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Work tolerance and subjective responses to wearing protective clothing and respirators during physical work

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This study examined work tolerance and subjective responses while performing two levels of work and wearing four types of protective ensembles. Nine males (mean age = 24·8 years, weight = 75·3 kg, $\dot{V}O_2\,max = 44{\cdot}6$ ml/kg min) each performed a series of eight experimental tests in random order, each lasting up to 180 min in duration. Work was performed on a motor-driven treadmill at a set walking speed and elevation which produced work intensities of either 30% or 60% of each subject's maximum aerobic capacity. Work/rest intervals were established based on anticipated SCBA refill requirements. Environmental temperature averaged 22·6°C and average relative humidity was 55%. The four protective ensembles were: a control ensemble consisting of light work clothing (CONTROL); light work clothing with an open circuit self-contained breathing apparatus (SCBA); firefighter's turnout gear with SCBA (FF); and chemical protective clothing with SCBA (CHEM). Test duration (tolerance time) was determined by physiological responses reaching a predetermined indicator of high stress or by a 180-min limit. Physiological and subjective measurements obtained every 2·5 min included: heart rate, skin temperature, rectal temperature, and subjective ratings of perceived exertion, thermal sensation, and perspiration.

The mean tolerance times were 155, 130, 26, and 73 min, respectively, for the CONTROL, SCBA, FF, and CHEM conditions during low intensity work; and 91, 23, 4, and 13 min, respectively, during high intensity work. Differences between ensemble and work intensity were significant. FF and CHEM heart rate responses did not reach a steady state, and rose rapidly compared to CONTROL and SCBA values. SCBA heart rates remained approximately 15 beats higher than the CONTROL ensemble during the tests. At the low work intensity, mean skin

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temperatures at the end of the test were 32·7, 33·1, 36·7, and 36·3°C, while mean core temperatures were 37·6, 37·9, 37·9, and 38·5°C, respectively.

The subjective data indicated that, in general, subjects were able to perceive relative degrees of physiologic strain under laboratory conditions. Wearing protective clothing and respirators results in significant and potentially dangerous thermoregulatory and cardiovascular stress to the wearer even at low work intensities in a neutral environment. Physiologically and subjectively, firefighter's turnout gear (the heaviest ensemble) produced the most stress, followed by the CHEM, SCBA, and CONTROL protective ensembles.

1. Introduction

Thousands of workers in emergency services and waste clean-up occupations must rely on personal protective equipment and respirators to insure their health and safety against hazardous materials. However, less obvious but perhaps more critical dangers may occur with the use of such equipment, one being the potential thermal hazard. At present there is inadequate knowledge and only minimal guidelines for workers using respirators and protective clothing (Ronk *et al.* 1984, NIOSH 1972). There exist abbreviated guidelines for heat stress exposure which consider such factors as acclimatization, clothing, age, obesity, and gender (Ramsey 1978), but there is little information available to serve as guidelines for workers wearing protective clothing and respirator ensembles while doing typical work/rest bouts at moderate and heavy work intensities. While studies have examined the physiological effects of protective clothing and respirator ensembles on work tolerance, only a very few have examined physiological effects in conjunction with subjective reactions.

Some studies have examined the physiological reactions of firefighter equipment (Duncan *et al.* 1979, Lemon and Hermiston 1977, Manning and Griggs, 1983, Myhre *et al.* 1979, Reischel and Stransky 1980, White and Hodous 1988) and chemical protective clothing (Atterbom and Mossman 1978, Mihal 1981, Raven *et al.* 1979, Shvartz and Benor 1972, Smolander *et al.* 1985, Tanaka *et al.* 1978, Thomas *et al.* 1976). These and other studies have indicated that the thermoregulatory and cardiorespiratory stresses involved in wearing such clothing are significant. Subjective responses to wearing respirators have also been given some consideration (NIOSH 1987, Morgan 1983a, 1983b, Morgan and Brown, 1981, Morgan and Raven 1985, Shimozaki *et al.* 1988, White *et al.* 1988). However, the literature lacks comparisons with appropriate control conditions, and relatively few tolerance studies have included an evaluation of the workers' subjective or emotional states during exposure to each experimental condition.

The purpose of the present study was to determine the effects of protective clothing and respirator ensembles worn during alternating work/rest exercise bouts of moderate ('low intensity') and heavy ('high intensity') physical work on work tolerance and worker subjective states.

2. Materials and method

2.1. *Subjects*

The nine male subjects in this investigation were healthy volunteers with training and prior experience concerning the use of respirators and protective clothing. These subjects were (mean $\pm$ SD) $24{\cdot}8 \pm 4{\cdot}5$ years of age, $177{\cdot}0 \pm 3{\cdot}8$ cm tall, $75{\cdot}3 \pm 8{\cdot}3$ kg, $19{\cdot}9 \pm 5{\cdot}3\%$ body fat, with an aerobic capacity of $44{\cdot}6 \pm 4{\cdot}9\ \mathrm{ml\,kg^{-1}\,min^{-1}}$ and a maximum heart rate of $191{\cdot}4 + 10{\cdot}8\ \mathrm{bp\,min^{-1}}$. Subjects signed an informed consent statement and were medically screened with a health history and physical examination before inclusion in the study. Maximal aerobic capacity was determined by a standard protocol (Balke and Ware 1959) with the subjects wearing shorts and sneakers.

2.2. *Design*

Each subject completed a series of eight exercise tests, in random order, in a 2×4 (workload $\times$ protective ensemble) design. Two workloads were chosen representing 30 and 60% of each subject's maximum aerobic capacity while not wearing any protective ensemble. Four clothing/respirator protective ensembles were tested: (1) CONTROL – a control ensemble consisting of light work clothing with a low resistance mask (NOTE: this mask was not designed to provide respiratory protection, but allowed collection of expired air for metabolic analysis); (2) SCBA – light work clothing with an open circuit self-contained breathing apparatus (SCBA); (3) FF – firefighter's turnout gear with a SCBA; (4) CHEM – chemical protective clothing with SCBA. Most tests were spaced one week apart, although in all cases a minimum of 48 h separated them.

2.3. *Task*

Work was performed on a Quinton motor-driven treadmill (Model Q55) at a set walking speed and elevation indicative of either 30 or 60% of maximum aerobic capacity for each individual while not wearing any protective ensemble. Average treadmill speeds and elevations were 5·3 kilometres per hour (3·3 mph), 0·67% grade for the low intensity work (estimated to be equivalent to 3·9 METS or 290 kcal/hr) and 5·6 kph (3·5 mph), 8·5% grade for the high intensity work (7·7 METS or 580 kcal/hr). The low work rate was chosen to be representative of that which could be continued for an entire workshift without protective clothing (Astrand and Rodahl 1977, Harber *et al.* 1984), while the high work rate was representative of that which might be performed during an underground mine escape manoeuvre and in firefighting tasks (Kamon *et al.* 1983, Lemon and Hermiston 1977). The environmental temperature averaged 22·6°C dry bulb, 17°C wet bulb (55% relative humidity). Since popular open circuit SCBAs require replacement after about 25 min during moderate work and 10 min during heavy work, the periods of work and standing rest were: 25 min work/5 min rest for the low intensity test and 10 min work/5 min rest for the high intensity tests. As required by the NIOSH's Human Subject's Review Board, tests progressed for safety reasons at the prescribed intensity for up to or until one of the following criteria was met: (1) 90% of maximum heart rate (Dassler 1966); (2) rectal temperature of 39·0°C; (3) skin temperature equalling or exceeding rectal temperature (Pandolf and Goldman 1978); (4) objective signs of severe discomfort or fatigue; or (5) subject reporting an inability to continue. The duration of the test was recorded as the tolerance time.

2.4. *Protective ensembles*

Four protective ensembles were selected for study. The CONTROL ensemble consisted of Mine Safety Appliance one-piece coveralls (Chemklos II) made of a modacrylic material which was lightweight, flame resistant, and had good air permeability, Servus industrial neoprene boots, and a light-weight (0·08 kg) low resistance mask (Vacumed Speak-Easy II). This control mask was not designed to provide respiratory protection, but was used to permit the measurement of ventilatory variables. The resistance offered by this mask-valve combination was less than 5 mm of water for both inspiratory and expiratory resistance at 100 l/min flow, and mask physical dead space was 172 ml. The total weight of the CONTROL ensemble was 3·8 kg.

The SCBA ensemble consisted of the same clothing as the CONTROL ensemble, with the addition of a Mine Safety Appliances (MSA Model 401) open-circuit, pressure-demand self-contained breathing apparatus (SCBA). This unit was equipped with a full facepiece and a 30-minute composite compressed air cylinder. In order to avoid repeatedly changing air cylinders, breathing air was supplied to the subjects through the SCBA regulator which was attached to a large (6550L) compressed air cylinder. The measurement of ventilatory response was made possible by adding an extension to the exhalation port so that a 34 mm diameter hose could be attached to collect expired air. The diaphragm and other features of the mask were not altered. The physical dead space of the SCBA mask was 757 ml. Total weight of the SCBA ensemble wad 15·6 kg, with the SCBA component (mask, harness, and air cylinder) weighing 11·6 kg.

The FF ensemble consisted of the Chemklos II coveralls and SCBA with the addition of the following: Janesville NFPA turnout coat and pants (with a 7·5 oz quilted nomex liner and neorpene coated poly/cotton vapor barrier), Ziamatic nomex hood, Firecraft gloves, Cairns 660C metro helmet, Servus bunker boots, and suspenders. Total weight of the FF ensemble was 23·1 kg.

The CHEM ensemble consisted of the Chemklos II coveralls and SCBA with the addition of a three piece Edmont chemical protective suit made of polyurethane on nylon (Wet-Wear 900 including coveralls, jacket, and hood), Edmont nitrile gloves, and Servus neoprene industrial boots. The cuffs of both the pants and jacket were taped and the hood drawn, as is the common practice in actual use. Total weight of the CHEM ensemble was 16·7 kg.

2.5. *Dependent measures*

The physiological and subjective measurements were: tolerance time, heart rate, skin temperature, rectal temperature, ventilation volume, tidal volume, respiratory rate, sweat rate, and subjective ratings (of perceived exertion, thermal sensation, and perspiration). Ventilatory responses, sweat rate and additional physiological data have been reported elsewhere (White and Hodous 1987).

Electrocardiographic signals were monitored and recorded on a Physiocontrol Life-Pak 6. Thermoregulatory measurements were made at 2·5 min intervals with a Yellow Springs Instruments tele-thermometer utilizing series 400 thermisters. These thermisters were secured to the skin surface using surgical tape. Core temperature was measured using a flexible vinyl-covered thermistor inserted 10 cm in the rectum. Mean skin temperature was calculated as the mean weighted temperature of six body sites using the equation of Teichner (1958).

Five subjective measurements were recorded every 2·5 min. Differentiated ratings of perceived exertion (RPE) (Robertson *et al.* 1979) were obtained based on the 15-point Borg scale (Borg 1973). Subjects were asked to indicate numerical ratings most closely matching how they felt in their legs, chest, and overall. Thus, RPE were obtained for both peripheral ('Legs') and central ('Chest') sensations, as well as the combined ('Overall') rating. Ratings of thermal sensation were reported on a 7-point scale according to Vokac *et al.* (1976): (1) very cold, (2) cold, (3) slightly cold, (4) neutral, (5) slightly warm (6), warm, and (7) very warm. Ratings of perspiration were reported on a 6-point scale: (1) skin clammy; feels moist to touch, (2) skin damp; perspiration just visible, (3) skin wet, sweat covering the surface, drop formation, (4) parts of clothing wet, (5) most of clothing wet, and (6) all of clothing saturated.

2.6. *Treatment of data*

Data were analysed using a 2 × 4 (Work Intensity × Ensemble) repeated measures analysis of variance (ANOVA) design. Most statistical analyses involved end of test ('peak') data. *Post hoc* tests were conducted using the Tukey Wholly Significant Difference (WSD) procedure (Hendrick and Vercruyssen, 1989). Pearson correlation coefficients were computed between various objective and subjective data. A 0·05 level of significance was used for all statistical contrasts, employing a statistical package called ANOVR: Analysis of Variance for Repeated Measures (Games 1981, Games *et al.* 1980).

3. Results

3.1. *Tolerance times*

Mean tolerance times during low intensity work for the CONTROL, SCBA, FF, and CHEM ensembles were 164 (±17), 129 (±33), 25 (±9), and 72 (±18) min, respectively (table 1) all significantly different from each other ($p<0·05$). The high intensity mean tolerance times were 91 (±45), 23 (±24), 4 (±1), and 13 (±13) min, respectively, with the CONTROL value significantly different from the other three ($p<0·05$). Overall, each ensemble was significantly different from the others ($p<0·0005$). Tolerance times were significantly greater for low intensity than for high intensity work ($p<0·0005$). Also significant was the ensemble-work interaction ($p=0·008$); subjects worked significantly longer at low intensity than high intensity work in all cases except for the FF where the difference was not significant.

3.2. *Heart rate response*

Mean peak work heart rates (table 1) during low intensity work for the CONTROL, SCBA, FF, and CHEM ensembles were 119 (+13), 136 (+23), 172 (+9), and 166 (+9) bpmin, respectively. Mean peak heart rates during high intensity work were 161 (+19), 169 (+11), 169 (+9), and 169 (+12) bpmin, respectively.

Heart rates for the CONTROL and SCBA ensembles rose very slowly over time, and the heart rate for the SCBA ensemble was approximately 15 bpmin higher than the CONTROL at any given time. Heart rate during the FF and CHEM tests rose at a much faster rate, and did not approach steady-state levels.

Table 1. Partial summary of data (mean values) ($n=9$).

Work intensity	[Low intensity]				[High intensity]			
Variable	Control	SCBA	FF	Chem	Control	SCBA	FF	Chem
Tolerance time (min)	164	129	25	72	91	23	4	13
Peak heart rate (bp min)	119	136	172	166	161	169	169	169
Peak RPE	14·0	16·6	16·4	16·4	14·3	13·1	13·0	13·8
Peak rectal temp (°C)	37·6	37·9	37·9	38·5	37·5	37·8	38·1	38·5
Peak skin temp (°C)	32·7	33·1	36·7	36·3	33·3	33·1	34·2	34·2

3.3. *Temperature responses*

Peak work skin temperatures during low intensity work were 32·7 (+1·2), 33·1 (+1·2), 36·7 (+0·6), and 36·3 (+0·6)°C for the CONTROL, SCBA, FF and CHEM ensembles, respectively. Respective high intensity values were 33·3 (+1·0), 33·1 (+0·8), 34·2 (+0·5), and 34·2 (+1·2)°C. The FF and CHEM ensembles produced significantly higher skin temperatures than those for CONTROL and SCBA, and FF was higher than CHEM ($p<0{\cdot}05$). Skin temperature was significantly higher for low intensity work compared to high intensity work. There was also a significant interaction ($p<0{\cdot}0005$), with a disproportionally higher increase in skin temperature with the CHEM and FF ensembles during low intensity work.

Skin temperature increases over time were significantly different for the four ensembles. During low intensity work, maximum skin temperatures were reached within the first hour of exercise with CONTROL and SCBA and then tended to decline. In contrast, neither FF or CHEM skin temperatures appeared to approach a steady state during the (shorter) test duration. The mean increases in skin temperature over the first 20 min of low intensity exercise for the CONTROL, SCBA, FF, and CHEM ensembles were 0·6, 1·4, 2·0, and 2·7°C, respectively. High intensity work data appeared to show a similar pattern, but were not analysed due to the very short duration of some tests.

Peak work rectal temperatures during low intensity work were 37·6 (+0·5), 37·9 (+0·5), 37·9 (+0·5), and 38·5 (+0·5)°C for the CONTROL, SCBA, FF and CHEM ensembles, respectively. Respective high intensity values were 37·5 (+0·3), 37·8 (+0·5), 38·1 (+0·5), and 38·5 (+0·4)°C. The calculated temperature rises per hour were 0·23, 0·41, 1·85, and 1·07°C for the four conditions during low intensity work. Rectal temperatures were significantly ($p<0{\cdot}05$) higher for the CHEM than the CONTROL for both low intensity and high intensity work. During low intensity work, CHEM caused significantly ($p<0{\cdot}05$) higher values than the SCBA. The only ensemble to show significant ($p<0{\cdot}05$) peak work difference between low intensity and high intensity was the FF where high intensity work caused a higher core temperature.

3.4. *Subjective responses*

At peak work, mean overall ratings of perceived exertion (RPE) were 14·0 (2·4), 16·6 (2·4), 16·4 (2·3), and 16·4 (3·0) during low intensity work for the CONTROL, SCBA, FF, and CHEM ensembles, respectively (table 1). Corresponding high intensity values were 14·3 (3·7), 13·1 (2·8), 13·0 (2·1), and 13·8 (1·2). In each case there were no significant differences among the ensembles. Low intensity work RPE were higher than those at high intensity ($p<0{\cdot}005$), although only the three ensembles using a SCBA had significant differences between the two work intensities.

Examination of the leg and chest subcomponents of RPE revealed similar findings. At peak work, mean ratings of leg exertion were greater for low intensity than high intensity work (Mean = 15·4, 11·6; $p<0{\cdot}0005$) with no other contrasts showing significant differences. Ratings of exertion in the chest also showed higher values for low intensity than high intensity work (Mean = 13·8, 9·8; $p<0{\cdot}0005$), with no other differences being significant.

Mean peak ratings of thermal sensation for low intensity work were 6·1 (0·8), 6·7 (0·5), 6·9 (0·3), and 6·9 (0·3), for CONTROL, SCBA, FF, and CHEM respectively. Mean values for high intensity work were 6·2 (1·0), 5·8 (0·8), 5·9 (0·9), and 6·4 (0·7), respectively. CHEM and FF ratings were significantly higher than CONTROL, but not significantly different from each other or from SCBA. Mean peak work ratings of thermal sensation were greater for low intensity than high intensity work (Means = 6·3, 5·8; $p < 0.003$).

Peak work ratings of perspiration averaged over work intensity were 3·8 (1·5), 5·1 (1·1), 5·3 (0·7), and 5·7 (0·5) for the CONTROL, SCBA, FF, and CHEM, respectively. Respective high intensity values were 4·3 (1·4), 3·1 (1·5), 2·8 (1·6), and 3·6 (1·2). Ratings were higher for FF and CHEM than CONTROL, with no significant difference between the former two. SCBA ratings did not differ from the others. Ratings were significantly higher during low intensity than high intensity work (mean ratings = 5·0 vs 4·6, $p < 0.05$).

3.5. *Correlations between objective and subjective data*
Using the data from the end of the first (25 min) work period during low intensity work, the following significant $p < 0.05$) correlations were observed: overall RPE and heart rate ($r = 0.58$); thermal sensation and skin temperature ($r = 0.66$); thermal sensation and rectal temperature ($r = 0.52$); perspiration rating and skin temperature ($r = 0.62$); and perspiration rating and rectal temperature ($r = 0.58$). Correlation coefficients using peak data were lower (for example, overall RPE and peak heart rate $r = 0.38$), and most were not statistically significant.

4. Discussion

4.1. *Objective measures*
At low intensity work, the reason for stopping the test differed with each ensemble. When wearing the CONTROL ensemble, five subjects completed the 180-min test, and the remaining four subjects stopped because of fatigue or sore feet. When wearing the SCBA ensemble, subjects stopped because of fatigue or sore feet (7/9) and elevated rectal temperature (1/9). One subject completed the 180-min test. In the FF ensemble, all subjects stopped because of the heart rate criteria. Reasons for stopping the CHEM suit testing were high heart rate (4/9), high rectal temperature (3/9), and fatigue or sore feet (2/9). Test termination during high intensity work was due to attainment of the heart rate criteria (90% of HRmax) for 32 of 36 tests. The four remaining tests (all CONTROL) continued the entire 180 min.

The physiological data from this study indicate that the most stressful clothing-respirator protective ensemble was the firefighter's (FF), followed in order by the CHEM, SCBA, and CONTROL. The FF produced the lowest tolerance times (table 1) and in general the highest rates of increase in heart rate and skin and rectal temperature. This can be attributed to the heavy weight of the FF (at least 6 kg heavier than all other ensembles) and its heat insulating characteristics (or clo value).

The CHEM ensemble was more stressful than either SCBA or CONTROL, as reflected by its lower tolerance times and higher skin and rectal temperature. In fact, peak work rectal temperatures were (non-significantly) higher than those for FF. However, it is important to emphasize that these represent end of test values. Peak work data thus represent both the rate of change of a parameter over time and the duration of exercise. Furthermore, since the end of test was determined (in most cases) by heart rate or rectal temperature criteria, it is not surprising that the different ensembles would have similar peak work results. While only 1·1 kg heavier than the SCBA, the CHEM created substantial additional heat stress compared to SCBA due to its vapour barrier characteristics.

The SCBA ensemble has significantly lower tolerance times and higher heart rates than CONTROL. However, temperature differences between the two were minimal (table 1). In contrast to FF and CHEM, both SCBA and CONTROL appeared to reach steady states for skin and rectal temperatures during low intensity exercise. The major difference between SCBA and CONTROL was weight (8 kg), although other respirator stresses (such as added resistance and dead space) can reduce exercise capability (Cerretelli *et al.* 1969, Hermanson *et al.* 1972, Louhevaara 1984).

The high intensity work data, in general, showed fewer differences among the ensembles than did the low intensity data. This is not unexpected since as one approaches maximum workload, the time of exercise approaches the floor of zero, and the effects of competing stresses become obscured. The short high intensity exercise time with FF also explains the apparently paradoxical higher rectal and skin temperatures (as well as subjective ratings) at peak work with this ensemble during the lower intensity work. At the high work intensity, the rapidly responding heart rate reached the end of test criteria very quickly (after an average of 3·1 min of exercise) before body temperature could respond.

A major finding of this study is the severe stress created by wearing FF or CHEM ensembles. Our data indicates that trained, young, healthy men reach near-maximal stress levels after 72 min with CHEM and 25 min with FF while doing low intensity work in a neutral environment. With high intensity work, the corresponding times are approximately 12, and 3 min. Heart rates were at or near the 90% of maximum stopping criteria in all cases, although 5 subjects were stopped for other reasons (3 for elevated rectal temperature, 2 for fatigue or sore feet). In addition, neither rectal nor skin temperature appeared to reach steady state values during either low or high intensity work with the FF and CHEM ensembles. These findings extend that of other investigators (Atterbom and Mossman 1978, Duncan *et al.* 1979, Smolander *et al.* 1984, 1985, Tanaka *et al.* 1978) to situations involving low intensity work in neutral environments.

4.2. *Subjective measures*

The subjective data accurately mapped the physiological strain and indicated that the responses were influenced primarily by the type of ensemble and duration (not intensity) of the work. These data support and extend findings from the literature, which indicate that subjects are able to perceive their level of exertion accurately under laboratory conditions (Kamon *et al.* 1974, Mahevic 1981, Morgan and Raven 1985, Pandolf 1978, Shimozaki *et al.* 1988). A low but significant correlation was found between heart rate and overall RPE after 25 min of low intensity work ($r = 0{\cdot}58$). Peak work overall RPE were not different among the four ensembles, but as noted above these values represent the duration as well as the level of stress. Even subjects using the least stressful ensemble (CONTROL) were exhibiting high levels of stress by the end of the test, as evidenced by the fact that half of these tests were prematurely terminated due to fatigue/sore feet or heart rate criteria.

The initial increases in overall RPE suggested that subjective stress was higher for FF and CHEM compared to SCBA, and least for CONTROL. For example, after 2·5 min at the low intensity work, subjects perceived the CONTROL ensemble as 'very, very light', the SCBA as slightly more stressful, the CHEM as 'very light', and the FF as slightly more stressful. After 25 min the CONTROL ensemble was still perceived as 'light', while the CHEM was perceived as 'somewhat hard' and the FF as 'hard'. At peak work, subjects reported higher overall, leg and chest RPE at low intensity compared to high intensity work. As might be expected, subjects also reported higher peak work chest RPE for the three SCBA-containing ensembles compared to CONTROL.

Both subjective ratings of thermal strain (thermal sensation and perspiration) followed a similar pattern in distinguishing between high and low intensity work, and in reporting higher strain with FF and CHEM compared to CONTROL, but not SCBA. Ratings over time again suggested that subjective stress paralleled that of the objective data: order of thermal strain, heaviest to lightest was FF, CHEM, SCBA, and CONTROL. For example, rating of thermal sensation for the CONTROL and SCBA ensembles were initially rated 'neutral' while FF and CHEM were viewed as 'slightly warm'.

Ratings of perspiration over time followed a similar pattern to that of thermal sensation with the average rating initially being low (or 'just visible' range) for all tests, then increasing as the test progressed. After 25 min at the low intensity the rating was still low for the CONTROL ensemble, but increased to 'parts of the clothing wet' for the SCBA and CHEM, and 'most of the clothing wet' for the FF. The mean time at which the rating 'most of the clothing wet' was obtained was 87·5 min for the SCBA ensemble, 20 min for the FF, and 37·5 min for the CHEM. This rating was not achieved in the CONTROL ensemble, indicating a perceived lower degree of sweating.

By the end of the test with FF and CHEM, there were many maximal values recorded for thermal sensation and perspiration. This ceiling effect using the 7 and 6 point scales, respectively, probably caused underestimation of the subjective ability to distinguish thermal strain. This may be true particularly for thermal sensation where the highest possible rating was only 'very warm'. Despite this problem, when data from the end of the first work period were analysed, significant correlations between skin and rectal temperatures and the subjective ratings were observed. These relationships remained low in terms of predictability, however.

In conclusion, these data indicate that wearing a protective clothing and respirator ensemble is potentially dangerous since it can pose significant thermoregulatory and cardiovascular stress to the wearer, even at low to moderate work intensities in a neutral environment. The subjective data paralleled the objectively determined strain, and may in some cases serve as a useful indicator of safe tolerance limits and contribute to the design of protective ensembles (see also Shimozaki *et al.* 1988). The discomfort experienced may also have important effects on worker safety and efficiency. The firefighter's ensemble (the heaviest of the four ensembles studied) provided the most physiological stress, followed by the CHEM, SCBA, and CONTROL protective ensembles. Although protective ensembles are essential to protect workers in many settings, the adverse effects inherent in their use should be recognized.

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Dans cet article on étudie la tolérance au travail et les réponses subjectives pendant l'accomplissement d'un travail à deux niveaux tout en portant quatre types différents d'équipements de protection. Chacun des 9 hommes (moyennes âge = 24,8 ans; poids = 75,3 kg; $\dot{V}O_2$ max = 44,6 ml/kg. mn) a effectué un ensemble de 8 épreuves, en ordre aléatoire, pendant 180 mn chacune. Le travail a été effectué sur un tapis roulant avec une vitesse de marche et une pente destinées à produire des puissances de travail équivalentes à 30% ou à 60% de la capacité aérobie maximum individuelle, Les intervalles travail-repos ont été fixés selon les nécessités de remplissage de l'appareil respiratoire autonome (SCBA). L'ambiance thermique était de 22,6°C et l'humidité relative moyenne de 55%. Les quatre équipements de protection étaient: un ensemble de référene consistant en un vêtement léger (CONTROL); un ensemble léger plus un appareil respiratoire autonome à circuit ouvert (SCBA; une tenue de pompier avec SCBA (FF) et un vêtement de protection anti-chimique avec SCBA (CHEM). On a déterminé le temps de tolérance à partir de la réponse physiologique atteignant une valeur prédéterminée de contrainte intense ou atteignant la limite de 180 mn. Les relevés physiologiques et subjectifs effectués toutes les 2,5 mn comportaient la fréquence cardiaque, la température cutanée, la température rectale, ainsi que les cotations subjectives de l'effort perçu de la sensation thermique et de la transpiration, Les temps moyens de tolérance étaient de 155, 130, 26 et 73 mn pour, respectivement, CONTROL, SCBA, FF et CHEM, au cours du travail à faible intensité; ils étaient de 91, 23, 4 et 13 mn, respectivement, au cours du travail à forte intensité. Les différences entre les équipements et les différences entre les intensités de travail étaient significatives. Les fréquences cardiques pour FF et CHEM n'ont pas atteint l'état stable et ont augmenté rapidement comparées à celles de CONTROL et SCBA. Les fréquences cardiaques de SCBA sont restées, durant le test, à environ 15 battements au-dessus de celles de CONTROL. Pour la

faible intensité de travail, les températures cutanées moyennes, à la fin du test, étaient respectivement de 32,7°, 33,1°, 36,7° et 36,3°, alors que les températures centrales étaient respectivement de 37,6°, 37,9°, 37,9° et 38,5°C. Les donne)es subjectives ont montré qu'en général, les sujets étaient capables de percevoir les degrés relatifs de la containte physiologique, en situation de laboratoire. Le port d'un vêtement de protection et d'un respirateur entraîne, chez le porteur, une contrainte thermorégulatrice et cardiovasculaire potentillement dangereuse, même à des intensités de travail faibles dans un environnement neutre. Physiologiquement et subjectivement, la tenue de feu des pompiers (l'ensemble le plus lourd) entraîne la contrainte la plus élevée, suivie de CHEM, SCBA et CONTROL.

In dieser Untersuchung wurden die Arbeitstoleranz und die subjektiven Reaktionen bei zwei verschiedenen Arbeitsschwierigkeiten und vier Typen von Schutzkleidung ermittelt. Neun Männer (Durchschnittsalter = 24,8 Jahre, Gewicht = 75,3 kg, $\dot{V}O_2$ max = 44,6 ml/kg min) nahmen an einer Serie von acht Versuchen in zufälliger Reihenfolge teil, die jeweils bis zu 180 min dauerten. Die Arbeit wurde auf einem motorgetriebenen Laufband verrichtet, wobei Gehgeschwindigkeit und Steigung so eingestellt waren, daß eine Arbeitsintensität von 30% oder 60% der maximalen aeroben Kapazität des jeweiligen Probanden erreicht wurde. Arbeits-/Pausenintervalle wurden auf der Basis der vorausberechneten Nachfüllzeiten der Personen-Atemgeräte (SCBA) gewählt. Die Umgebungstemperatur lag bei durchschnittlich 22,6°C und die relative Feuchtigkeit bei 55%. Die vier Schutzkleidungen waren: Eine Kontroll-Bekleidung, die sich aus leichter Arbeitskleidung zusammensetzte (CONTROL); leichte Arbeitskleidung und SCBA mit offenem Kreislauf (SCBA); Feuerwehrmann-Schutzanzug mit SCBA (FF); und chemische Schutzkleidung mit SCBA (CHEM). Die Testdauer (Toleranzzeit) wurde durch die physiologischen Reaktionen bestimmt, die einen festgelegten Indikator hoher Belastung oder den 180-min-Grenzwert erreichten. Physiologische und subjektive Messungen wurden alle 2,5 min von den folgenden Größen durchgeführt: Herzschlagfrequenz, Hauttemperatur, Rektaltemperatur sowie subjektive Einstufungen der empfundenen Anstrengung, des thermischen Empfindens und des Schwitzens.

Die mittleren Toleranzzeiten betrugen 155, 130, 26 und 73 min für die Bekleidungen CONTROL, SCBA, FF und CHEM bei niedriger Arbeitsintensität, bzw. 91, 23, 4 und 13 min bei hoher Arbeitsintensität. Die Unterschiede zwischen Bekleidungen und Arbeitsintensität waren signifikant. Bei FF und CHEM erreichte die Herzschlagfrequenz kein steady state und stieg im Vergleich zu CONTROL und SCBA schnell an. Die SCBA-Herzschlagfrequenz lag während der Versuche näherungsweise 15 Schläge höher als bei der CONTROL-Bekleidung. Bei der niedrigen Arbeitsintensität betrug die mittlere Hauttemperatur am Versuchsende 32,7, 33,1, 36,7 und 36,3°C, bzw. die mittlere Körperkerntemperatur 37,6, 37,9, 37,9 und 38,5°C.

Die subjektiven Daten zeigen, daß die Probanden im allgemeinen in der Lage waren, relative Grade der physiologischen Beanspruchung unter Laborbedingugngen wahrzunehmen. Das Tragen von Schutzkleidung und Atemschutzmasken führt selbst bei niedrigen Arbeitsintensitäten in einer neutralen Umgebung zu signifikanten und möglicherweise gefährlichen thermoregulatorischen und kreislaufmaßigen Belastungen. Physiologisch und subjektiv erwies sich der Feuerwehrmann-Schutzanzug (die schwerste Montur) als am meisten belastend, gefolgt von den CHEM, SCBA und CONTROL Schutzbekleidungen.

本研究は２つの作業レベルを実施し，４種類の防護服を着用しているときの作業許容度と主観的反応を調査した。９名の成人男性（平均年令 = 24.8歳，体重 = 75.3kg，VO_2max = 44.6ml／kg・min）が各々最大180分の実験作業を８種類無作為順に実施した。作業は電動トレッドミルで予め設定した歩行測度と高さで実施した。作業強度は各被験者の最大有酸素的能力の30%または60%に相当した。作業／休憩間隔は予測 SCBA 補充必要量に基づいて設定された。環境温度は平均22.6℃，平均相対湿度は55%であった。４種類の防護服は軽作業服より成る対照衣服（CONTROL），軽作業服と開回路自給呼吸装置（SCBA），消防士服と SCBA（FF），化学防護服と SCBA（CHEM）であった。試験時間（許容時間）は高ストレスの予設定指標に達する生理的反応または180分の限度によって求められる。2.5分毎に得た生理的，主観的測定値は心拍数，皮膚温，直腸温および知覚努力，温度感覚，発汗の主観的評点であった。

平均許容時間はそれぞれ CONTROL，SCBA，FF，CHECM で低強度作業中に155，130，26，73分，高強度作業中に91，23，４，13分であった。防護服と作業強度の間の差は有意であった。

FF と CHEM の心拍数反応は定常状態に達せず，CONTROL と SCBA の値に比較して急速に増大した。SCBA の心拍数は試験中に CONTROL の場合よりも約15拍高かった。低作業強度では試験終了時の平均皮膚温はそれぞれ32.7，33.1，36.7，36.3℃で，平均核心温度はそれぞれ 37.6，37.9，37.9，38.5℃であった。

主観的データは一般的に被験者は実験室条件で生理的ストレインの相対的程度を知覚できることを示した。防護服と呼吸装置を着用すると，中性的環境で作業強度が低くても着用者にとって体温調節と心臓血管のストレスになることがある。生理的，主観的には，消防士服（最も重い衣服）がストレスが最高で，その後は CHEM，SCBA，CONTROL の順になった。