Cardiovascular and Metabolic Responses During Maximal Incremental Exercise in Firefighter's Personal Protective Equipment

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ABSTRACT

Personal protective equipment (PPE) is worn by firefighters to protect them from work related hazards. Work in PPE increases the metabolic cost of a given work load. Due to added weight, restrictive properties and the circulatory effects of full encapsulation, working in PPE may affect the relationship between heart rate (HR) and oxygen uptake (VO_2) as expressed as the chronotropic index (CI) (slope of the regression line for HR vs. VO_2); however, the extent to which the physiological stress imposed by PPE impacts the CI is unknown. **PURPOSE:** To investigate the effects of PPE on cardiovascular and metabolic responses during incremental exercise and to determine if PPE affects the CI. **METHODS:** HR and VO_2 were measured in 10 male participants (age, 21 ± 2 yr; height, 178 ± 8 cm; weight, 76.2 ± 3.1 kg; VO_2max, 51.9 ± 5.0 ml·kg^{-1}·min^{-1}) when performing graded exercise tests across 3 conditions: control (CON; wearing athletic attire), wearing PPE (PPE) and weighted vest (WV) (weight equal to PPE). **RESULTS:** Time to exhaustion was significantly different across all 3 conditions (CON, 866 ± 121 s; PPE, 582 ± 92 s; WV, 671 ± 105 s; ($p < 0.01$). Over time, submaximal VO_2 and HR were significantly lower in the CON condition ($p < 0.01$) compared to the PPE and WV conditions, which were similar to each other. Peak HR was significantly higher in the CON (191 ± 11 b·min^{-1}) condition compared to the WV (187 ± 10 b·min^{-1}) and PPE (183 ± 9 b·min^{-1}) conditions ($p < 0.01$). There was a tendency for peak HR in the PPE condition to be lower than the WV condition ($p = 0.07$). VO_2max was significantly different among all 3 conditions ($p < 0.01$). VO_2max was 9.4% higher in the CON (4.0 ± 0.5 l·min^{-1}) condition compared to the PPE (3.6 ± 0.4 l·min^{-1}) condition ($p < 0.01$). VO_2max was 4.8% higher in the CON condition compared to the WV (3.8 ± 0.4 l·min^{-1}) condition; however, this was not statistically significant ($p = 0.07$). The CI (CON, 31.8 ± 4.7; PPE, 31.7 ± 5.7; WV, 32.6 ± 4.9) and y-intercept (CON, 71.9 ± 21.6; PPE, 74.6 ± 19.8; WV, 72.0 ± 25.1) were similar across all conditions. **CONCLUSION:** The present study has shown that increasing the physiological strain with PPE or equivalent weight increases HR and VO_2; however, the tight linear relationship between HR and VO_2 (CI) remains unaffected.

INTRODUCTION

Personal protective equipment (PPE) is worn by firefighters to protect them from a variety of work related hazards. Despite the many benefits, there is an increased physiological burden and performance impairment imposed by the use of PPE (1). Firefighting PPE contributes to cardiovascular strain in firefighters by increasing energy expenditure and reducing heat dissipation (2). Additionally, PPE increases the metabolic cost of work by resisting movement and increasing the total mass that the individual must transport (3).

During incremental exercise a strong linear relationship has been reported between oxygen uptake (VO_2) and heart rate (HR) (4). The slope of this relationship has been expressed as the chronotropic index (CI) (5). The extent to which stress imposed by PPE affects the CI has not been investigated.

PURPOSE

To investigate and isolate the effects of PPE's weight and insulative properties on cardiovascular and metabolic responses during incremental exercise to volitional exhaustion and to determine if PPE affects the relationship between HR and VO_2 when expressed by the CI.

METHODS

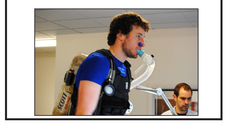
Design; Repeated measures; 3 conditions

Control **(CON) -**
First trial, normal athletic attire

Randomized

PPE+SCBA (14.5 ± 0.1 kg) -
Turnout pants, coat, flashover hood, gloves, self-contained breathing apparatus (SCBA)

Weighted Vest (**WV**) +SCBA (14.5 ± 0.1 kg) -
Weighted-vest and SCBA over athletic attire



Protocol

- Graded Exercise Test
- 3-min warm-up
- 5.9 km·hr^{-1}
- Grade increase 1.5%·min^{-1}

Participants

- Ten healthy, fit men (mean ± *SD*) age 21 ± 2 yrs, body mass 76.2 ± 3.1 kg, height 178 ± 8 cm.

Measurements

- Oxygen uptake (VO_2), respiratory exchange ratio (RER); (TrueMax 2400 Metabolic Measurement System, Parvo Medics, Sandy, UT).
- Heart rate (HR); (Polar FS1, Polar Electro, Lake Success, NY).

Calculations

- For each trial, HR was regressed on VO_2 using linear regression and the slope of the regression line was identified as the chronotropic index (CI). The mean CI for the ten trials within each condition is presented along with the y-intercept.
- To derive a single CI for each condition, the regression analyses were performed by pooling HR and VO_2 data from all 10 trials within the condition.

Statistical Analysis

- A two-factor ANOVA determined differences among conditions. A one-way ANOVA determined differences among conditions for the CI and y-intercept ($p < 0.05$).

RESULTS

- Time to fatigue was significantly different among conditions (Table 1; $p < 0.01$).
- Submaximal HR in the CON condition was significantly lower compared to PPE and WV (Figure-1 A; $p < 0.01$). Submaximal VO_2 was significantly different among conditions at all times (Figure-1 B; $p < 0.01$).
- Maximal HR was significantly different between PPE and CON and between WV and CON ($p < 0.01$). Maximal VO_2 was significantly different between PPE and CON ($p < 0.01$).
- No differences in CI or y-intercept were found among conditions (Table 1). However, a moderate linear relationship was observed within each condition (Figure 2)

Table 1: Performance variables during maximal exercise test (mean ± *SD*)

	CON	WV	PPE
Exercise time (sec)	866 ± 121	671 ± 105#*	582 ± 92#
VO_2 peak (l·min^{-1})	4.0 ± 0.5	3.8 ± 0.4	3.6 ± 0.4#
Peak HR (b·min^{-1})	191 ± 11	187 ± 10#	183 ± 9#
Peak RER	1.2 ± 0.1	1.2 ± 0.0	1.2 ± 0.1
CI (b·l^{-1})	31.8 ± 4.7	32.6 ± 4.9	31.7 ± 5.7
y-intercept	71.9 ± 21.6	72.0 ± 19.8	74.6 ± 25.1

VO_2, oxygen consumption; HR, heart rate; RER, respiratory exchange ratio; CI, chronotropic index; CON, control; WV, weighted vest; PPE, personal protective ensemble
# $p < 0.01$ compared to CON condition; * $p < 0.01$ compared to PPE condition

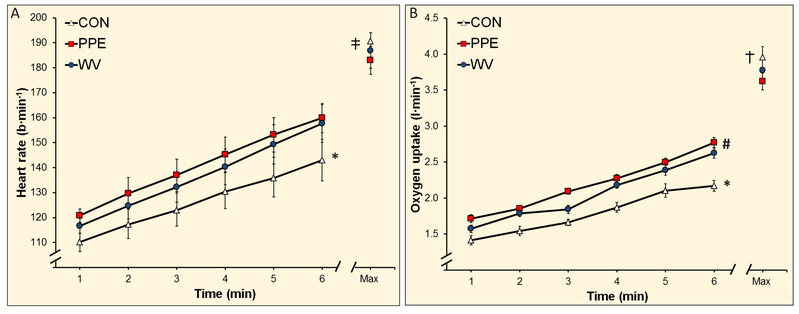


Figure 1: Average HR (A) and VO_2 (B) responses during initial 6 min of exercise and at max. Submaximal:*CON < WV, PPE; #WV < PPE; Maximal: ‡CON > WV, PPE; †CON > PPE; $p < 0.05$

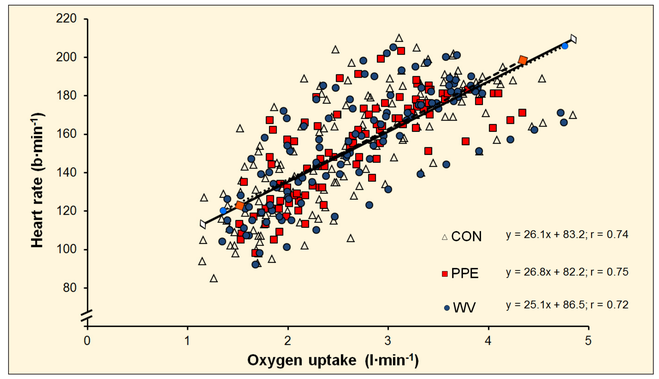


Figure 2: Relationship between HR and VO_2 during incremental exercise with linear regression analyses performed from pooled data for each condition.

DISCUSSION/CONCLUSIONS

- It has long been known that there is a strong linear relationship between HR and VO_2 (4). Our research sought to examine if the added weight and insulative properties of PPE would impact the slope of this relationship.
- We found reductions in time to fatigue in the PPE and WV conditions compared to CON which reinforces the fact that added weight and restriction of movement significantly reduces the capacity of individuals to perform work. Consistent with previous research, we found that for a given workload, both HR and VO_2 responses were greater when additional weight was worn (6).
- CI and y-intercepts were not significantly different among conditions as HR responses for a given increase in VO_2 were similar despite different levels of physiological strain imposed by PPE and WV compared to the CON condition.
- The present study showed that although imposing physiological strain on an individual with additional weight and encapsulation significantly increases HR and VO_2, the slope of the relationship between HR and VO_2, when expressed as the CI remains unaffected during an incremental test to exhaustion.

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