Chapter 2
Perceived Fatigue Evaluating Model in Health Men Performing Backpack Load-Carriage Exercises

Yuhong Shen, Jiewen Zheng, Chenming Li, Yafei Guo and Pengfei Ren

Abstract *Objectives* This study aimed to develop a fatigue model for human load carriage during endurance exercise using quantification of perceived pains and physiological parameters. *Methods* Heart rate, skin contact pressure, and perceived pains and corresponding locations of five healthy participants were measured during treadmill tests on non-consecutive days under three different conditions of backpack payloads (29, 31.5, and 34 kg). *Results* All participants could complete the trials without resting using 29, 31.5, and 34 kg payloads for 50 min. The slopes for heart rate regression equations in three-payload conditions became steeper as the payload increased. The trends of root mean square (RMS) of skin contact pressure in back, shoulder, and hip regions are all changing smoothly. But the overall amplitudes of RMS of pressure in shoulder region in all three-payload conditions are higher comparing with other two regions. Perceived fatigue intensity results showed that shoulder region was the most discomfort region on the body and was highest using 34-kg payload. *Conclusions* The results suggested that shoulder fatigue may limit endurance performance, thereby indicating the importance of a well-designed shoulder strap. A fatigue intensity predictive model was proposed to allow prediction of human load carriage limits and fatigue intensity trend for endurance exercise.

Keywords Backpacks · Biomechanical assessment · Load carriage · Fatigue intensity predictive model · Skin contact pressure

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2.1 Introduction

Backpacks or personal load carriage systems are commonly used by soldiers to carry heavy loads in different terrains and gradients even in long-distance marching or in the fighting [1]. With technological advancements, loads carried by soldiers especially in terms of increased firepower and protection equipments have progressively increased. Unfortunately, carrying heavy loads often caused discomfort, fatigue, and injuries and affecting soldiers' operational performance [2]. In a recent military report, US rifle squads carried fighting load of 28.3 kg (34.9 % body weight (BW)), approach march load of 43.1 kg (52.6 % BW), and emergency approach march load of 58.2 kg (73.6 % BW) [3]. A difficulty for military personnel have to face is to assess the fatigue or injury that various loads will have on foot soldiers. Even though payload and mission are known, there are only a few strategies to assess or predict the impact of loads on the soldiers. It is important to develop a predictive model or equation that encompasses more of the major variables that limit performance of load carriage in the field.

Till date, the studies of fatigue predictive model for human load carriage particularly in military conditions are limited and less reported, especially applying both biomechanical and physiological approaches. This paper will explore the relationships between fatigue and backpacks and give some suggestions for improving the design of backpack and reducing discomfort or fatigue when carrying heavy loads. Finally, a fatigue intensity predictive model was proposed to allow prediction of human load carriage limits and fatigue intensity trend for endurance exercise, which would be used to provide backpackers and military with a simple guideline to assess the load reasonably carried by a soldier or backpacker, the duration with corresponding load, and the dropout rate for a certain task.

2.2 Methods

2.2.1 Subjects

Five male individuals with a mean (±SD) age, body weight, and height of 24.2 ± 3.7 years, 64.5 ± 11.59 kg, and 172.2 ± 2.39 cm, respectively, enrolled in this study. The participants were healthy Chinese men and had no muscular or skeletal illness that would influence load carriage performance. Both written consent and verbal consent were obtained from all participants prior to experiment. They were asked to have a good rest and avoid caffeine, alcohol, smoking, and intense physical activity at least 24 h prior to the experiment.

2.2.2 Apparatus and Measurements

The pressures at shoulder, back, and hip regions were measured by miniature pressure sensor (Model 9801, Tekscan, USA). The 9801 sensor has sensing region dimension of 7.6 × 20.3 cm that is so small that a minimal change to the curvature of the shoulder strap can be measured. Two 9801 sensor pads were put on each region to detect pressure of both sides, as shown in Fig. 2.1. Each 9801 sensor was plugged into a data scanner where pressure data were collected and sent to PC via USB cable where the data can be viewed, analyzed, and stored in real time with I-Scan® application software. Heart rate (HR) was acquired using a chest HR belt and a wristwatch monitor (S610i, Polar, Finland). The HR data stored in wristwatch monitor will be uploaded to PC via infrared port after experiment.

2.2.3 Procedure

The experimental trials began at 08:00. Temperature of the climate chamber was maintained at 25 °C throughout all the trials. Participants visited the climate chamber at our institute for three exercise sessions on non-successive days. The payloads were packed into the modern Chinese army backpack that was adjusted to fit each participant with a balanced and uniform load distribution. Five participants will perform treadmill tests (5 km/h speed, 0 % incline) under three

Fig. 2.1 Location of 9801 pressure sensors

different conditions (29, 31.5, or 34 kg). Every three minutes, numerical fatigue intensity (0 to 10 where "0" indicates "no fatigue" and "10" indicates "fatigue as bad as it can be") on three regions (shoulder, back, and hip) and whole body were recorded by the researcher, until finishing 50 min of trail or until the participant reported stopping exercising.

2.2.4 *Statistics*

Descriptive statistics were used to calculate mean values for fatigue intensity. The root mean square (RMS) was used to describe the magnitude of skin contact pressure in three minutes. $P < 0.05$ was considered significant. All statistical analyses were performed in SPSS 11.0 and MATLAB 7.0.

2.3 Results

Figure 2.2 shows the mean HR resulting from 50 min of load carriage on a treadmill for three payloads. In Fig. 2.2, the regression equation for each payload was calculated based on time (independent variable) and mean HR (dependant variable). The slope for regression equation became steeper as the payload increased. Figure 2.2 also shows that mean HRs generally reached a plateau (slopes became gentle) between 25 and 40 min of exercise.

Figure 2.3 shows the RMS of skin contact pressure during 50 min of load carriage exercise for three payloads. It can be seen that the trends of RMS of skin contact pressure in back, shoulder, and hip regions in three-payload conditions are all changing smoothly. But the overall amplitudes of RMS of pressure in shoulder regions are higher comparing with other two regions (back and hip). And the difference is most obvious in 34 kg payload.

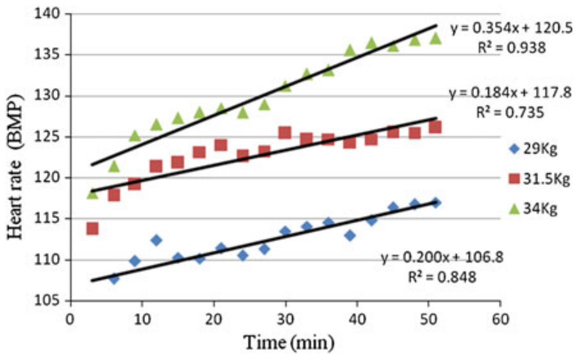


Fig. 2.2 Mean HR during 50 min of load carriage exercise

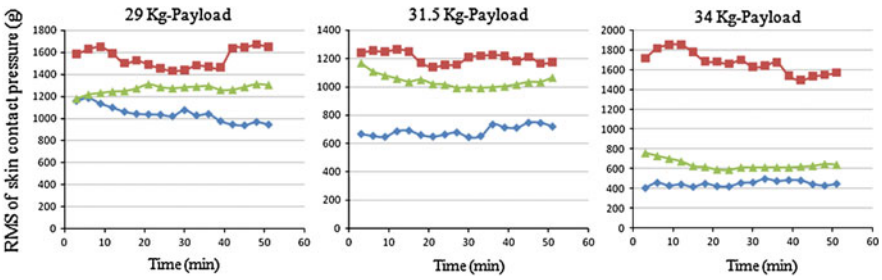


Fig. 2.3 The RMS of skin contact pressure during 50 min of load carriage exercise

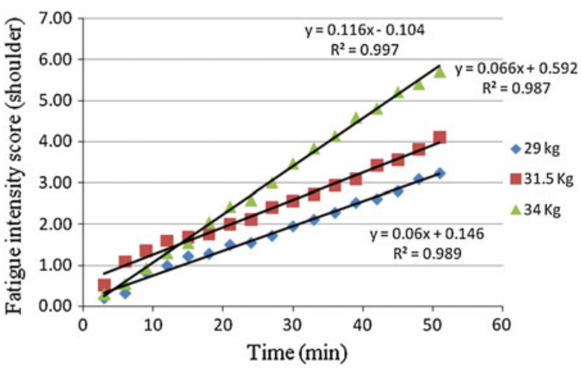
Table 2.1 Perceived fatigue score of shoulder, back, and hip regions and whole body in three-payload conditions

Time	Shoulder			Back			Hip			Whole body		
	29 kg	31.5 kg	34 kg	29 kg	31.5 kg	34 kg	29 kg	31.5 kg	34 kg	29 kg	31.5 kg	34 kg
50 min	3.2	4.1	5.7	3.3	2.1	1.3	3.1	2.3	3.7	3.6	3.3	3.9

Table 2.1 shows perceived fatigue scores of three regions and whole body during 50 min exercises in three-payload conditions. In shoulder and hip regions, the fatigue scores increased as the payloads changing from 29 to 34 kg. But the opposite is in back region. Whereas there is no regular changes of the whole body fatigue score. Table 2.1 also shows that shoulder region was the most discomfortable region on the body and was highest using 34-kg payload.

To develop fatigue predictive model for load carriage, a number of regression equations were calculated. Figure 2.4 shows the regression equations for each payload, calculated based on fatigue scores from the most discomfortable of shoulder region (dependent variable) and time (independent variable). Figure 2.5 shows the regression equations, calculated based on shoulder fatigue (dependent

Fig. 2.4 The relationship between shoulder region fatigue and excising time during load carriage



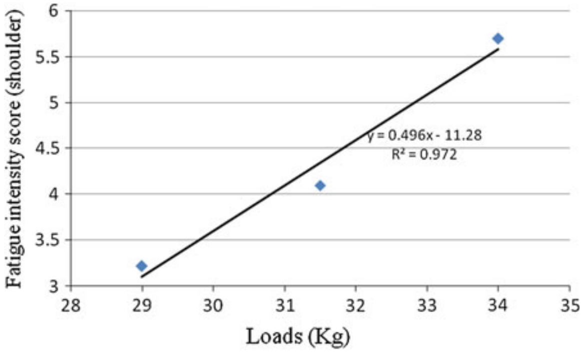


Fig. 2.5 The relationship between shoulder region fatigue and payload during load carriage

Model 1 Prediction of load carriage duration for discrete payloads ≤ 34 kg	Model 2 Prediction of percent of maximal fatigue intensity for a given payload during 50-minute exercise.
If payload is known (e.g. 29, 31.5, 34 kg), then the maximal duration can be predicted. Choose appropriate regression equation from Figure 4; Where, x = time; y = shoulder fatigue score. **For example:** To predict how long backpacker can endure 31.5 kg before fell exhausted. y = 0.066x + 0.592; (31.5 kg), when y = 5.7, x = 77 minutes; Therefore, backpacker can endure 77 minutes exercise when carrying 31.5 kg payload.	If the payload is known, then the percent of maximal fatigue intensity can be predicted. **Step 1:** Use equation from Figure 5: y = 0.496x - 11.28 Where, x = load; y = shoulder fatigue intensity. **Step 2:** Use following equation: % maximal fatigue limit: = y/5.7 × 100%. **For example:** If 33 kg payload is carried for 50 minutes, backpacker will be working at the following percent of his maximal fatigue limit. **Step 1:** y = 0.496× 33 –11.28 y = 5.1 **Step 2:** % maximal fatigue limit: = 5.09/5.7 × 100%= 89.3% Therefore, fatigue is predicted to be 5.1/10 during payload carriage of 33 kg for 50 minutes which is 89.3% of maximal load carriage fatigue limit.

Fig. 2.6 The fatigue intensity predictive model

variable) and payload (independent variable). For this test, all participants could complete 50-min exercises without resting using all three payloads.

Based on above findings, a simple fatigue predictive model will be proposed (Fig. 2.6).

2.4 Discussions

As expected, each participant showed increasing tendency of mean HR in all three-payload conditions and reached a plateau between 25 and 40 min (Fig. 2.2). When starting exercise, the cardiorespiratory system is trying to accommodate body to changed load conditions, so the HR increased rapidly. After about 25 to 40 min, the body tends to balance, so a plateau appeared. But the HR would continue to grow up as the exercising intensity increased, and then, the body would explore potential of the body to adapt to new change [4]. The highest mean HR recorded was 137 beat/min (BPM) (34-kg payload), suggesting that the HR was in the low end of cardiorespiratory limit. Tanaka et al. reported that following equation could be used to predict maximal HR (HRmax): HRmax $= 208 - (0.7 \times \text{age})$ [5]. Based on mean age of our participants (24.2 year), the expected HRmax would be 191 BPM. From Fig. 2.2, it can be calculated that the participants were excising at 71.1 % of HRmax (34 kg). Kenney et al. reported that about 70 % of HRmax could be accepted for most healthy individuals [6]. Based on above, all participants always took exercises within maximal cardiorespiratory limit, even for the heaviest 34-kg payload, suggesting that HR may be not a major factor for predicting fatigue when carrying under 34-kg payload.

Some studies have suggested that the shoulder region played the most important role in determining load carriage limit and will be most vulnerable region of feeling fatigue or pain [7, 8]. This study gets similar results that both in 31.5- and 34-kg payloads condition, fatigue scores of shoulder region are the biggest. But in 29-kg payload, the most discomfortable region was back. Table 2.1 shows that fatigue scores of the shoulder, back, and hip regions in 29-kg payload were 3.2, 3.3, and 3.1, respectively, suggesting the differences between them had no significances ($P > 0.05$). This maybe can be explained that perceived fatigues in three regions are so small in this low payload condition (29 kg) that it cannot be differentiated. In all payloads conditions, fatigue score of shoulder region in 34 kg was highest, suggesting that shoulder fatigue may limit endurance performance, thereby indicating the importance of a well-designed shoulder strap. The sternum strap and hip belt may also improve fatigue by reducing shoulder pressure through the redistribution forces over a larger surface on the anterior body during endurance exercise. These results are similar to other studies [1, 9, 10].

Figure 2.3 shows the RMS of pressure in shoulder region in all three-payload conditions are higher than other regions, but almost no differences existed among three-payload conditions. By contrast, the RMS of pressure in back and hip regions seemed to present regular trends of increasing as adding payloads. It was possible that the sternum strap and hip belt shared much pressures distributed in shoulder region when payload increased. So that is why the RMS of pressure in shoulder had less change, whereas those of back and hip increased. This also on the other hand proved that well-designed sternum strap and hip belt would improve backpack performance in load carriage and proved the backpack used in this study had good performance. The skin contact pressures could be acquired with film-type sensors, but some indeterminacy due to volatile contact areas between skin and backpacks, bending errors, poor repeatability, and calibration limitations still existed [11]. So modern pressure mapping technology must resolve these problems or explore alternative methods to study biomechanical factors in load carriage. As such, using two 3-axis accelerometers to assess the contact forces and pressures between the backpack and person seems to be a prosperous method [12].

Some limitations of our studies must be pointed out. First, payload or duration should be increased. In this study, the maximum payload was 34 kg, 52.7 % of BW. But Fig. 2.4 shows that the maximal mean fatigue score was only 5.7 in shoulder region. It was obvious that the participants did not reach their physical limits. US army defined the limit of payload in load carriage was 50 kg based on previous statistical data acquired from Afghanistan and the Falkland Islands battles. Second, the number of participants was small (N = 5). It was important to have a dropout rate in order to develop a comprehensive fatigue predictive model through increasing samples, payloads, or duration of exercise. Third, this study tested a limited payloads (29, 31.5, 34 kg), march speed (5 km/h), incline (0 %), and duration (50 min). Only when testing wide conditions, the predictive model could have good performance in actual application.

2.5 Conclusion

A fatigue intensity predictive model was proposed to allow prediction of human load carriage limits and fatigue intensity trend for endurance exercise. The fatigue predictive model only considering limited physiological and biomechanical aspects. But more factors should be introduced, such as demographic factor including body size, gender, and age, fitness and injury factors, and so on. In this paper, the study on fatigue predictive model is only elementary and groping, and a lot of work need to do in the future.

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