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A Thermal Stress Treadmill Walk for Clinic Evaluation of Candidates for Hazardous Materials (HazMat) Duty

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A Thermal Stress Treadmill Walk for Clinic Evaluation of Candidates for Hazardous Materials (HazMat) Duty

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U.S. guidance for examining hazmat workers recommends stress testing be considered when heat stress is expected. However, the most common stress test—Bruce protocol treadmill electrocardiography (BPTE) wearing gym clothes—creates little thermal stress. ***Objective.*** *Evaluate a novel thermal stress treadmill walk (TSTW).* ***Methods.*** *Body temperatures and heart rates during BPTE in 93 current and potential hazmat workers wearing gym clothes were compared with later values in 35 of these subjects while they were wearing thermally-restrictive "sauna suits" during a 45-min TSTW. Physiological strain index (PSI) was calculated from temperature and heart rate changes and compared with PSI values from hazmat simulations and climatic chamber exercises.* ***Results.*** *Tympanic temperature (TT) rose 0.5 °C* (SD *0.5) during BPTE lasting 12.4 min* (SD *2.9). PSI reached 6.0* (SD *1.3). TT rose 1.0°C* (SD *0.5) during TSTW,* $p < .01$*. PSI averaged 6.6* (SD *1.9) in 29 subjects who completed TSTW, versus 5.7* (SD *5.7) in the 6 subjects who did not. Ingested thermistor temperatures increased more than did TT during TSTW, yielding PSI of 7.0* (SD *1.5), equal to PSI values from climatic chamber exercises, i.e., 7.0* (SD *1.0).* ***Conclusion.*** *TSTW increased body temperature and PSI in 29 of the 35 subjects who completed it to levels matching those of operational simulations in climatic chambers and during hazmat exercises. This TSTW may be useful for evaluating candidates for hazmat duty.*

heat stress hazardous materials medical evaluation fitness for duty electrocardiography

1. INTRODUCTION

Heat stress is a serious risk to persons wearing bulky, encapsulating ensembles like level A and B chemically resistant suits (Figure 1) currently worn by hazmat responders [1]. Such encapsulation is required to protect these responders from toxic chemicals and homeland security risks including radioisotopes and micro-organisms. However, it also impedes dissipation of metabolic heat by the usual routes of evaporation and convection. Studies since World War II showed that such ensembles reduced physiological tolerance times. Darling, Johnson, Moreira, et al. found, e.g., that endurance time of men marching at 3 mph (4.8 km/h) in such apparel fell by 75%, as ambient temperatures increased from 21 to 29 °C [2]. Thermoregulatory and cardiorespiratory strain induced by impervious ensembles has also been documented by more recent investigations demonstrating high thermal strain when encapsulating suits are worn during hazmat exercises [3, 4, 5].

Hazmat responders require medical evaluation according to U.S. federal regulations [6, 7]. While the content of such evaluations is left up to the

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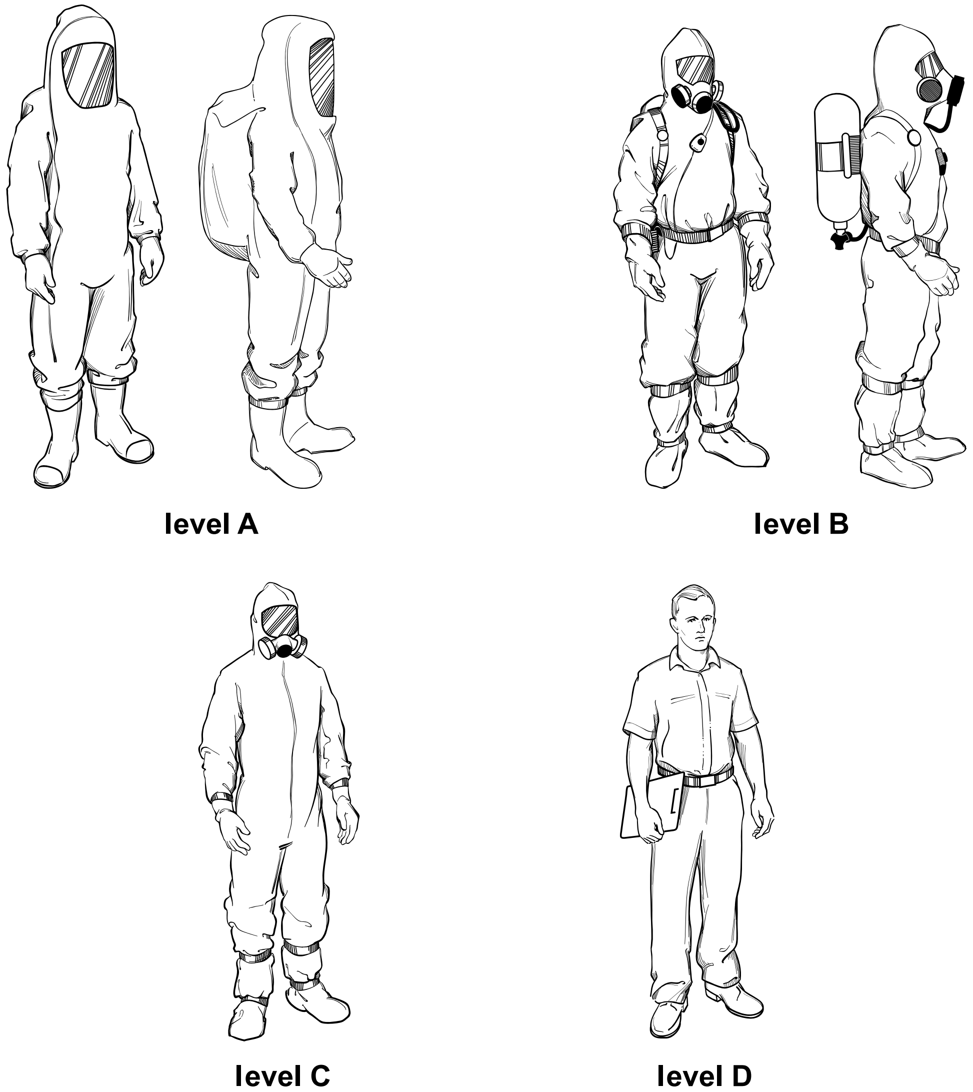

Figure 1. The 4 types of protective equipment defined by the U.S. Environmental Protection Agency [1]. *Notes.* The most protective ensemble (level A) also poses the greatest impediment to dissipation of metabolic heat.

examiner, stress testing has been recommended by the American Academy of Family Physicians, American Thoracic Society, the American College of Cardiology and American Heart Association, and the U.S. Preventive Services Task Force in accord with U.S. federal guidance, since heat strain is often found in hazmat exercises [8, 9, 10, 11]. Our interest in this issue was spurred by heat illness in three hazmat responders who previously completed maximal Bruce protocol treadmill electrocardiography (BPTE) to levels of 13–15 metabolic equivalent of task (MET) without difficulty. However, each became ill while wearing level A suits [1] 10 weeks later, during antiterrorism exercises. They displayed confusion, dizziness and shortness of breath, with profuse sweating. All were healthy without evidence of alcohol or drug abuse, and took no medications predisposing to heat intolerance. Each responded promptly to removal of the level A suits and rehabilitation with portable fans, cool drinks and shielding from solar radiation. However, we became concerned that Bruce protocol testing of subjects wearing gym clothing might not adequately screen persons for hazmat duty. Potential heat stress forms the basis for U.S. federal recommendations that stress testing be considered in evaluations for such duty, but the stress test employed does not incorporate thermal stress. Specifically, our preliminary observations of Bruce protocol testing found that tympanic temperature (TT) increased only 0.4 °C (*SD* 0.6) [12, 13] compared to increases of 0.9 °C (*SD* 0.3) during simulated hazmat responses [3, 4, 5]. The aim of the present study, therefore, was to test the hypothesis that treadmill exercise in a medical clinic can create physiological strain similar to that imposed by hazmat incidents.

In addition, we reviewed reports on physiological strain created in climatic chambers or activities such as firefighting, rescue or military maneuvers, to add perspective to our current findings. The physiological strain index (PSI) [14] was used to address both of these aims, incorporating the changes in body temperature and heart rate induced by such interventions.

2. METHODS

2.1. Study Subjects

The 93 subjects were current and potential candidates for hazmat work, including 45 hazmat technicians, 39 health care professionals and 9 support staff (14% smokers; 20% female; age 35 years [*SD* 8]; body mass index [BMI] 27.6 [*SD* 4.8]), who provided medical and occupational history and underwent physical examination prior to BPTE [15], after giving written, informed consent to undergo BPTE testing. All evaluations were performed in a family medicine clinic. A subgroup of 35 experimental subjects (17% female; age 37 years [*SD* 9]; BMI 26.4 [*SD* 3.0]) provided a second written, informed consent to participate in the experimental procedures termed a thermal stress treadmill walk (TSTW). The Institutional Review Board of the Carolinas HealthCare System approved both BPTE and TSTW protocols. A stipend of 100 USD was provided for each BPTE and TSTW session, regardless of the level of completion.

2.2. Experimental Procedures

BPTE and TSTW were performed at clinic temperatures of 21–22 °C with 40%–42% relative humidity using a motorized treadmill (Q4500 Stress Test Monitor, Quinton Instruments, USA). The electrocardiogram (ECG), cardiac rate and rhythm, and arterial blood pressure were monitored by a trained nurse and a physician experienced in stress testing, who interpreted all results. During BPTE, speed and grade of the treadmill are increased every 3 min, eliciting maximal cardiovascular performance in a brief time period. The person being tested determines how long the test continues, unless the physician determines that it be terminated sooner, based on ECG changes indicating cardiac ischemia or dysrhythmia, or a sustained abnormality of blood pressure, or physical signs of excessive distress (e.g., pallor, grimacing).

The TSTW differed from the usual treadmill stress testing:

- clothing: in addition to the gym shorts and T-shirts usually worn for stress tests, an impervious vinyl “sauna suit” (athletic works vinyl conditioning suit, WalMart Stores, USA) was worn during the TSTW;
- duration and intensity: whereas typical stress testing of hazmat workers involves 10–18 min of increasing treadmill speed and grade [12], the TSTW employed a constant 5% grade and speed chosen to approximate maximal walking velocity (6 km/h, 3.7 mph) aiming to complete 30 min, after which grade was increased to 10% for an additional 15 min. Each subject wore a 2.65-kg (5-lb) weight on each wrist and ankle during TSTW, simulating tools, first aid and other emergency equipment.

For BPTE testing, subjects wore typical gym clothes consisting of a T-shirt, shorts, athletic socks and underwear. The same clothing was worn during the TSTW, underneath a vinyl sauna suit. On the day of BPTE or TSTW testing, the subject was asked to eat and take fluids normally, except for abstaining from all oral intake for at least 1 h before reporting for the experimental procedure, which took place at mid-day in a clinic room devoted to treadmill stress testing. Ambient temperature and humidity were measured at the time of testing with a digital hygrometer (model 44550, Extech Instruments, USA). After completion of the medical history and physical examination, ECG electrodes and a sphygmomanometer cuff were applied, and pre-exercise data were obtained. These included cardiac rate, blood pressure and TT, measured with a thermistor bolometer (Omron model MC-505, Omron Health Care, USA). TT was estimated by making three measurements in each ear, and recording the highest of the six values. (No sublingual temperatures are reported because of the likelihood of error due to exercise hyperpnea.) Subjective thermal status was queried during TSTW according to the Young index: 4 = *comfortable*, 6 = *hot*, 8 = *unbearably hot* [16]. Each subject was reminded of the scale of values when asked to comment verbally at 10-min intervals. These descriptions were also recorded on completion of the stress test, and 6 min later. The perceived exertion was also recorded during TSTW, using the Borg index: 6 = *nil*, 11 = *light*, 13 = *somewhat hard*, 15 = *very hard*, 20 = *maximum tolerable* [17]. The Borg scale (6–20) was displayed on the wall facing the exercising subject so that it was visible at all times, and the subject could readily respond with a numerical value when asked at 10-min intervals. Since only the physician and nurse were present during the one-subject BPTE and later TSTW, the Young index and Borg scale responses remained confidential. The reason for termination was also recorded (e.g., breathlessness, leg discomfort, thermal discomfort). On completion of the 6-min recovery period, during which subjects sat at rest, final readings were taken and each subject was given a preliminary account of their results, plus answers to any questions.

The TSTW occurred 2–10 weeks after the baseline BPTE day described in the previous paragraph, depending on the subject's availability. The same routine was followed, with two exceptions. First, an ingestible, disposable thermistor (CorTemp HT150002 Core Body Temperature Sensor, HQInc, USA) was swallowed by the subject, no less than 3 nor more than 14 h prior to coming to the clinic. This ingested thermistor (ITT) enabled central body temperature to be monitored, in addition to the TT and thermal discomfort. The second difference, in addition to the ITT, between the BPTE and the TSTW, was the addition of a vinyl suit donned over the gym clothes, after ECG electrodes had been applied. This vinyl sauna suit was intended to interfere with the normal convective and evaporative dissipation of metabolic heat that occurs when level A or B protective suits are worn (Figure 1).

For both the BPTE baseline observations and the TSTW treadmill walk, the physiological strain index (PSI) was derived from changes in heart rate and body temperature in the manner described by Moran, Shitzer and Pandolf [14], with 5–6 = *moderate strain*, 7–8 = *high strain*, and >8 = *very high strain*. For our study, PSI was calculated as follows:

$$PSI = 5\,(HR_{\mathrm{p}} - HR_{\mathrm{i}})/(180 - HR_{\mathrm{i}}) \\ + 5\,(T_{\mathrm{p}} - T_{\mathrm{i}})/(39.5 - T_{\mathrm{i}}),$$

where HR_{i}, HR_{p} = initial resting and peak heart rate; T_{i}, T_{p} = initial and peak central body temperature (°C) measured with either the tympanic bolometer or the ITT. HR_{i} did not appear to be affected by anxiety or anticipation in these subjects, perhaps due to their familiarity with the test procedures and absence of any competitive aspects of the protocols. Values of PSI from published investigations were calculated in the same manner, except for those in which pre-procedure, resting heart rates were not available; in such instances, a value of 72 beats per minute (bpm) was assumed, on the basis of those reports in which such resting heart rates were provided.

The risk of cardiac disease for each subject was estimated on the basis of BPTE results using horizontal or down-sloping depression of the electrocardiographic ST-segment as an indicator of myocardial ischemia [18]. To minimize false-positive indications of ischemia, we used 2 mV of ST-depression as the criterion for a positive (abnormal) test. To improve prognostic value of the test, we also assessed three additional dependent variables derived from the ECG and symptoms: (a) heart rate recovery (HRR) at 1 min after exercise, (b) the chronotropic index (CI), and (c) the Duke treadmill score (DTS). CI is the proportion of the heart rate reserve in use at peak exercise, hence (peak heart rate minus resting rate) divided by (age-predicted maximal heart rate minus the resting rate), with a normal CI range of

0.8–1.3. DTS is calculated by subtracting two values from the treadmill exercise duration: (a) 5 × maximal ST-segment depression and (b) 4 × angina index of 0 or 1 or 2, depending on the intensity of pain. Normal, low-risk values of DTS are ≥5, moderate risk from +4 to –10, and high-risk values are <–10. HRR, CI and DTS have been used in combination and shown to have superior predictive value with regard to cardiovascular mortality in a large number of patients [19].

All statistical analyses were done with commercially available software (Microsoft Excel). Descriptive statistics, including means and standard deviations, and counts and percentages, are reported. The primary analysis compares the mean change in body temperature (TT and ITT) from pre- to post-exercise, using Student's paired *t* test. A priori, the success of the TSTW was to be gauged by a rise in central body temperature of ≥1.0 °C [3, 4, 5] and the development of profuse sweating, which is uncommon in BPTE.

Sample size was based on the use of pre- and post-exercise temperatures. However, the standard deviations for the difference in temperatures were not known, so effect sizes were used in determining the sample size. Thirty-two subjects were needed to detect an effect size of .5 with $\alpha = .5$ and a power of 80%. An effect size of .5 is when the clinically important difference is one half of a standard deviation. The mean values of PSI in our subjects were compared using unpaired *t* tests between those who did, versus did not, complete 45 min of TSTW duration. In addition, PSI results from the present study were compared with those published by others.

3. RESULTS

No adverse effects occurred in any of the 93 subjects undergoing BPTE or the 35 subjects during or after the TSTW. However, 6 of 35 curtailed their TSTW participation because of symptoms after walking for only 27 min (*SD* 11, range: 11.7–36.0). Three were limited by heat discomfort, two by leg pain and one by generalized fatigue. The mean Young index of thermal discomfort at end-exercise was 7.0 (*SD* 0.8) for the 29 subjects completing the 45-min TSTW, non-significantly higher than that of the 6 whose exercise duration was shorter; 6.5 (*SD* 1.5), $p = .24$. The average values of the Borg relative perceived exertion scale were also similar, 12.0 (*SD* 4.6) and 14.8 (*SD* 2.8), respectively ($p = .16$).

3.1. Body Temperature and Physiological Strain Index Effects

The BPTE-induced increases in TT were maximal at 6 min post-exercise, although some individual maxima occurred earlier, such that the mean maximal increase was 0.5 °C (*SD* 0.5), slightly greater than the 0.4 °C difference between the pre-exercise and 6-min post-exercise means (Table 1). As expected, the rise in TT was positively associated with duration of BPTE ($r = .45$, $p = .001$). Sweating was absent or minimal, but was not quantified. The mean PSI value was 6.0 (*SD* 1.3), consistent with a moderate degree of physiological strain [14].

The temperature increases in response to TSTW were greater than those following BPTE (TT of 1.0 versus 0.5 °C, $p = .001$) (Table 1). The rate of rise of TT was higher during BPTE than TSTW (0.04 [*SD* 0.04] versus 0.02 °C/min [*SD* 0.01], $p < .004$), as might be expected from the greater intensity of exertion during BPTE. As measured with ITT, the temperature rise related to TSTW exceeded that of the TT (Table 1), both in the 29 subjects who competed the target duration of 45 min and in the 6 who did not. Although all TSTW subjects exhibited marked sweating, only 76% of them experienced at least a 1.0 °C rise, largely due to the failure of 6 subjects to complete the TSTW.

Based on changes in ITT, PSI values resulting from TSTW averaged 7.2 (*SD* 1.3) in the 29 subjects who completed the 45-min walk versus 6.0 (*SD* 1.2) in the 6 who completed a shorter duration ($p = .045$). Lower values of PSI after TSTW (6.5 [*SD* 1.8]) were calculated using changes in TT, which was consistently lower than simultaneous ITT.

3.2. Cardiovascular Effects

For the 93 subjects, BPTE duration averaged 12.4 min (*SD* 2.9) (equivalent to 15.1 MET), and was limited by dyspnea, leg fatigue or a burning

TABLE 1. Body Temperature (°C) Responses of Subjects During Bruce Protocol Treadmill Electrocardiography (BPTE) and Thermal Stress Treadmill Walk (TSTW), *M* (*SD*)

	Timing				
Temperature	**Pre**	**End**	**6-min Post**	**10-min Post**	**Max Rise**
BPTE (*N* = 93)					
TT	36.9 (0.6)	37.2 (0.7)	37.3 (0.7)	—	0.5 (0.5)
TSTW (*N* = 35)					
TT[a]	36.8 (0.5)	37.7 (0.8)	37.6 (0.8)	37.4 (0.7)	1.0 (0.5)
ITT[a]	37.2 (0.5)	38.3 (0.5)	38.4 (0.4)	38.3 (0.5)	1.3 (0.4)
TT[b]	36.4 (0.7)	37.2 (0.7)	36.9 (0.7)	36.9 (0.8)	0.8 (0.3)
ITT[b]	36.9 (1.3)	37.4 (1.3)	37.4 (1.2)	37.5 (1.2)	0.9 (0.4)
TT[c]	36.7 (0.6)	37.6 (0.8)	37.4 (0.8	37.3 (0.7)	1.0 (0.5)
ITT[c]	37.1 (0.7)	38.1 (0.8)	38.2 (0.7	38.1 (0.7)	1.2 (0.4)

Notes. Pre = pre-exercise; end = end-exercise; post = post-exercise; TT = tympanic temperature; ITT = ingested thermistor; a = subjects who completed 45 min of TSTW; *N* = 29; b = subjects who completed <45 min of TSTW; *N* = 6, duration: 27.0 (10.7) min; c = combined groups; *N* = 35, duration: 41.9 (8.0) min.

sensation in the thigh and/or calf muscles, but without chest pain, cardiac dysrhythmia or evidence of cardiac ischemia. No serious symptoms or adverse effects occurred in this series of observations. Hence, it was not necessary for any of the experimental procedures to be aborted by the attending staff. BPTE duration was negatively correlated with BMI ($r = -.52$, $p < .001$) but not with age ($r = -.16$, $p > .05$). The maximal heart rate during BPTE averaged (*SD*) 181 (13) bpm, equivalent to 98% (6%) of the age-predicted maximum of (220 – age). Only 1 of the 93 subjects failed to reach 85% of this value, which is the heart rate criterion for a valid stress test to identify cardiac ischemia [18]. Electrocardiographic indications of such ischemia (2-mm ST-segment depression) were observed in 4 subjects. All four were interpreted to be false positives, based on the lack of other evidence of myocardial ischemia (i.e., no chest pain or persistence of ST-segment depression) and normal values of the HRR, CI, and DTS, which averaged (*SD*) 35 (12),

TABLE 2. Maximal Heart Rate, Blood Pressure and Related Variables in Healthy Subjects During Thermal Stress Treadmill Walk (TSTW) and Bruce Protocol Treadmill Electrocardiography (BPTE) *M* (*SD*)

	BP_{max} (mmHg)				
HR_{max} (bpm)	**SBP**	**DBP**	**PP**	**CI**	**HRR (bpm)**
BPTE (*N* = 93)					
184 (13)[a]	225 (39)	66 (20)	160 (48)	0.98 (0.10)	29 (8)
182 (10)[b]	200 (43)	60 (18)	139 (36)	0.96 (0.10)	25 (6)
184 (12)*[c]	221 (41)	64 (20)	157 (47)	0.98 (0.10)*	28 (8)*
TSTW (*N* = 35)					
166 (19)[a]	240 (51)	58 (15)	183 (57)	0.85 (0.18)	22 (10)
166 (11)[b]	227 (46)	62 (17)	165 (55)	0.83 (0.07)	27 (15)
166 (17)*[c]	238 (50)	58 (15)	180 (56)	0.84 (0.23)*	23 (11)*

Notes. * $p < .01$, mean values for TSTW versus BPTE; HR_{max} = maximal heart rate; bpm = beats per minute; BP_{max} = maximal blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure; CI = chronotropic index; HRR = heart rate recovery; a = subjects who completed 45 min of TSTW; *N* = 29; b = subjects who completed <45 min of TSTW; *N* = 6, duration: 27.0 (10.7) min; c = combined groups; *N* = 35, duration: 41.9 (8.0) min. CI, HR_{r} and HR_{max} during TSTW were lower than corresponding values during BPTE ($p < .01$), but differences in BP were nonsignificant ($p > .09$).

0.97 (0.10) and 12.1 (3.6), consistent with low 5-year, all-cause mortality of 0.1% to 0.3% [19]. Mean (*SD*) systolic and diastolic blood pressure during maximal exercise were 207 (46) and 67 (24), respectively, with a corresponding mean (*SD*) pulse pressure of 141 (57).

Among the 35 TSTW subjects (Table 2), the maximal heart rate during the TSTW averaged 166 ± 17, equal to 89% ± 18% of the age-predicted maximum, thus exceeding the 85% criterion for a valid cardiovascular stress test [18]. As expected, this averaged maximal exercise heart rate during TSTW was significantly lower than corresponding peak heart rates during BPTE (Table 2), in which subjects exercised to their individual maximal tolerance. Also lower at the end of the TSTW were the respective values of the CI and HRR. Maximal systolic and diastolic blood pressure averaged (*SD*) 238 (50) and 58 (15), respectively, with a mean pulse pressure of 180 ± 56. None of these blood pressure values during TSTW differed significantly from the corresponding ones of the 35 subjects during BPTE.

4. DISCUSSION

The aim of this study was to evaluate a novel stress test for use in the medical screening of hazmat candidates in a clinic setting. The study was stimulated by three considerations. First was the occurrence of heat illness during hazmat exercises in 3 subjects who had previously undergone medical evaluations including BPTE without difficulty. Secondly, BPTE as commonly performed in subjects wearing gym clothes induces little heat stress, in contrast to hazmat exercises [3, 4, 5], whereas anticipated heat stress is the *raison d'être* for stress testing of hazmat candidates and incumbents. Finally, we found in an earlier study [20] that the duration of BPTE did not correlate with performance in a manikin rescue task. The current study employed a TSTW which partly simulates hazmat responses. The results demonstrated that BPTE performance correlated weakly with that of the TSTW ($r = .14$, p nonsignificant), while the TSTW induced a mean rise in central body temperature twice that of the BPTE. PSI values, based partly on these temperature increases, were significantly greater in subjects who completed the 45-min target of the TSTW than in those who did not, and also exceeded the PSI values induced by the BPTE. The mean (*SD*) PSI value of 6.0 (1.3) during BPTE in 93 subjects reflected a rise in TT of 0.5 °C, similar to the 0.4 °C rise found earlier in a smaller group of examinees [13]. This moderate level of PSI [14] from BPTE was accompanied by little or no sweating, and a lesser degree of subjective thermal discomfort than in the TSTW.

We also wished to compare PSI values from the TSTW—6.5 with TT and 7.0 with ITT—with changes in body temperature and PSI values from 13 other studies of sustained treadmill walking. In 10 of these, subjects also wore protective clothing which impeded dissipation of metabolic heat (Table 3), such as firefighter turnout gear, impermeable apparel designed for military purposes or otherwise thermally-restrictive ensembles, categorized by the Agency for Toxic Substances and Disease Registry [1] as levels A, B or C (Figure 1). Three of these 13 reports [5, 21, 22] did not include resting heart rates, for which instances, to estimate PSI a value of 72 bpm was assigned based on similar studies. In three of the studies whose subjects wore gym clothes [5, 21, 23], TSTW was performed at ambient temperatures of 24.4, 33.0 and 49.0 °C , with resulting PSI values of 1.2, 4.8 and 7.6, as might be expected from these respective ambient temperatures. The 13 studies employed a wide range of durations. To compare their results, it was, therefore, necessary to divide the PSI values by the time intervals over which they were induced, hence Table 3 includes a column for PSI per minute of exertion. Also shown in Table 3, the increase in core temperature in the present TSTW study performed at a laboratory temperature of 22 °C was similar to that observed in subjects wearing thermally-restrictive ensembles in the 10 studies conducted at increased ambient temperature, 33.3 °C (10.4), as was the mean PSI and its rate of rise. As might be expected, all of these values exceeded corresponding results in subjects wearing gym suits at an average ambient temperature of 35.5 °C.

TABLE 3. Summary of 13 Studies of Sustained Treadmill Walking With Combined Heat Stress

			Treadmill Walk					Rise in T_c			
Reference	T_a (°C)	%RH	Speed (km/h)	Grade (%)	Duration (min)	M/F	Clothing	°C	°C/min	PSI	PSI/min
Thermally-restrictive ensembles											
Baker, Grice, Roby, et al. [24]	21	55	6.0	10.0	60	18/0	turnout	1.3	0.220	6.9	0.12
Barr, Gregson, Sutton, et al. [25]	50	13	5.0	7.5	40	9/0	“protective”	2.1^a	0.052^a	9.6^a	0.24^a
Duncan, Gardner & Barnard [26]	42	100	4.0	10.0	15	11/0	turnout	0.83	0.055	5.7	0.38
Hostler, Gallagher & Goss [27]	21	70	4.3	3.3^b	45	8/2	level C/RP	1.1^a	0.025	9.3^a	0.21^a
Moran, Shitzer & Pandolf [14]	43	20	(425 W)	—	180	7/0	“protective”	0.9	0.006	7.0	0.04
Semeniuk, Dionne, Makris, et al. [22]	35	50	3.1	0	67	5/0	level B	1.1	0.016	5.5	0.08
Smith, Petruzzello, Kramer, et al. [28]	24	50	3.5	10.0	15	10/0	turnout	0.7	0.047	6.4	0.43
Smolander, Louhevaara, Tuomi, et al. [29]	24	40	$(41\%)^c$	0	30	6/0	“gas PPE”	1.0	0.033	6.9	0.23
Tanaka, Brisson & Volle [30]	33	65	5.0	0	50	10/0	impermeable	0.94	0.031	6.4	0.21
Tikuisis, McLellan & Selkirk [31]	40	30	3.5	0	60	20/6	semipermeable	1.3	0.020	6.4	0.11
M (*SD*)	33 (10)	49 (26)						1.1 (0.4)	0.051 (0.06)	7.0 (1.1)	0.20 (0.13)
Thermally nonrestrictive garments											
Armstrong, Maresh, Garabee, et al. [23]	33	56	5.6	5.0	90	10/0	gym suit	1.0	0.011	4.8	0.05
Sawka, Young, Latzka, et al. [21]	49	20	$(45\%)^c$	0	180	17/0	gym suit	1.6	0.009	7.6	0.04
Williamson, Carbo, Luna, et al. [4]	24	42	3.2	0	45	12/0	gym suit	0.07	0.002	1.2	0.03
M (*SD*)	36 (12)	39 (18)						0.9 (0.8)	0.007 (0.005)	4.5 (3.2)	0.04 (0.01)
Present study	22	41	6.0	5–10	41.7	29/6	sauna suit^d	1.2	0.029	7.0	0.17

Notes. Physiological strain index (PSI) was derived from the respective publications. Rates of PSI per minute were based on durations of TSTW. Level B and C protective ensembles are shown in Figure 1. T_a = ambient temperature; RH = relative humidity; M = male subjects; F = female subjects; T_c = core temperature; PPE = personal protective equipment; RP = respiratory protection; a = core temperature was measured with an ingested thermistor, while all other studies employed rectal thermistors; b = male and female subjects carried a steel bar weighing 8.1 kg and 6.8 kg, respectively; c = percentage of maximal oxygen consumption; d = athletic works vinyl conditioning suit (WalMart Stores, USA).

TABLE 4. Summary of 15 Studies of Heat Stress From Simulations of Hazmat Responses, Firefighting, Rescue and Military Activities

			Treadmill Walk					Rise in T_c			
Reference	T_a (°C)	%RH	Speed (km/h)	Grade (%)	Duration (min)	M/F	Clothing	°C	°C/min	PSI	PSI/min
Hazmat response simulations											
Williamson, Carbo, Luna, et al. [4]	24	42	3.2	0	45	12/0	level A	0.70	0.016	2.9	0.06
Richardson & Capra [5]	40	N/A	standard task	0	20	20/0	level A	0.75	0.030	5.0	0.25
Richardson & Capra [5]	35	N/A	standard task	0	20	20/0	level A	0.64	0.032	4.4	0.22
Richardson & Capra [5]	30	N/A	standard task	0	20	20/0	level A	0.54	0.027	4.0	0.20
Veghte & Annis [3]	41	42	standard task	0	45	5/0	level A	1.24	0.028	7.0	0.16
Veghte & Annis [3]	32	65	standard task	0	45	5/0	level A	1.11	0.024	6.8	0.15
M (*SD*)	35 (9)	N/A						0.9 (0.01)	0.027 (0.30)	5.0 (2.0)	0.16 (0.09)
Firefighting or rescue simulations											
Angerer, Kadlez-Gebhardt, Delius, et al. [32]	>200	N/A	firefighting	0	30	49/0	turnout, SCBA	0.80	0.027	6.4	0.21
Bennett, Hagan, Banta, et al. [33]	44–76	N/A	firefighting	0	31.4	9/0	USNFF + OBA	1.90	0.061	9.6	0.30
Carter, Banister & Morrison [34]	40	70	step test	0	40	12/0	turnout, SCBA	1.50	0.038	9.3	0.23
Griefahn, Kunemund, Schafer, et al. [35]	17–25	70	rescue	0	25	3/0	turnout, SCBA	0.83	0.033	7.5	0.30
Ilmarinen, Måkinen, Lindholm, et al. [36]	22–25	48	rescue	0	28	23/0	turnout, SCBA	0.60	0.021	4.0	0.14
Ilmarinen, Måkinen, Lindholm, et al. [36]	45	35	rescue	0	54	23/0	turnout, SCBA	1.00	0.019	6.6	0.12
Smith, Petruzzello, Kramer, et al. [37]	90	N/A	firefighting	0	16	16/0	turnout, SCBA	3.15	0.197	10.4	0.65
Smith, Manning & Petruzzello [38]	47–60	N/A	firefighting	0	21.1	7/0	turnout, SCBA	0.80	0.038	6.2	0.83
M (*SD*)	73 (60)	N/A						1.4 (0.90)	0.059 (0.06)	8.0 (1.7)	0.38 (0.26)
Military activity simulations											
Cheung & McLellan [39]	40	30	3.5	0	93	8/0	Canadian NBC	1.85	0.020	7.6	0.08
Cheung & McLellan [39]	40	30	4.8	4	58	8/0	Canadian NBC	1.83	0.032	7.4	0.13
Cheuvront, Goodman, Kenefick, et al. [40]	35	30	5.6	2	240	11/0	U.S. Army combat	1.33	0.006	6.2	0.03
Chinevere, Cadarette, Goodman, et al. [41]	35	75	200 W/cm^2	0	60	6/0	U.S. Army combat	1.42	0.024	6.2	0.10
Hadid, Yanovich, Erlich, et al. [42]	40	40	5.0	2	115	12/0	Israeli combat	1.45	0.014	5.5	0.05
McLellan, Frim & Bell [43]	40	N/A	4.8	4	40	8/0	Canadian NBC	1.83	0.045	5.9	0.15
M (*SD*)	38 (3)	N/A						1.58 (0.02)	0.24 (0.02)	5.9 (0.8)	0.08 (0.05)
Present study	22	41	6.0	5–10	41.7	29/6	sauna suit[a]	1.20 (0.03)		7.0	0.17

Notes. Values of physiological strain index (PSI) were derived from the respective publications, for the highest ambient temperatures reported. See Figure 1 for level A protective ensembles. T_a = ambient temperature; RH = relative humidity; M = male subjects; F = female subjects; T_c = core temperature; N/A = not applicable; SCBA = self-contained breathing apparatus; USNFF = U.S. Navy firefighting dress; OBA = oxygen breathing apparatus; NBC = nuclear, biological chemical protective apparel; a = athletic works vinyl conditioning suit (WalMart Stores, USA).

Simulations of firefighting, rescue, military activities, and responses to hazmat releases have been reported in 15 studies from which PSI can be estimated (Table 4). These estimates vary greatly due to differences in activities, ambient temperature, protective ensembles and duration, so the effect of duration was again controlled by expressing PSI in terms of its rate of rise with time of exertion. It is recognized that this estimate may lack accuracy due to a lag in core temperature at the start of exercise, as well as missing a continued rise after the end of exercise. The inaccuracy might be greater in short-duration protocols.

The median temperature of the 15 studies was 40 °C, substantially higher than that of the present study. The rates of rise in core temperature and PSI in our subjects were similar to the average values found in the three hazmat simulations [3, 4, 5], and were greater than corresponding values found in military activities, but lower than for firefighting or rescue simulations. Thus, the methods used in the TSTW described here provide a means of inducing thermal strain as would likely be encountered in future hazmat responses, but done in a clinic setting. That is, the same degree of thermal and physiological strain can be achieved in a clinic equipped with a standard treadmill, as has been achieved in less readily available settings such as temperature-controlled chambers or operational simulations.

The present study has a number of limitations. Although the thermal stress induced by the TSTW was accompanied by profuse sweating, the protocol did not include sensitive weighing which could have documented this effect. The duration of the TSTW is obviously longer than the typical treadmill stress test, prolonging the process of screening numerous candidates for hazmat duty. But this longer duration is more typical of actual responses or exercises, in which 4500-psi compressed-air cylinders can support moderate exertion for up to 60 min. The added thermal stress is also typical of such situations, in contrast to the usual Bruce protocol testing. The use of hand- and ankle-weights during the TSTW approximates equipment often carried by hazmat responders. However, our subjects did not wear self-contained breathing apparatus (SCBA) and level A or B encapsulating suits, for the following reasons. First, SCBA is not likely to be available in most clinics where hazmat examinations are done. Its use would add considerable expense to these mandatory examinations, which are repeated at 2-year intervals. The level A ensembles are costly and incompatible with running on a treadmill, indeed, with running in any mode. We, therefore, chose the inexpensive, off-the-shelf sauna suits which similarly impede evaporative and convective heat transfer, as do level A ensembles. The sauna suits can enable TSTW to be replicated in many parts of the world including the USA, which are subject to federal regulations governing hazmat work.

A further weakness is our failure to meet the a priori criterion of 80% of subjects experiencing a temperature rise >1 °C. Only 76% of the subjects did so, due to the failure of 6 subjects to complete the planned 45 min of TSTW exercise. Only 2 of these 6 subjects experienced an increase in central body temperature of >1 °C. When our analysis is restricted to the 29 subjects who completed the TSTW, 84% experienced a temperature rise of ≥1 °C. Although our overall sample size was limited, 35 is comparable to most of the other studies evaluating PSI in the setting of thermal stress testing.

One might consider the failure to complete the 45-min TSTW as disqualifying a candidate for hazmat assignments, such as in the 6 persons who stopped exercising early, but we believe that such a judgment would be premature. Our study was not designed to evaluate the significance of failure to achieve the target duration upon future performance. We do suggest that the TSTW can add useful information to the medical evaluation of candidates for hazmat duty. However, it remains unknown whether failure to achieve the TSTW target duration of 45 min in a clinical setting would herald performance deficits in actual responses.

5. CONCLUSION

The TSTW described here more closely simulates the heat stress of hazmat activities than does BPTE, which—as we previously noted—did not correlate well with a manikin rescue task by hazmat responders. In the present study, BPTE duration did not correlate well with that of TSTW endurance, either in those who failed to complete the target of 45 min or in the group as a whole. Thus, TSTW does not simply measure endurance. It employed inexpensive suits and treadmill exercise usually available in clinics where hazmat examinations are done, and it increased body temperature and PSI to levels similar to those of operational simulations in climatic chambers. The TSTW provides a tool for evaluating workers for hazmat duty, which can readily be done in primary care settings.

REFERENCES

1. Agency for Toxic Substances and Disease Registry (ATSDR). Managing hazardous materials incidents . Volume I (revised). Emergency medical services: a planning guide for the management of contaminated patients. Atlanta, GA, USA: ATSDR; 2001. Retrieved March 10, 2014, from: http://www.atsdr.cdc.gov/MHMI/index.asp.
2. Darling RC, Johnson RE, Moreira M, Forbes WH. Part I, physiological tests of impermeable suits (Report No. 21). Boston, MA, USA: Office of Scientific Research and Development; 1943.
3. Veghte JH, Annis JF. Physiologic field evaluation of hazardous materials protective ensembles (Final report, task 4, FEMA Contract EMW-85-C-2130). Washington, DC, USA: U.S. Fire Administration; 1991. Retrieved March 10, 2014, from: http://www.usfa.fema.gov/downloads/txt/publications/fa-109.txt.
4. Williamson R, Carbo J, Luna B, Webbon BW. A thermal physiological comparison of two HAZMAT protective ensembles with and without active convective cooling. J Occup Environ Med 1999;41(6):453–63.
5. Richardson JE, Capra MF. Physiological responses of firefighters wearing level 3 chemical protective suits while working in controlled hot environments. J Occup Environ Med 2001;43(12):1064–72.
6. Occupational safety and health guidance manual for hazardous waste site activities. Washington, DC, USA: U.S. Department of Health and Human Services; 1985. Retrieved March 10, 2014, from: https://www.osha.gov/Publications/complinks/OSHG-HazWaste/all-in-one.pdf.
7. Occupational Health and Safety Administration. Hazardous waste operations and emergency response. Fed Reg. 1987;52:31852.
8. American Academy of Family Physicians. Age charts for periodic health examination (Reprint No. 510). Kansas City, MO, USA: American Academy of Family Physicians; 1994.
9. Harber P, Barnhart S, Boehlecke BA, Beckett WS, Gerrity T, McDiarmid MA, et al. Respiratory protection guidelines. This official statement of the American Thoracic Society was adopted by the ATS Board of Directors, March 1996. Am J Respir Crit Care Med. 1996;154(4 Pt 1):1153–65.
10. Gibbons RJ, Balady GJ, Beasley JW, Bricker JT, Duvernoy WF, Froelicher VF, et al. ACC/AHA guidelines for exercise testing. A report of the American College of Cardiology/American Heart Association task force on practice guidelines (Committee on exercise testing). J Am Coll Cardiol. 1997;30(1):260–311.
11. U.S. Preventive Services Task Force. Guide to clinical preventive services: report of the US Preventive Services Task Force. 2nd ed. Baltimore, MD, USA: Williams & Wilkins. 1996.
12. Raymond LW, Barringer TA, Konen JC. Stress testing in the medical evaluation for hazardous materials duty: Results and consequences in three groups of candidates. J Occup Environ Med. 2005;47(5):493–502.
13. Raymond LW, Barringer TA, Konen JC. Heart disease deaths among firefighters. New Engl J Med. 2007;356(24):2535–6.
14. Moran DS, Shitzer A, Pandolf KB. A physiological strain index to evaluate heat stress. Am J Physiol. 1998;275(1): R129–34. Retrieved March 10, 2014, from: http://ajpregu.physiology.org/content/275/1/R129.
15. Bruce RA, Blackmon JR, Jones JW, Strait G. Exercise testing in normal subjects and cardiac patients. Pediatrics. 1963;32(4): 742–56.

16. Young AJ, Sawka MN, Epstein Y, Decristofano B, Pandolf KB. Cooling different body surfaces during upper and lower body exercise. J Appl Physiol (1985). 1987;63(3):1218–23.

17. Borg G. Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med. 1970;2(2):92–8.

18. Froelicher VF, Meyer J. Exercise and the heart. 5th ed. Philadelphia, PA, USA: Saunders Elsevier; 2006.

19. Lauer MS. Exercise electrocardiogram testing and prognosis. Novel markers and predictive instruments. Cardiol Clin. 2001; 19(3):401–14.

20. Busko JM, Blackwell TH, Raymond LW. Stress test performance does not predict manikin rescue performance [abstract]. Prehosp Emerg Care. 2005;9:109.

21. Sawka MN, Young AJ, Latzka WA, Neufer PD, Quigley MD, Pandolf KB. Human tolerance to heat strain during exercise: influence of hydration. J Appl Physiol (1985). 1992;73(1):368–75.

22. Semeniuk KM, Dionne JP, Makris A, Bernard TE, Ashley CD, Medina, T. Evaluating the physiological performance of a liquid cooling garment used to control heat stress in hazmat protective ensembles. In: Yarborough P, Nelson CN, editors. Proceedings of the ASTM F23 Eighth Symposium on Performance of Protective Clothing: Global Needs and Emerging Markets. Conshohocken, PA, USA: American Society for Testing and Materials (ASTM); 2004. p. 51–63.

23. Armstrong LE, Maresh CM, Garabee CV, Hoffman JR, Kavouras SA, Kenefick RW, et al. Thermal and circulatory responses during exercise: effects of hypohydration, dehydration, and water intake. J Appl Physiol (1985). 1997;82(6):2028–35. Retrieved March 10, 2014, from: http://jap.physiology.org/content/82/6/2028.long.

24. Baker SJ, Grice J, Roby L, Matthews C. Cardiorespiratory and thermoregulatory response of working in fire-fighter protective clothing in a temperate environment. Ergonomics. 2000;43(9):1350–8.

25. Barr D, Gregson W, Sutton L, Reilly T. A practical cooling strategy for reducing the physiological strain associated with fire-fighting activity in the heat. Ergonomics. 2009;52(4):413–20.

26. Duncan HW, Gardner GW, Barnard RJ. Physiological responses of men working in fire fighting equipment in the heat. Ergonomics. 1979;22(5):521–7.

27. Hostler D, Gallagher M Jr, Goss FL, Seitz JR, Reis SE, Robertson RJ, et al. The effect of hyperhydration on physiological and perceived strain during treadmill exercise in personal protective equipment. Eur J Appl Physiol. 2009;105(4):607–13.

28. Smith DL, Petruzzello SJ, Kramer JM, Warner SE, Bone BG, Misner JE. Selected physiological and psychobiological responses to physical activity in different configurations of firefighting gear. Ergonomics. 1995;38(10):2065–77.

29. Smolander J, Louhevaara V, Tuomi T, Korhonen O, Jaakkola J. Cardiorespiratory and thermal effects of wearing gas protective clothing. Int Arch Occup Environ Health. 1984;54(3):261–70.

30. Tanaka M, Brisson GR, Volle MA. Body temperature in relation to heart rate for workers wearing impermeable clothing in a hot environment. Am Ind Hyg Assoc J. 1978;39(11):885–90.

31. Tikuisis P, McLellan TM, Selkirk G. Perceptual versus physiological heat strain during exercise-heat stress. Med Sci Sports Exerc. 2002;34(9):1454–61.

32. Angerer P, Kadlez-Gebhardt S, Delius M, Raluca P, Nowak D. Comparison of cardiocirculatory and thermal strain of male firefighters during fire suppression to exercise stress and aerobic exercise testing. Am J Cardiol. 2008;102(11):1551–6.

33. Bennett BL, Hagan RD, Banta G, Williams F. Physiological responses during shipboard firefighting. Aviat Space Environ Med. 1995;66(3):225–31.

34. Carter JB, Banister EW, Morrison JB. Effectiveness of rest pauses and cooling in alleviation of heat stress during simulated fire-fighting activities. Ergonomics. 1999;42(2):299–313.

35. Griefahn B, Kunemund C, Schafer K, Aschenbrenner D. On the use of new compressed air breathing apparatus by fire brigades. Dräger Review. 1999;(83):2–5.

36. Ilmarinen R, Måkinen H, Lindholm H, Punakallio A, Kervinen H. Thermal strain in fire fighters while wearing task-fitted versus EN 469:2005 protective clothing during a prolonged rescue drill. International Journal of Occupational Safety and Ergonomics (JOSE). 2008;14(1):7–18. Retrieved March 10, 2014, from: http://www.ciop.pl/25858.
37. Smith DL, Petruzzello SJ, Kramer JM, Misner JE. The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill. Ergonomics. 1997;40(4):500–10.
38. Smith DL, Manning TS, Petruzzello SJ. Effects of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. Ergonomics. 2001;44(3):244–54.
39. Cheung SS, McLellan TM. Influence of hydration status and fluid replacement on heat tolerance while wearing NBC protective clothing. Eur J Appl Physiol Occup Physiol. 1998;77(1–2):139–48.
40. Cheuvront SN, Goodman DA, Kenefick RW, Montain SJ, Sawka MN. Impact of protective vest and spacer garment on exercise-heat strain. Eur J Appl Physiol. 2008;102(5):577–83.
41. Chinevere TD, Cadarette BS, Goodman DA, Ely BR, Cheuvront SN, Sawka MN. Efficacy of body ventilation system for reducing strain in warm and hot climates. Eur J Appl Physiol 2008;103(3):307–14.
42. Hadid A, Yanovich R, Erlich T, Khomenok G, Moran DS. Effect of a personal ambient ventilation system on physiological strain during heat stress wearing a ballistic vest. Eur J Appl Physiol. 2008;104(2):311–9.
43. McLellan TM, Frim J, Bell DG. Efficacy of air and liquid cooling during light and heavy exercise while wearing NBC clothing. Aviat Space Environ Med. 1999;70(8):802–11.