24)	(0.25)	(0.19)
$\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$)^{B,C}	23.7	23.7	24.7	24.2	25.6	25.6	25.6	25.8
	(2.1)	(3.1)	(2.7)	(2.5)	(3.1)	(3.2)	(3.7)	(3.3)
$\dot{V}CO_2$ ($L \cdot min^{-1}$)^C	1.97	1.98	2.04	2.02	1.65	1.67	1.70	1.70
	(0.25)	(0.25)	(0.23)	(0.26)	(0.24)	(0.22)	(0.24)	(0.18)
R	0.90	0.90	0.89	0.89	0.89	0.90	0.92	0.91
	(0.06)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)	(0.04)	(0.04)
$\dot{V}E$ ($L \cdot min^{-1}$)^C	56.8	57.3	58.4	57.8	52.8	51.8	54.1	54.4
	(8.0)	(8.9)	(7.9)	(8.0)	(10.4)	(10.6)	(8.9)	(7.8)
PIF ($L \cdot min^{-1}$)^C	142	142	143	145	119	130	130	130
(8 men, 10 women)	(25)	(25)	(24)	(22)	(21)	(20)	(18)	(16)
PEF ($L \cdot min^{-1}$)	132	131	133	138	111	126	121	124
(8 men, 10 women)	(26)	(24)	(28)	(24)	(21)	(20)	(24)	(18)
HR (bpm)	159	159	162	162	164	167	165	164
	(17)	(17)	(17)	(15)	(12)	(14)	(16)	(14)

Note: Values are presented as mean (SD).
^{A}Significant effect of boot weight in men only ($P < 0.05$).
^{B}Significant difference between genders ($P < 0.05$).
^{C}Significant effect of boot weight ($P < 0.05$).

men and 4% for women. However, during treadmill walking, total gear and hose weight equaled approximately 33% of men's body weight and 42% of women's body weight; the greater relative load carried by the women firefighters may have further diminished the effect of boot weight during walking. Although the differing relative loads for men and women may be seen as a study limitation, it was deemed important to the current study that equipment/clothing weights reflect a realistic protective equipment scenario.

The small but significant 2 to 3% increases in oxygen consumption per kg increase in boot weight seen in men and women during stair ergometry in the current study are smaller than the 4% increase observed in a previous study of leather and rubber boots where subjects wore only gym shorts.[4] The additional clothing and equipment load of 23% of body weight for men and 29% for women in the present study may have diminished the effect on metabolism of additional weight added to the feet during stair ergometry. While statistically

TABLE VI. Effect of Boot Weight (Effect Estimates, 95% CI, and Predicted Percent Change per kg Increase in Boot Weight) on Physiological Variables During Stair Climbing at 45 Steps/Min, by Gender

	Men (n = 25)			Women (n = 25)		
Variable	Estimate	95% CI	% Change	Estimate	95% CI	%Change
$\dot{V}O_2$ ($L \cdot min^{-1}$)	0.08^A	0.03–0.13	3.8%	0.02	−0.02–0.06	0.9%
$\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$)	0.6^A	0.2–1.0	2.5%	0.6^A	0.2–1.0	2.3%
$\dot{V}CO_2$ ($L \cdot min^{-1}$)	0.06^A	0.01–0.11	3.1%	0.06^A	0.02–0.10	3.3%
R	0.00	−0.02–0.01	0.0%	0.02	0.00–0.04	2.2%
$\dot{V}E$ ($L \cdot min^{-1}$)	1.7^A	0.1–3.3	3.0%	1.7^A	0.1–3.3	3.3%
PIF ($L \cdot min^{-1}$) (8 men, 10 women)	5.5^A	0.2–10.8	3.9%	5.5^A	0.2–10.8	4.2%
PEF ($L \cdot min^{-1}$) (8 men, 10 women)	5.9	0.0–11.8	4.5%	5.9	0.0–11.8	4.7%
HR (bpm)	1.6	−1.8–4.9	1.0%	1.6	−1.8–4.9	1.0%

^{A}Significant effect of boot weight ($P < 0.05$).

significant, 2 to 3% increases in oxygen consumption may not be practically significant in actual firefighting scenarios.

The current firefighter Candidate Physical Ability Task (CPAT) has as one of its eight events a 3-min bout of high-intensity stair ergometry (60 steps per minute with a 22.7-kg weighted vest, and two 5.7-kg shoulder weights).[14] A recent study examined the responses of 12 firefighters to this high-intensity simulated stair climbing in rubber (2.93 kg) and leather (2.44 kg) firefighter boots.[15] Small, insignificant increases in HR of 2–3% and an insignificant 2% increase in $\dot{V}O_2$ were observed for rubber compared with leather boots. This finding could be evidence that during very high-intensity, short duration simulated stair climbing in full gear and added shoulder weight, the effects of boot weight are further diminished compared with the moderate-to-high-intensity, steady-state stair climbing of the present study.

The 4 to 5% increases in PIF ($P < 0.05$) and PEF per kg increase in boot weight observed during simulated stair climbing are greater than those seen during treadmill walking in the present study and have not been reported elsewhere. These increased flows may represent an additional physiological burden of extra weight on the feet when a firefighter is required to generate increased flow while wearing an SCBA facepiece with an exhalation valve and a positive-pressure inhalation valve.

CONCLUSIONS

Results of the current study expand the findings of previous investigations of the effects on energy expenditure of additional boot weight by testing men and women wearing full turnout clothing and firefighting equipment. Mean increases in metabolic and respiratory variables per 1-kg increase in boot weight were in the 5 to 12% range observed elsewhere for men during treadmill walking, but were considerably smaller for women (3 to 4.5%). This could be due to the greater relative weight of clothing and gear for women as compared with men (42 vs. 33%), as well as to the prior observation that women shorten their stride length when carrying a back load while men do not.[12] Mean increases in variables during stair ergometry were smaller in the current study than in a previous study,[4] possibly due to the greater relative weight of clothing and gear (23% men, 29% women) vs. t-shirts and shorts. No additional significant effects due to boot design (leather vs. rubber) were observed for either exercise task.

Future research should include the additional factor of sole type to assess any further effects of cemented vs. stitched boot soles. The results of this and future research will be considered by the NFPA 1971 Technical Committee on Structural and Proximity Firefighting Protective Clothing and Equipment in updating firefighter boot standards and may encourage boot manufacturers to continue to improve firefighter boot design.

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REFERENCES

1. **Bilzon, J., E. Scarpello, C. Smith, N. Ravenhill, and M. Rayson:** Characterization of the metabolic demands of simulated shipboard Royal Navy fire-fighting tasks. *Ergonomics 44(8)*:766–780 (2001).
2. **Kales, S., E. Soteriades, C. Christophi, and D. Christiana:** Emergency duties and deaths from heart disease among firefighters in the United States. *N. Engl. J. Med. 356(12)*:1207–1215 (2007).
3. **National Fire Protection Association (NFPA):** *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting (NFPA 1971)* [Standard] Quincy, Mass.: NFPA, 2007.
4. **Neeves, R., D. Barlow, J. Richards, M. Provost-Craig, and P. Castagno:** Physiological and biomechanical changes in firefighters due to boot design modifications. Abstract in *Proceedings of the Tenth Annual Redmond Foundation Symposium on the Occupational Health and Hazards of the Fire Service*, 1989. p.42.
5. **Knapik, J., K. Reynolds, and E. Harman:** Soldier load carriage: Historical, physiological, biomechanical, and medical aspects. *Mil. Med. 169*:1–45 (2004).
6. **Soule, R., and R. Goldman:** Energy cost of loads carried on the head, hands, or feet. *J. Appl. Physiol. 27*:687–690 (1969).
7. **Jones, B., M. Toner, W. Daniels, and J. Knapik:** The energy cost and heart rate response of trained and untrained subjects walking and running in shoes and boots. *Ergonomics 27(8)*:895–902 (1984).
8. **Martin, P.:** Mechanical and physiological responses to lower extremity loading during running. *Med. Sci. Sports. Exerc. 17(4)*:427–433 (1985).
9. **Jones, B., and J. Knapik:** The energy cost of women walking and running in shoes and boots. *Ergonomics 29(3)*: 439–443 (1986).
10. **Miller, J., and B. Stamford:** Intensity and energy cost of weighted walking vs. running for men and women. *J. Appl. Physiol. 62(4)*:1497–1501 (1987).
11. **Legg, S., and A. Mahanty:** Energy cost of backpacking in heavy boots. *Ergonomics 29(3)*:433–438 (1986).
12. **Martin, P., and R. Nelson:** The effect of carried loads on the walking patterns of men and women. *Ergonomics 29(10)*:1191–1202 (1986).
13. **DeVita, P., and T. Hortobagyi:** Age causes a redistribution of joint torques and powers during gait. *J. Appl. Physiol. 88*:1804–1811 (2000).
14. **Williams-Bell, F.M., R. Villar, M.T. Sharratt, and R.L. Hughson:** Physiological demands of the firefighter candidate physical ability test. *Med. Sci. Sports. Exerc. 41(3)*:653–662 (2009).
15. **Huang, C.-J., R.S. Garten, C. Wade, H.E. Webb, and E.O. Acevedo:** Physiological responses to simulated stair climbing in professional firefighters wearing rubber and leather boots. *Eur. J. Appl. Physiol. 107*:163–168 (2009).