ENERGY EXPENDITURE OF WALKING WITH DIFFERENT TYPES OF ARMORED VESTS IN MILITARY PERSONNEL – A PILOT STUDY

Brinnell Caszo[1], Zubaidah Hasain[2], and Justin Gnanou[2*]

[1]School of Medicine, International Medical University, Malaysia
[2] Faculty of Medicine and Defence Health, National Defence University of Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur, Malaysia.

[*]E-mail: justingnanou@gmail.com
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Abstract

The use of armoured vests is an additional burden on the wearer, and has an impact on the ability to function for military personnel. In light of the limitations of the number of rations that can be carried, the aim of this study was to determine the energy cost of wearing armoured vests and compare the energy cost of six different types of vests. In this pilot study, six well trained volunteers from a military training academy were chosen. Their basal metabolic rate was measured. Then they used six different vests in a cross-over study design, and their energy expenditure was measured using an indirect calorimeter while walking on a treadmill. Data from our study revealed that using the vests, energy expenditure was increased by an average of 2.7 Kcal/Kg/day over basal metabolic rate. However, there were no significant differences between the six different vests. Thus, we were able to quantify the amount of additional energy that is required for walking at a speed of 3.5km/hr. This study also revealed that there is no difference in energy expenditure between different types of armoured vests. Further investigation is required to study the effects at greater workloads to document the effect of the vests.

Keywords: Armoured vests, basal metabolic rate, energy expenditure, indirect calorimetry

Introduction

Historically, body armour has been in use since time immemorial. Ancient armours have been written about extensively, from those made of bamboo to chain mail and metal plate amour (Summer and D'Amato, 2009). The protection offered by body armour has been documented in several settings in recent days (Orr, Schram & Pope, 2018). It has helped reduce the incidence of thoracic injuries as well as fatalities (Larsen, Netto & Aisbett, 2011). However, to this day the ideal armour remains elusive. In the age of modern protective body armour, fatalities and injuries have been some of the lowest, as documented by Mabry et al. (2000), regarding injuries and fatalities from the recent conflicts in Iraq and Afghanistan, penetrating chest injuries especially those that were fatal were much reduced. Tong and Beirne (2013) reported that wearing of combat body armour reduced the fatality and severity of injuries sustained in combat.

While the benefits of protective body armour are undoubtedly proven by these examples, it is also of importance to note that wearing of protective armour may have other consequences and may reduce the effectiveness, and in fact impede the wearer from functioning effectively. Majumdar, Srivastava, Purkayastha, Pichan, and Selvamurthy (1997) showed that wearing of the armour might reduce the endurance as well as the ability to perform physical activity. According to these authors, body armour increased the energy cost of tasks and also increased cardiovascular strain, and increased the effort for breathing. Hasselquist, Bensel, Corner, Gregorczyk, and Schiffman (2008), demonstrated an increased metabolic cost in terms of oxygen consumption (VO_2) measured while performing a set of tasks and also changed the gait pattern and biomechanics while wearing protective body armour. Cadarette, Blanchard, Staab, Kolka, and Sawka (2001) researched the effects of body armour on thermal stress experienced by the wearer under laboratory conditions. Vest design and construction must therefore take into account both these aspects, providing maximum protection, with the least amount of discomfort, heat stress and metabolic cost. Thus, assessing the effects of design of the body armour on physiological parameters would help in designing more ergonomically favourable and functional body armour.

Thus the aim of this study was to determine the energy cost of wearing body armour and compare the energy cost of six different types of armour differing in their design and material composition with similar weight.

Method

The objective of the study was to compare the effects of wearing six different body armours on energy expenditure for a walking speed of 3.5 km/hour. The choice of walking as the exercise protocol was based a study by Wyss and Mader (2010) in which the activities unique to military life was identified. They included: walking, marching with a backpack, lifting and lowering loads, lifting and carrying loads, digging and running. This study was a pilot study, we chose walking while wearing armoured vest as our physical activity to estimate the energy expenditure. A cross-over study design was used in which all participants used the six body armours by turn. Participants were required to complete the study protocol from day 1 through day 6. The subject-vest combination for each of the days is as shown in Table 1. Each subject was also assigned numbers 1 to 6 and wore a different vest labelled from A to F on each of the study days.

Table 1: Cross over design for subject-vest combination.

Subject	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
	Vest	Vest	Vest	Vest	Vest	Vest
1	A	F	E	D	C	B
2	B	A	F	E	D	C
3	C	B	A	F	E	D
4	D	C	B	A	F	E
5	E	D	C	B	A	F
6	F	E	D	C	B	A

Participants

Six male soldiers were recruited from the Military Training Academy. They were young healthy adults with an average age of 32.7 ± 2.2 years. Six different protective body armours were selected. Their specifications are shown in Table 2.

Table 2: Tactical vests' specifications

Tactical Vests	Weight
Vest A (kg)	4.9
Vest B (kg)	5.4
Vest C (kg)	6.9
Vest D (kg)	4.9
Vest E (kg)	5.1
Vest F (kg)	5.8
Average	5.5
Standard Deviation	0.76
Variance	0.58

The average mass of the six body armours was 5.5 ± 0.76 kg. All the 6 body amours were within ± 2 standard deviations and had a variance of 0.58, which shows that all the six body armours varied less from the average weight and hence were considered comparable. The armours were color-coded and each participant picked lots to determine the order in which the armour would be worn. The study protocol was explained to them, and written informed consent was obtained. The study protocol was reviewed by the University Research Committee and the study was conducted in accordance with the Declaration of Helsinki and the guidelines of Resolution on 198/96 of the National Health Council.

Baseline measurements

Participants were advised to come to the lab in the morning following an overnight fast. They were advised to abstain from consuming any caffeinated drinks, and only drank sips of water after 6 am on the day of the experiment. Their height and mass was recorded using a stadiometer and digital weighting scale (Seca, Hamburg Germany). Body composition was assessed via bioimpedance analysis (N2O Segmental Body Composition Analyzer, U.Healthcare System, Singapore), while standing on the weighing scale wearing minimal clothing and with bare feet. Blood pressure was measured in the sitting position with a non-invasive blood pressure monitor (Welch Allyn, Skaneateles Falls, USA). Lung function was assessed using the pulmonary function module of the metabolic cart (QUARK CPET, COSMED, Italy) in the standing position, three trials were conducted to satisfy ATS criteria (Miller et al., 2005). Table 2 provides the results of the above measurements.

Table 2: Anthropometry and lung function parameters

Anthropometry		Mean±SD	
	Age (years)	32.7± 2.2	
	Mass (cm)	166.6± 5.8	
	Stature (kg)	69.3± 5.8	
	Body mass index (kg/m^2)	25.0± 1.3	
	Fat-free mass (kg)	52.8± 5.2	
	Fat Mass (kg)	16.4± 1.7	
	Systolic blood pressure (mmHg)	122.0± 12	
	Diastolic blood pressure (mmHg)	76.3± 6.2	
Lung function		Mean±SD	%Predicted ± SD
	FVC (l)	4.2±0.8	94±0.4
	FEV1 (l)	3.2±0.4	85±0.3
	FEV1/FVC	83.7±5.0	100±0.4

Footnotes: FVC: Forced vital capacity, FEV1: forced expiratory volume in the first second, PEF: Peak expiratory flow rate, l: litre, sec: second

Experimental procedure

At the start of the experiment, participants were asked to pick lots to determine the order in which they would wear the body armours. They were familiarized with both the facemask as well as canopy hood for the measurement of energy expenditure and basal metabolic rate using the indirect calorimeter respectively a day prior to the start of the experiment.

Measurement of basal metabolic rate

After the initial baseline measurements, the participants reclined on a bed without any disturbance for 30 minutes. Then, the participants were fitted with a canopy hood connected to the indirect calorimeter. A recording of their basal metabolic rate (BMR) was made using the ventilated canopy and metabolic cart (QUARK CPET, COSMED, Italy). An open circuit calorimeter with a canopy hood ventilated by a pump and connected to a turbine was used. The turbine was calibrated with a 3L syringe before the experiment. The gases sampled were analysed by fast response infra-red carbon dioxide and paramagnetic oxygen analysers (Blond et al. 2010). Gas analysers were calibrated against a gas mixture of 4% carbon dioxide, 15% oxygen and remainder of the mixture nitrogen after the recommended warm up period was observed. The analysers were also calibrated against room air. Data were recorded for approximately 20 min. All measurements were carried out in a quiet room with an ambient temperature between 23–25 degrees Celsius, barometric pressure of 750–770 mmHg and constant humidity of 60 %.

Measurement of energy expenditure of walking with six different body armours

During the next part of the experiment, participants were connected to an open-circuit calorimeter by means of a face mask (QUARK CPET, COSMED, Italy). Participants were then fitted with the protective body armour, and 2 armour plates; one on the front of the vest, and one on the back portion of the vest. The same armour plates were used for all 6 vests. After resting for 15 min, they walked on the treadmill (COSMED T170, COSMED, Italy) at a speed of 3.5km/hr and at 0˚ inclination. Respiratory gases were collected in "breath-by-breath mode". Gas samples were fed into rapid response oxygen and carbon dioxide gas analysers. One baseline recording was made for all participants. All participants performed trials wearing each of the six vests in this manner. In total, each participant underwent 7 different measurements. Data obtained was exported to Microsoft excel and averaged for a duration of 10 minutes, and expressed as averages.

Statistical analysis

The data was expressed as mean ± standard deviation. In order to compare the six different armoured vests, a one-way multivariate analysis of variance (one-way MANOVA) was carried out on the energy expenditure measures using SPSS 17.0. A p value of <0.05 was considered to be statistically significant.

Results

The average BMR of the participants was 1426.2 ± 248.1 Kcal/day. The comparison of energy expenditure (Kcal/Kg/day) controlled for body weight, of wearing the six different body armours and walking at a speed of 3.5 km/hour and the cost of walking on treadmill without wearing the vest are shown in Table 3.

Table 3: Energy cost and oxygen consumption (VO_2) of BMR, walking and wearing the vest

	VO_2 ml/min ±SD	VO_2ml/min/Kg ±SD	Kcal/Kg/day ±SD	Kcal/Kg/day less BMR ±SD
BMR	191.1±31	2.7±0.4	20.6±4	
Walking	931.5±108	13.5±1	95±10	77.1±9
Vest A	939.3±105	13.6±1	96.1±9	76.9±10
Vest B	956.8±106	13.8±8	97±8	83±6
Vest C	982.7±126	14.2±1	100±9	79.4±9
Vest D	970.7±90	14±1	98.8±6	78.2±5
Vest E	1011.2±126	14.69±1	102.8±9	83.5±12
Vest F	963.3±78	13.9±1	98.1±8	77.9±10

Walking without the vest showed an average increase of 77.1 ± 9 Kcal/Kg/day in energy expenditure above the BMR. Wearing of the body armour caused on an average increase of 2.7 Kcal/Kg/day in the energy expenditure when compared to walking without body armour. This ranged between 77 Kcal/kg/day to 83.5 Kcal/kg/day. However, multivariate analysis comparing the energy expenditure of wearing six different body armours did not show any statistically significant difference between the body armours ($p>0.05$).

Discussion

In this study we studied the energy expenditure of wearing body armour used by the armed forces in combat after 10 minutes of walking at a regular walking pace. We also compared the energy expenditure differences between six different types of body armour. We found an increase in energy expenditure when wearing the armoured vests; however, design appeared to have no effects on energy expenditure. In a study of energy expenditure among fire fighters found that VO2 max was reduced, and duration of the run was reduced, when performing Bruce protocol on a treadmill, with participants using rubber boots and protective clothing, as compared to that while running in sports clothing and shoes (Lee, Bakri, Kim, Son, & Tochihara, 2013). Another study demonstrated a 56% decrease in tolerance to exercise with PPE with women experiencing a greater fall in exercise tolerance compared to men. A partitioned analysis of the energy expended revealed that larger amounts of energy or oxygen consumed at any given work rate were used for non-exercise purposes (Taylor, Lewis, Notley, & Peoples, 2012).

Protective clothing worn by armed forces personnel for protection from cold was investigated by Duggan (1998). Energy expended VO2 increased by up to 16% depending on the number of layers of clothing used while performing a stepping test. Patton, Bidwell, Murphy, Mello and Harp (1995) also found that VO2 increased between 5 to 29% while performing tasks. They also observed a gender effect. Hasselquist, Bensel, Corner, Gregorczyk, and Schiffman, (2008) showed that VO2 increased while wearing body armour, when scaled for body weight showed a 30% increase over unloaded/without vest condition. Wearing the armoured vest also changed the ergonomic pattern.

Harman et al. (1999) tested two types of body armour and load carrying equipment designs on female soldiers. They reported no significant difference between the two designs; however, wearing the armour and webbing increased energy expenditure and the increase was between 17.09 to 18.05ml/kg/min, representing 37% of the maximal oxygen consumption rate of the participants while walking at a speed of 3mph on a treadmill at 0 inclination. A similar study among male volunteers revealed a value of 15.88 ml/kg/min, representing an increase over baseline of 14%. In this study, the system with the greatest weight was actually more efficient in design than the lighter designs. The authors propose that the unexpected result was due to the way the backpack and the entire system, including the integrated armour, fit on the individual (LaFiandra, Wagenaar, Holt & Obusek, 2003).

In recently completed studies by Costello, Stewart and Stewart (2015), the effects of increasing work rate were studied while participants wore personal protective equipment for protection against chemical and explosive threats. Time to fatigue (tolerance) was reduced as the work rate increased; however, at high work rates, the effects of ambient temperature and humidity had a smaller effect than the actual work rate. At lower work rates, ambient conditions did play a significant role in effort tolerance. Wearing additional chemical protective clothing had a greater effect on effort tolerance than wearing only protective clothing for explosive ordinance disposal, resulting in a significantly shortened duration of effort tolerance. Reduced tolerance may be attributed to a combination of factors including layers of clothing and weight carried during the physical activity.

Data from our study was collected at low work rate of 3.5 km/hour walking speed on a treadmill. Walking alone costs an average of 77 Kcal/min/day, representing a 3.9 to 4.2 times increase. Wearing of the different vests however did not significantly affect the energy cost of walking, and all vests had a comparable effect on energy expenditure. A study by Payne, Portier, Fairweather, Zhi and Snow (1988) found that a low intensity / work rate such as walking with a charged hose had no effects of different type of personal protective clothing on physiological measurements, which is similar to the findings of our study. Thus our data indicates that at rest, and at low work rates, wearing of the vest may not have a significant effect on performance and exercise tolerance. However, our study included only male participants and so the results of this study can be applied only to males. Thus, it is clear that characterization of the properties of the vest in all work conditions must be included while assessing the suitability of a vest in a given circumstance.

Conclusion

Walking at speed of 3.5 km/hour on a treadmill at 0˚ inclination while wearing a vest increased energy expenditure by 77 Kcal/kg/day to 83.5 Kcal/kg/day. This increase was not statistically significant ($p>0.05$) and did not depend upon the vest worn, at the described work rate. Though not statistically significant, such an increase may be important at higher work rates. An assessment of the energy cost of wearing PPE must be taken into account while selecting appropriate models, and investigated over a suitable range of physical activity.

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References

Blond, E., Maitrepierre, C., Normand, S., Sothier, M., Roth, H., Goudable, J., & Leville M. (2010). A new indirect calorimeter is accurate and reliable for measuring basal energy expenditure, thermic effect of food and substrate oxidation in obese and healthy participants. *European e-journal of clinical nutrition and metabolism, 6*,e7-e15.

Cadarette, B., Blanchard, L., Staab, J., Kolka, M., & Sawka, M. (2001). *Heat Stress When Wearing Body Armor*. Natick, Thermal and Mountain Medicine Division, United States Army Research Institute of Environmental Medicine.

Costello, J.T., Stewart, K.L., & Stewart, I.B. (2015). The effects of metabolic work rate and ambient environment on physiological tolerance times while wearing explosive and chemical personal protective equipment. *BioMed Research International, 2015,* 857536.

Duggan, A. (1998). Energy cost of stepping in protective clothing ensembles. *Ergonomics, 31*, 3-11.

Harman, E., Frykman, P., Pandorf, C., Tharion, W., Mello, R., Obusek, J., & Kirk J (1999). *Physiological, Biomechanical, and Maximal Performance Comparisons of Female Soldiers Carrying Loads Using Prototype U. S. Marine Corps Modular Lightweight Load-Carrying Equipment with Interceptor Body Armor and U.S. Army All-Purpose Lightweight Individual Carrying Equipment with PASGT Body Armor.* Natick, U.S. Army Research Institute of Environmental Medicine.

Hasselquist, L., Bensel, C.K., Corner, B., Gregorczyk, K.N., & Schiffman, J.M. (2008). *Understanding the physiological, biomechanical and performance effects of body armour use*. Natick, Natick Soldier Research, Development and Engineering Centre.

Larsen, B,. Netto, K., Aisbett, B. (2011). The effect of body armour on performance, thermal stress, and exertion: A critical review. *Military Medicine*, 176, 1265–1273.

LaFiandra, M., Wagenaar, R.C., Holt, K.G., Obusek, J.P. (2003). How do load carriage and walking speed influence trunk coordination and stride parameters? *Journal of Biomechanics*, *36*,87-95.

Lee, J.Y., Bakri, I., Kim, J.H., Son, S.Y., & Tochihara, Y. (2013). The impact of firefighter personal protective equipment and treadmill protocol on maximum oxygen uptake. *Journal of Occupational and Environmental Hygiene*, *10*, 397-407.

Mabry, R.L., Holcomb, J.B., Baker, A.M., Cloonan, C.C., Uhorchak, J.M., Perkins, D.E., Canfield, A.J., & Hagmann, J.H. (2000). United States Army Rangers in Somalia: an analysis of combat casualties on an urban battlefield. *Journal of Trauma, 49*,515-528.

Majumdar, D., Srivastava, K.K., Purkayastha, S.S., Pichan, G., & Selvamurthy, W. (1997). Physiological effects of wearing heavy body armour on male soldiers. *International journal of industrial ergonomics, 20*,155-161.

Miller, M.R., Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., Coates, A., Crapo, R., Enright, P., van der Grinten, C.P., Gustafsson, P., Jensen, R., Johnson, D.C., MacIntyre, N., McKay, R., Navajas, D., Pedersen, O.F., Pellegrino, R., Viegi, G., & Wanger, J. (2005). Standardisation of spirometry. *European Respiratory Journal, 26,*319–338.

Orr, R., Schram, B., & Pope, R. (2018). A comparison of military and law enforcement body armour. *International Journal of Environmental Research and Public Health*, 15, 339.

Payne, W., Portier, B., Fairweather, I., Zhi, S., Snow, R. (1988). Physiological and psychological responses to wearing fully encapsulated protective clothing during simulated work in various thermal environments. *Workplace Australia*, 2-68.

Patton, J.F., Bidwell, T.E., Murphy, M.M., Mello, R.P., Harp, M.E. (1995). Energy cost of wearing chemical protective clothing during progressive treadmill walking. *Aviation, Space and Environmental Medicine, 66,*238-242.

Summer, G, & D'Amato R. (2009). *Arms and Armor of the Imperial Roman Soldier – From Marius to Commodus, 112 BC – AD 192*. London: Frontline Books.

Taylor, N.A., Lewis, M.C., Notley, S.R., & Peoples, G.E. (2012). A fractionation of the physiological burden of the personal protective equipment worn by firefighters. *European Journal of Applied Physiology, 112,* 2913-21.

Tong. D, & Beirne, R. (2013). Combat body armour and injuries to the head, face, and neck region: a systematic review. *Military Medicine, 178,* 421-426.

Wyss, T., & Mader, U. (2010). Recognition of military-specific physical activities with body-fixed sensors. *Military Medicine, 175,* 858-864.