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AN ERGONOMIC EVALUATION OF MOUNTAINEERING BACKPACKS

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ABSTRACT

Backpack is one of the essential equipment that must be owned by a nature lover or a mountaineer when doing the adventurous activities. There are various types of backpacks on the market with a variety of brands, shapes and sizes according to the desires and needs. However, there are still complaints from the users when or after using those bags. Therefore, this study was conducted to analyse the backpack from the ergonomics side, specifically the influence of the use upon the body muscle and the heart muscle tension on three types of mountaineering backpacks that are often used namely Pack X, Y and Z. This study used Surface Electromyography (EMG) to analyse the muscle activity, Electrocardiography (ECG) to analyse the electrical activity of heart muscle, and Nordic Body Map (NBM) questionnaires to investigate the user perceptions of musculoskeletal discomfort. Twenty nature lover students were participated as the subject in the study. EMG and ECG data retrieval as well as filling out the NBM questionnaire performed before and after simulated trip for an hour using the treadmill in the laboratory by 20 subjects. The results indicated that Pack Z is less ergonomic than Pack X and Pack Y. The study also generates some criteria in choosing the ergonomic backpack based on analysis of muscle and heart electrical activities of the subjects.

Keywords: ergonomic, EMG, ECG, backpack, mountaineering.

1. INTRODUCTION

Adventurous activities, especially climbing or mountaineering, are becoming increasingly popular in Indonesia, especially for young nature lovers. Besides should have strong and healthy body physically and mentally, a mountaineer should also be equipped with convenient and safety equipment, one of them is backpack. This affects the development of mountaineering backpacks design. The design of current high-performance backpacks is very sophisticated with variety of features, sizes, and price. However, preliminary study results show that there are still many complaints from users after using those backpacks.

The preliminary study was conducted in Padang, West Sumatera, to 30 mountaineering backpack users through interviews. It was found that users frequently felt pain in some parts of their body after using the backpacks. The highest complaint perceived by the users is on the right shoulder (90%), on the left shoulder (83.33%), and on the waist (60%).

There is a large body of research addressing the evaluation of backpacks, most of them are backpacks for school children [1]-[4]. Many researchers had studied extensively about the physiological, biomechanical, and psychological effects of different types of backpacks [5]-[8]. Some previous researches also discussed the comparison of some different types of backpacks [9] and [10]. However, there is still lack study in evaluating mountaineering backpacks in terms of ergonomics and make comparison on some types of those backpacks.

A previous study by Retnari *et al.* [11] has been conducted to analysis the use of mountaineering backpack on female mountaineers. The study then designed the ergonomic mountaineering backpack for female mountaineers in Indonesia.

Therefore, this study conducted to evaluate three types of mountaineering backpacks mostly used in Padang, West Sumatera Indonesia in terms of ergonomics. The study also gives some recommendations for choosing or designing ergonomics mountaineering backpacks.

2. MATERIALS AND METHODS

a) Subjects

Twenty nature lover students from University of Andalas, Padang, West Sumatera, Indonesia (10 male and 10 female) participated in the study. All subjects were informed the procedures of the experiment and gave their informed consent to participate in the study. The subjects were healthy and had no acute back or neck complaints which would influence their performance adversely. Their mean (SD) physical characteristics were: age 21.60 (1.82) years, stature 1.64 (0.08) m, body weight 55.65 (9.39) kg.

b) Backpacks

Table-1. Backpack features.

No.	Features	Type		
		X	Y	Z
1	Weight	2,95 kg	5 kg	2,50 kg
2	Height adjustable lid closure	√	√	√
3	Back adjustment system	√	-	-
4	Well-padded shoulder strap	√	√	√
5	Sternum strap	√	√	√
6	Well-padded waist strap	√	√	√
7	Breathable back system	√	√	-
8	Internal contoured frame design	√	√	√
9	Material	*Duratex*	*Cordura 500D, Cordura 1000D*	*Full Cordura*

Three high-performance and internationally renowned mountaineering backpacks with 60 litre average volume were used. Pack X was manufactured in Germany, while Pack Y and Z were manufactured in Indonesia. The features of each backpack were presented shown concluded in Table-1. Those backpacks were chosen because they were the most likely to be used by the respondents in Padang, West Sumatera, Indonesia.

c) Instrumentations

Cobra 4 Sensor-Unit Electrophysiology: Electrocardiography (ECG) and Electromyography (EMG) System complete with disposable surface electrodes Ag/AgCl/Solid adhesive pre-gelled were used to record the electrical activity of heart and muscle. Data obtained was then analyzed using Cobra4 software from PHYWE System GmbH and Co.KG.

d) Experimental design

Each subject simulated a climbing trip with walked for an hour on a treadmill at 3 km per hour with various tilt angles. The experiment was carried out in Laboratory of Work System Design and Ergonomics, Department of Industrial Engineering, University of Andalas, Padang, West Sumatera, Indonesia. In the first 10-minute, the walk was conducted at the angle of 0^{0}, then, in the second 10-minute, the walk was conducted at the angle of 4^{0}. The third 10-minute, the walk was conducted at the angle of 8^{0}, and 30 minutes later, the walk was conducted at the angle of 10^{0}. The subjects were measured while carrying the each backpack in an ambient climate of 20-25^{0} C and 30-40% relative humidity while carrying each backpack. The backpack was adjusted for comfort immediately prior to the start of the treadmill walk. The subjects wore their own pants, shorts, T-shirt, socks and gym shoes.

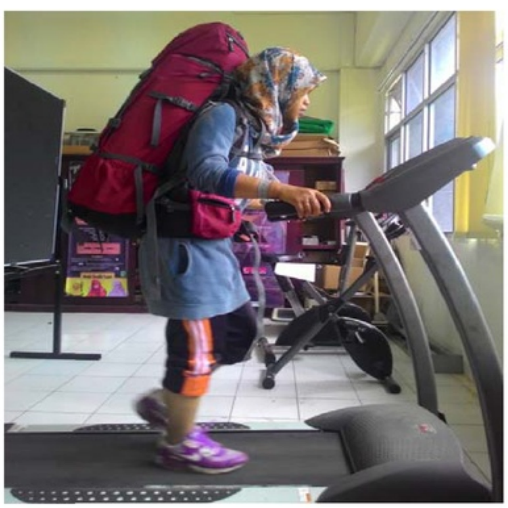

Figure-1. Subjects were simulating a climbing trip using treadmill.

Experimental walks for each subject were undertaken on three different days from 09:00 until 13:00 using different backpacks. The distance between the first and subsequent retrieval of data is at least 3 days for each subject, with the aim of restoring the physical condition of the subjects. The experiment was conducted from December 2015 until March 2016.

e) Measurements

1) Surface EMG and ECG: Surface EMG serves to see the impact of backpack used to the subject's muscle. Based on preliminary survey results, the users often experience pain on the right shoulder after using backpack. Therefore, the right upper trapezius muscle was chosen to record the EMG signals when performed the task. The subjects' skin was prepared and cleaned for placing the electrode. Bipolar Ag/AgCl surface electrodes were placed with an inter electrode distance of 20 mm at the belly of the right upper trapezius muscle. Electrode positions were located according to Hermens *et al.* [12].

Furthermore, ECG was used to measure the electrical activity of the heart muscle that is useful to see the impact of backpack to the subjects' heart pressure or tension after simulating the climb. ECG leads are attached on the front of the chest. A small amount of gel is applied to the skin, which allows the electrical impulses of the heart to be more easily transmitted to the ECG leads.

EMG and ECG measurements performed twice for each measurement day. Firstly it was conducted before the subjects bear the backpack and perform walk simulation. The second measurements were performed after simulated climbing for an hour. The measurements were taken while the subjects sitting on a chair in a relax position.

Figure-2. Measurements of EMG and ECG.

2) Perceived Musculoskeletal Discomfort: A modified Nordic Body Map questionnaire has been used to capture subject perceptions of musculoskeletal discomfort before and after task performance [13] and [14]. It is essential to know the relationship between the objective and subjective measures of musculoskeletal discomfort. It caused by people respond to the surroundings as they

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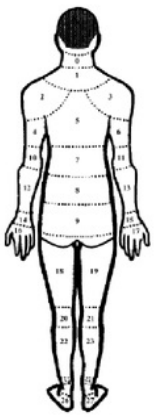
perceive it rather than as it "really is" [15]. The advantage of using subjective measurements such as rating scales is that they are easy to administer and do not require any instrumentation or calibration. The process is generally non-invasive (although it may interrupt the task), and the data are easy to interpret [16].

3)



No	Location	Grade of complaints			
0	Pain/stiff in the upper neck	A	B	C	D
1	Pain in the lower neck				
2	Pain in the left shoulder				
3	Pain in the right shoulder				
4	Pain in the left upper arm				
5	Pain in the back				
6	Pain in the right upper arm				
7	Pain in the waist				
8	Pain in the buttock				
9	Pain in the bottom				
10	Pain in the left elbow				
11	Pain in the right elbow				
12	Pain in the left lower arm				
13	Pain in the right lower arm				
14	Pain in the left wrist				
15	Pain in the right wrist				
16	Pain in the left hand				
17	Pain in the right hand				
18	Pain in the left thigh				
19	Pain in the right thigh				
20	Pain in the left knee				
21	Pain in the right knee				
22	Pain in the left calf				
23	Pain in the right calf				
24	Pain in the left ankle				
25	Pain in the right ankle				
26	Pain in the left foot				
27	Pain in the right foot				

Figure-3. A modified nordic body map questionnaire. A (No pain = 1 point), B (Moderate pain = 2 point), C (Pain = 3 point), D (Very painful = 4 point) Source: [14].

These measurements were administered before and after an hour walk. The subjects were asked about their perceived muscular strain in the neck, shoulders, upper and lower back, elbows, wrists, hips, knees, ankles, etc. The administrations of the questions before and after the experiment were repeated in a balanced design for each backpack.

4) Data Analysis: Data derived from EMG and ECG measurements were processed and filtered using Cobra4 software from PHYWE System GmbH und Co.KG. The results, EMG and ECG amplitude, than were analysed statistically using the Microsoft Office Excel and Statistical Package for the Social Sciences (SPSS) for Windows version 20.0. Extreme outliers, results that are unreasonable and probably resulted from errors in measurement or recoding were carefully identified and eliminated. The data were tested for normality distribution before being used for further analysis using the Shapiro–Wilk test. It was found that the data was normally distributed. Descriptive statistics, including means and percentage of differences of the above measurements were calculated.

3. RESULTS

a) Surface EMG

Figure-4 presents the mean EMG amplitude before and after experiment for all types of backpack. The results show that the mean EMG amplitude of the right upper trapezius muscle increase after subjects conducting the experiment. It also specifies that percentages of EMG amplitude differences before and after the experiment were 27.17% for Pack X, 81.56% for Pack Y, and 87.67% for Pack Z. It indicates that the highest percentage of EMG amplitude differences is on Pack Z.

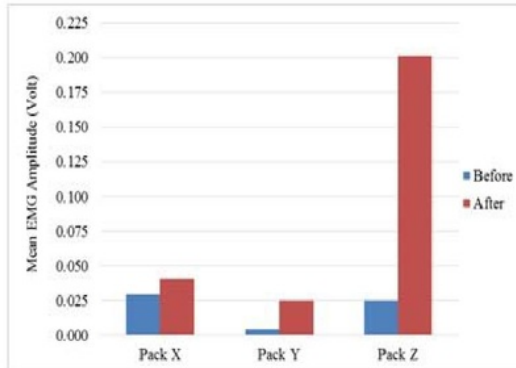


Figure-4. Mean EMG amplitude before and after experiment.

b) ECG

Figure-5 demonstrates the differences of mean ECG amplitude before and after experiment. The mean ECG amplitudes were higher after subjects conducting the experiment for all types of backpack. The differences of mean ECG amplitude were 8.22% for Pack X, 1.22% for Pack Y, and 52.28% for Pack Z. The results indicate that the largest discrepancy occurs when a subject using Pack Z for experiments.

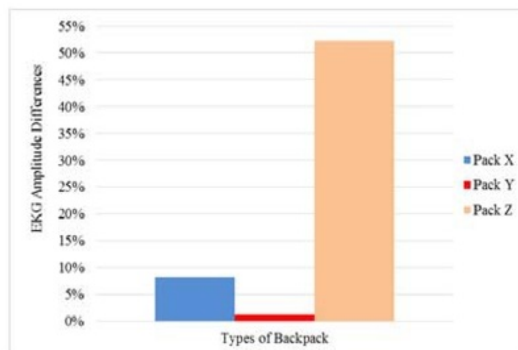


Figure-5. ECG amplitude differences.

c) Nordic body map questionnaire

Figure-6 illustrates the differences of musculoskeletal complaint scores for the five highest complaints for each backpack. The musculoskeletal complaints after experiment are higher than before experiment. Subjects felt more pain in the right and left shoulders after experiment using all types of backpack.

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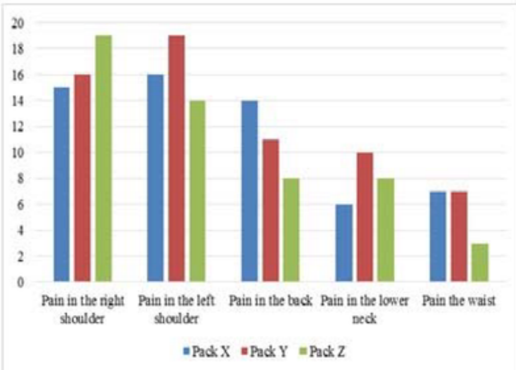

Figure-6. Nordic body map questionnaire score differences before and after experiment.

The highest difference of musculoskeletal complaint score in the right shoulder occurs when subjects use Pack Z (19 point). However, subjects experienced more pain in the left shoulder and the lower neck when they use the Pack Y (19 and 10 point, respectively), whereas for pain in the back was felt by subjects when using Pack X (14 point).

4. DISCUSSIONS

This study evaluated three types of mountaineering backpacks using physiological measurements (Surface EMG and ECG) and subjective measurement (Nordic Body Map questionnaire). The selection of backpacks used for experiment was based on preliminary studies conducted to investigate the frequently used backpacks in Indonesia, especially in Padang, West Sumatera.

The EMG data shows that mean EMG amplitude increased after conducting experiments. The increase in amplitude indicates that there has been occurred muscle fatigue on the measured muscle [17]-[19]. In addition, the results show that the highest increase in EMG amplitude occurs when subjects use Pack Z. This suggests that the use of Pack Z affects most to subjects' muscle fatigue. The reasons for this condition could be caused Pack Z do not have back adjustment system. It also has shoulder strap with soft foam but it is thin so if used for a long time, it can suppress the shoulder and cause pain. Pack Z also has no breathable back system causing heat feeling to the subjects.

Pack Y caused lower muscle fatigue than Pack Z. Pack Y also does not have back adjustment system, so that the subjects with extreme posture (Tall, short, slim, small or large), will feel a bit sore after a long time using the bag. Pack Y has a slightly thick foam strap so that respondents feel hot when using it. Air circulation was in the middle of backpack, but depressed and inhibited by back pad, so that the back cushion can be soaked in subjects' sweat. Pack Y is the heaviest bags compared to Pack X and Z. However, it has stronger material than Pack Z.

Muscle fatigue caused by use of Pack X is lower than use of Pack Y and Z. Pack X has back adjustment systems. It also has breathable back system so make the back is not hot or wet when used. Pack X also has a bearing backs like hollow body so that the users will feel more comfortable when use it. Pack X has a strong material, thick and soft pads.

Similar to the EMG results, the ECG data show that the highest electrical activity on heart muscle occurs when subjects using Pack Z, followed by Pack Y and X during experiments. This indicates that all backpacks causes fatigue among subjects, particularly in the Pack Z. This is due to Pack Z has a thin straps, so the subjects feeling pinched in the body near the armpit because of the backpack load. So that in a long use, subjects would feel pain and heavy. Pack X and Y also have thick and sturdy pad design and in accordance with the users' backs, so the backpack load does not suppress the body when use the packs.

Results from modified Nordic Body Map questionnaire demonstrated that subjects felt highest pain in the right shoulder, followed by in the back, neck, and waist. The reason for this issue might be that the subjects are all right handed. This muscle is located at the base of the neck, down towards the shoulder and arm, and passes under the shoulder blade. When this muscle shortens and tightens, it generates neck pain, usually caused by 'tension, stress, lack of exercise, poor ergonomics, or keeping a sitting posture for long time' [38]. These results were also consistent with other studies showing that the shoulder elevators are mainly sensitive to fatigue when performing tasks with the upper limb at or above shoulder level [21]-[23].

The Nordic Body Map questionnaire results also show that pain was mostly felt when subjects using Pack Z. So that this subjective measurement results support the objective measurement results using surface EMG and ECG.

Based on body and heart muscle activities as well as subjective measurement analysis, it can be captured some features for comfortable or ergonomic backpacks which are especially used for nature lover and mountaineer activities. Some recommendations can be derived are as follows:

a. The backpack should have head adjustable lid, so that the body does not bent forward
b. The backpack should have back adjustment system
c. The backpack should have well-padded shoulder strap which is fit the shoulder curve
d. The backpack should have sternum pad which serves to balance between the shoulder straps.
e. The backpack should have well-padded waist strap
f. The backpack should have internal contoured frame design
g. The backpack should have breathable back system
h. The backpack should have frame from strong and lightweight material.
i. The backpack should have cloth from strong and lightweight material

j. The bag should be sewn neatly and tightly so it does not penetrate water when using
k. The backpack should have the size and shape which fit the users' body size. It is recommended to use backpacks with <60 litre-volume for users with extreme body like short or small, and backpacks with >60 litre-volume for users with extreme body like tall and big.

5. CONCLUSIONS

This study used surface EMG, ECG and modified Nordic Body Map for evaluating the design of three mountaineering backpacks from ergonomic side. The results indicate that in this study, Pack X has better and more ergonomic features compared than Pack Y and Z when analyzed from electrical activity of body and heart muscles as well as subject perceptions of musculoskeletal discomfort. The results of this study would be a useful reference for users who want to choose or buy the ergonomic mountaineering backpacks, or for industries who want to design or produce ergonomic mountaineering backpacks. Future research should be designed an ergonomic mountaineering backpack based on the recommendations obtained.

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