# Impact of Combat Equipment on Respiratory Muscle Power during Load Carriage Performance


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## Background

Respiratory Muscle Power (RMP or Power of Breathing (Pb); i.e., work measured in Joules per unit of time ($J\cdot min^{-1}$)) is a relatively underappreciated respiratory physiological measurement with potential implications as a limiting factor to human performance during severe-intensity sustained activities.[1] The metaboreflex response, explaining the relationship between the respiratory system's response to severe-intensity exercise, limits endurance performance via sympathetic vasoconstriction of blood flow (reduction and redistribution) to the working muscle.[2,3] The tactical athlete is exposed to conditions that impose greater risks to performance reduction due to compounding effects of personal protective equipment (PPE), such as ground-based combat equipment configurations (CEC), that could alter breathing mechanics due to increased chest wall restriction and subsequently change RMP demand.[4,5] The purpose of this study was to investigate the impact of increased scaling-weight of CECs on RMP and breathing mechanics during standardized tactical movements (i.e., tactical road march (TRM), approach march (AP)) with operational combat loads (i.e., fighting load (FL), approach load (AL)) among military personnel.[6,7] The outcome of increased scaling-weight of CECs resulted in greater RMP demand, cumulatively, during endurance load carriage performance. Additionally, breathing mechanics metrics (i.e., breath frequency, esophageal pressures), had a concomitant increase in minute ventilation associated with the increased RMP demand for each progressively greater CEC, along with a strong-positive relationship between PbPV and combat load.

**Keywords:** respiratory muscle power, pulmonary function, load carriage performance, personal protective equipment, chest wall restriction

## Purpose

**Purpose:** The focus of this research was to investigate the effects of ground-based personal protective combat equipment configurations on respiratory muscle power during load carriage performance.

## Methods

**Subjects:** Subjects with combat PPE and load carriage experience (up to ~38.5 kg) were recruited from Ft. Carson, CO (U.S. Army 4th Infantry Division (USA 4ID) and the University of Colorado - Colorado Springs, Army Reserve Officer Training Corps (ROTC) Program. Final enrollment and data collection was performed with nine (9) male Soldiers (4ID, N = 5; ROTC, N = 4; Table 1). Primary IRB oversight by Rocky Mountain University.

**Design:** Over a four to six week period, subjects performed baseline testing and Load Carriage Protocol (LCP) trials during six (6) visits (V1-V6). V1 and V2 consisted of procedures for esophageal balloon placement, metabolic, pulmonary and body composition testing.

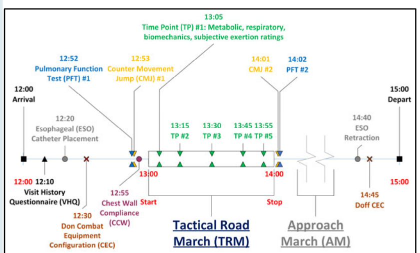


Figure 1. Standardized load carriage protocol (LCP) for visits 3 thru 6 (V3-6).

Table 1: Population Descriptive Statistics.

| | N | Mean | Std. Error | Std. Deviation |
|---|---|---|---|---|
| **Age (years) *** | 9 | 29.33 | 2.35 | 7.05 |
| **Height (cm)** | 9 | 174.33 | 2.66 | 7.97 |
| **Weight (kg)** | 9 | 85.17 | 4.08 | 12.25 |
| **$\dot{V}O2Max$ (Ab, $L\cdot min^{-1}$)** | 9 | 4.23 | 0.21 | 0.63 |
| **$\dot{V}O2Max$ (Rel, $ml\cdot kg^{-1}\cdot min^{-1}$)** | 9 | 49.84 | 1.58 | 4.74 |
| **$\dot{V}_E$ Max ($L\cdot min^{-1}$)** | 9 | 154.78 | 10.86 | 32.58 |
| **Bf Max ($br\cdot min^{-1}$)** | 9 | 53.29 | 2.35 | 7.04 |
| **HR Max ($b\cdot min^{-1}$)** | 9 | 185.70 | 3.47 | 10.42 |
| **FVC (L)** | 9 | 5.60 | 0.34 | 1.02 |
| **$FEV_1$ ($L\cdot min^{-1}$)** | 9 | 4.58 | 0.31 | 0.93 |
| **%BF (%)** | 9 | 23.66 | 1.78 | 5.34 |
| **BMI ($kg\cdot m^{-2}$)** | 9 | 27.78 | 0.66 | 1.97 |
| **BMD ($g\cdot cm^2$)** | 9 | 1.29 | 0.06 | 0.18 |

Maximal Oxygen Uptake ($\dot{V}O2Max$), Absolute (Ab), Relative (Rel); Maximal Minute Ventilation ($\dot{V}E$), Maximal Breathing Frequency (Bf), Maximal Heart Rate (HR), Forced Vital Capacity (FVC), Forced Expiratory Volume in one second ($FEV_1$), Percent Body Fat (%BF), Body Mass Index (BMI), Bone Mineral Density (BMD); * Significance level: $p < 0.05$

For V3-V6, subjects performed the LCP trials (i.e., TRM, 5.6 $km\cdot hr^{-1}$ @1% grade for 60-min; Figure 1). For familiarization, NL condition was performed on V3, while remaining CECs were counterbalanced across V4-V6. During the LPC trials, subjects Power of Breathing (Pb, $J\cdot min^{-1}$) using the Integrated Pressure-Volume (PV) method[8] was assessed at five (5) timepoints for five-minute sampling periods (i.e., Time Point (TP); TP1 = 0-5 min; TP2 = 12-17 min; TP3 =27-32 min; TP4 = 42-47 min; TP5 = 55-60 min; Figure 1) under four CECs (NL, No Load = 0 kg; BA, Body Armor = 13.5 kg (FL); LC, Load Carriage = 25 kg (FL); BA+LC = 38.5 kg (AL); Table 2 & Figure 2).

Table 2: Personal Protective Equipment (PPE) & Combat Equipment Configurations (CEC).

| Configurations | | Equipment | Descriptions | Weight (kg) |
|---|---|---|---|---|
| **Uniform*** | | Army Combat Uniform (ACU) | Blouse, Trouser (w/ 2" web belt), T-shirt, Footwear (boots). | 3.9 |
| **No Load (NL, 0 kg)** | | Tactical Harness (TH) | Mini-modular assault vest; 5.5" (h) x 14" (w); 23019LW-14. | 0.3 |
| **BA + LC (BALC, 38.5 kg)** | **Body Armor (BA, 13.5 kg)** | Plate Carrier (PC) | LBT-6094A (Medium; up to 180 cm & 90 kg) or LBT-6094B (Large; 183 cm +; 90-104 kg). | 1.8 |
| | | Plate Armor (PA) | Ballistic Armor; Single-Curve, Full, Front & Rear; 10"x12", 2.7 kg each. | 5.4 |
| | | Magazine Kits (MAG) | Non-ballistic Training Plates; 3"x4" 0.73 kg each; w/ 2x triple MOLLE Magazine Pouches. | 6.4 |
| | **Load Carriage (LC, 25 kg)** | Assault BVS (RUCK) | 3-Day Assault BVS ruck | 2.3 |
| | | Sandbags (LOAD) | Assault load; Rogue sandbag filled w/ standard playground dry-sand. | 22.7 |

* Donned across all CEC conditions.

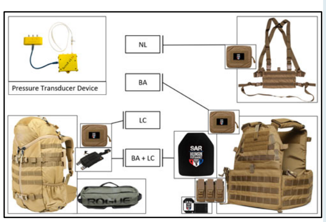


Figure 2. Personal Protective Equipment (PPE) & Combat Equipment Configurations (CEC).

**Statistical Approach:** Using SPSS 29, data analyses (reported Means ± Standard Error (SE), 95% Confidence Intervals (CI)) consisted of factorial, repeated measure analysis of variance (Pillai's Trace) and Bonferonni post hoc tests; significance level set at p = .05.

## Results

**Power of Breathing:** Statistical analysis revealed significance in the main effect on PbPV ($F=30.55$, $p<.001$, $\eta^2=.819$) plus interactions across CECs ($F=3.02$, $p=.001$, $\eta^2=.294$). Further contrasts analysis Test-Within Subjects showed a statistical significance in the main effect on PbPV ($F_{(1, 30)}=81.88$, $p<.001$, $\eta^2=.732$) plus interaction ($F_{(3, 30)}=29.31$, $p<.001$, $\eta^2=.746$). There was statistical significance between CECs ($F_{(3,30)}=29.16$, $p<.001$, $\eta^2=.745$). Bonferroni adjusted post hoc analysis comparison showed significant differences in CECs main effect: NL was less than LC (p = .004) and BALC (p < .001), not BA (p = .099); BA was less than BALC (p < .001), not NL (p = .099) and LC (p = 1.00); while BALC was greater than NL (p < .001), BA (p < .001), and LC (p < .001); (Figure 3).

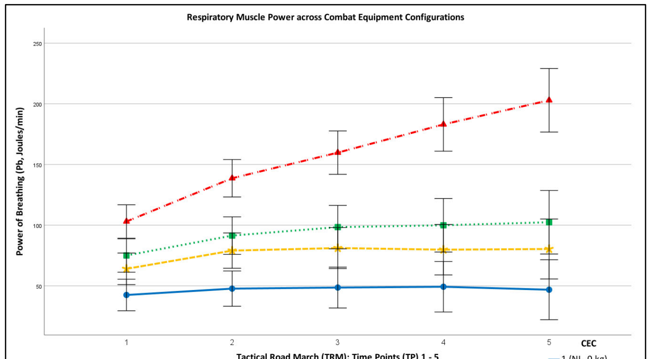


Figure 3. Respiratory muscle power measured at time points 1 – 5 across combat equipment configurations during the load carriage protocol trials - tactical road march phase. Combat Equipment Conditions (CEC): No Load (NL) = 0 kg; Body Armor (BA) = 13.5 kg; Load Carriage (LC) = 25 kg; Body Armor & Load Carriage (BALC) = 38.5 kg. (Error bars: 95% Confidence Intervals)

**Breathing Mechanics:** Statistical analysis revealed significance in the main effect and interactions across CECs: Minute Ventilation ($\dot{V}_E$), $F= 0.90$, $p<.001$, $\eta^2=.854$ and $F=2.70$, $p=.004$, $\eta^2=.265$ (Figure 4); Tidal Volume (VT), $F=1.94$, $p=.132$, $\eta^2=.217$ and $F=1.59$, $p=.110$, $\eta^2=.181$ (Figure 5); Breathing Frequency (Bf), $F=7.89$, $p<.001$, $\eta^2=.530$ and $F=1.86$, $p=.050$, $\eta^2=.199$ (Figure 6); and Absolute Esophageal Pressure Difference ($PRES_{diff}$), $F=3.37$, $p=.022$, $\eta^2=.325$ and $F=1.15$, $p=.328$, $\eta^2=.133$ (Figure 7).

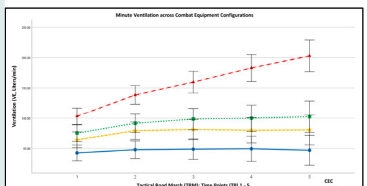


Figure 4. Minute ventilation (VE) measured at time points 1 – 5 across combat equipment configurations during the load carriage protocol trials - tactical road march phase. Combat Equipment Conditions (CEC): No Load (NL) = 0 kg; Body Armor (BA) = 13.5 kg; Load Carriage (LC) = 25 kg; Body Armor & Load Carriage (BALC) = 38.5 kg. (Error bars: 95% Confidence Intervals)

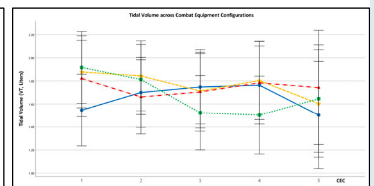


Figure 5. Tidal volume (VT) measured at time points 1 – 5 across combat equipment configurations during the load carriage protocol trials - tactical road march phase. Combat Equipment Conditions (CEC): No Load (NL) = 0 kg; Body Armor (BA) = 13.5 kg; Load Carriage (LC) = 25 kg; Body Armor & Load Carriage (BALC) = 38.5 kg. (Error bars: 95% Confidence Intervals)

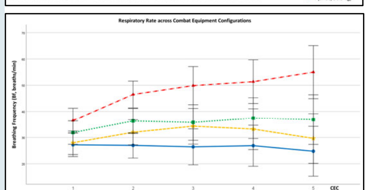


Figure 6. Breathing frequency (Bf) measured at time points 1 – 5 across combat equipment configurations during the load carriage protocol trials - tactical road march phase. Combat Equipment Conditions (CEC): No Load (NL) = 0 kg; Body Armor (BA) = 13.5 kg; Load Carriage (LC) = 25 kg; Body Armor & Load Carriage (BALC) = 38.5 kg. (Error bars: 95% Confidence Intervals)

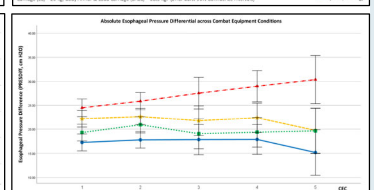


Figure 7. Esophageal pressure difference (PRESdiff) measured at time points 1 – 5 across combat equipment configurations during the load carriage protocol trials - tactical road march phase. Combat Equipment Conditions (CEC): No Load (NL) = 0 kg; Body Armor (BA) = 13.5 kg; Load Carriage (LC) = 25 kg; Body Armor & Load Carriage (BALC) = 38.5 kg. (Error bars: 95% Confidence Intervals)

**Correlations:** Spearman correlational analysis revealed statistically significant, strong-positive relationships between CEC weight (CECWt) to PbPV ($r_{(35)} = .860$, $p < .001$; 74%), CECWt to Chest Wall Restriction (CWR, $r_{(35)} = .516$, $p = .002$; 27%), and CWR to PbPV ($r_{(35)} = .425$, $p = .011$; 18%).

## Conclusion

The increased scaling-weight of combat equipment configurations resulted in greater respiratory muscle power demand and associated breathing mechanics necessary to perform a standardized sustainment load carriage task.

## Military Impact

- Aligned '21 Army Modernization Strategy: What We Fight With - Soldier Lethality.[10]
- Addresses 4 of top 11 identified "Priority Research Areas" 4th ICSPP.[9]
  (#1 - Physical demands in operational environment; #6 - Load impairing performance; #8 - Demands in training environment; #11 - Equipment impairing performance).
- Update critical education & training DOTMLPF-P doctrine / policy[6,11]
  (ATP No. 3-21.18 - FOOT MARCHES; FM 7-22 HOLISTIC HEALTH & FITNESS).
- Knowledge-product supports improved S&T materiel dev; revise PPE MIL-SPEC & MIL-STD.[10]

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