Ergonomics Redesign of Mountain Backpack for Female Hikers in Indonesia

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Abstract

Mountain climbing is a challenging natural activity that requires days and quite a lot of equipment stored in a backpack, which is usually called a mountain backpack. Mountain backpacks that already exist in the Indonesian market today tend to be designed according to male or unisex posture. Based on preliminary data from the Nordic Body Map questionnaire distributed to twelve female climbers at Diponegoro University, there were complaints in the neck, back, shoulders, and waist due to the use of mountain backpacks on the market today. Therefore, it is necessary to redesign the mountain backpack for female climbers. The consideration included technical, anthropometry, physiological, biomechanics, and usability. The results showed that female climbers wanted comfortable mountain backpacks. In the anthropometric aspect, the design of mountain backpacks is focused on the back pads and main straps. In the physiology aspect, the new design of mountain backpacks has a pattern of changes in the rate of change of working pulse smaller. It is found that the design of new mountain backpacks gives less pressure than the old designs. The usability test result found that the new design mountain backpack has a higher usability value than the old design mountain backpack.

Keywords
Mountain Backpack, Female, Anthropometry dimension, Perceived exertion, Cardiovascular load, and Static strength

1. Introduction

Outdoor activities are currently favoured by various groups, both students, students, workers, and others. Nature presents various types of sports that are challenging to do. Many nature-loving communities exist throughout Indonesia, both high schools, universities, and other communities. The community has the same goal of doing outdoor activities and preserving nature. One of them is WAPEALA UNDIP, a student mountaineering club at Diponegoro University.

Mountain climbing is one of the outdoor sports, which is full of challenges (Harley 2007). Climbing to the top of the highest mountain takes days. The climb requires much equipment. All equipment is stored in a backpack, which is often called a mountain backpack. Therefore, the mountain backpack must be designed appropriately so that it is safe and comfortable when used.

Factors to consider in choosing a mountain backpack are the size, function, price, comfort, material, and model capacity. When assessed in terms of ergonomics, the primary consideration factor is comfort. This comfort factor is directly related to the user's body posture and dimension. Therefore, it is necessary to adjust anthropometry in producing this mountain backpack so that when the mountain backpack is used, it does not cause injury or muscle fatigue to climbers. Anthropometric adjustments have already begun to be applied by mountain equipment manufacturers in producing mountain backpacks. However, most of backpack sold in market are brands from Europe and America.

Based on preliminary survey, Indonesian mountain bag manufacturers tend to use anthropometry of Asian male climbers and pay less attention to Asian female climbers. Whereas at this time, Asian female climbers, especially Indonesia, are increasing. The number of female climbers in WAPEALA UNDIP has increased in the past two years. The unavailability of a mountain bag that fit with women's anthropometry causes Indonesian female climbers to tend

to choose domestic products for male or unisex anthropometry. That is because the price is more affordable than a mountain bag that suits European women's anthropometry.
Several complaints were felt as a result of the use of the existing mountain bags. These complaints include discomfort, musculoskeletal fatigue, and psychological disorders during climbing that affect health. The anthropometric suitability used is essential to implement because if the use of backpacks is not as needed, it will harm users (Moore *et al*. 2007). These adverse effects can cause back pain, changes in posture and gait, and injuries (Bauer and Freivalds 2009).

It is evidenced by the results of preliminary data on 12 participants from the WAPEALA UNDIP for musculoskeletal disorders (MSDs) complaints as a result of the use of an existing mountain bag, which was carried out in March 2019 stating that, 83.3% of participants experienced pain in the lower neck, right shoulder, and left shoulder. As many as 75% of participants feel pain in the back and waist, and 66.67% of participants felt pain in their left upper arm and right upper arm. Based on this, it is crucial if Asian female climbers, especially Indonesia, use products or backpacks in line with Asian women's posture. Therefore, this research will design an ergonomic mountain bag for female climbers in Indonesia.

The design of the mountain bag in this study uses Indonesian female anthropometric data obtained from the Indonesian Ergonomics Association. The anthropometric data is used to design a mountain bag that fits the posture of Indonesian women. After designing a mountain bag based on anthropometry, the next design is to pay attention to technical aspects. This aspect is used to determine the needs and desires of consumers. The data was obtained from the voice of the customer through open interviews with participants and producers. This study reviewed the physiological aspect that is carried out in an evaluation of the mountain bags that already exist in the market and the design of mountain bags with physical workload analysis.

Another aspect is biomechanics used to determine the amount of force imposed by the body due to the use of weights. Furthermore, the biomechanical analysis was processed with 3D SSPP software. Another aspect of this research is the aspect of usability or usability level. This aspect of usability uses usability testing using the USE questionnaire. Based on these things, this study proposes the design of an ergonomic mountain bag for female climbers who look at the technical aspects, anthropometric aspects, physiological aspects, biomechanical aspects, and usability aspects.

2. Methods

The research design used is experimental. This study was conducted to determine whether there was a change as a result of the treatment of the object under study. Data collection in this study was conducted with primary and secondary data. Primary data was taken directly through questionnaires and interviews, while secondary data were anthropometric measurements and technical aspects from the bag manufacturer.

The study begins with a survey of female backpack user in WAPEALA UNDIP and the backpack manufacturer to obtain the design criteria. These criteria are used to create a prototype of the proposed backpack. The proposed backpack uses the anthropological data of Indonesian female. Experiments carried out on the use of prototype bags compared to existing products. The performances of the products are assessed from physiological, biomechanical, and usability aspects. Physiological aspect uses the cardiovascular load and Borg's Scale, biomechanical aspect uses the Static Strength Prediction method, and the usability aspect use the usefulness, satisfaction, and ease of use (USE) questionnaire.

2.1. Cardiovascular Load

According to Manuaba and Vanwonterghem (1996), the cardiovascular load determines the classification of workloads based on an increase in work pulse compared to the maximum pulse rate due to cardiovascular load (cardiovascular, % CVL). Where the maximum pulse is (220-age) for men and (200-age) for women. From the calculation of % CVL will then be compared with the classification that has been set as in Table 1.

Table 1. Cardiovascular load classification (Manuaba and Vanwonterghem 1996).

CVL	Classification
<30%	Fatigue does not occur
30- <60%	Repair is needed
60- <80%	Short-term work
80- <100%	Immediate action is needed
> 100%	Not allowed to move

2.2. Borg's Scale

Gunner Borg first discovered a measurement to measure the perceived exertion. This scale consists of several numbers (between 6-20), which represent the amount of work. The numbers on this scale, when multiplied by 10, will reflect heartbeats per minute. This scale is measured from 0-10 (or more) and is recognized as a ratio scale. The rating perceived exertion (RPE) scale applied in this study adapted from Kroemer *et al*. (2001) as in Table 2.

Table 2. Borg's RPE scale (Kroemer *et al*. 2001).

Scale	Description
0	Nothing at all
0.5	Extremely weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
7	Very strong
10	Extremely strong (almost max)

2.3. Static Strength Prediction

Michigan College of Engineering has developed a program on biomechanical and static strength capabilities from workers related to the work environment's physical needs, which is called the 3D Static Strength Prediction Program (3D SSPP). Ergonomists, engineers, therapists have used this method, and researchers, to evaluate a job, and to be used to redesign a job. 3D SSPP software is useful for analyzing movements with heavy material loads when biomechanical calculations assume that acceleration and momentum are ignored. In use, the 3D SSPP program requires data input, i.e.: (a) anthropometry, i.e. gender, height, and weight, (b) joint angles, and (c) hand loads (Agatha 2009).

2.4. Usability

Usability comes from the word usable, which generally means it can be used well. Usability can be said to be useful if the failure in its use can be eliminated or minimized and provide benefits and satisfaction to users (Chisnell and Rubin 2008). According to ISO 9241-11 (1998), usability is the extent to which a product or system can be used by its users to achieve specific goals, effectively efficiently, and users become satisfied.

Usefulness, Satisfaction, and Ease of Use (USE) is a questionnaire that can be used to measure usability in a product or a system. Several studies indicate a correlation and interplay between the ease of use and usefulness parameters (Rahadi 2014). An increase will follow an increase in the ease of use parameter in Usefulness. These two parameters will contribute significantly to satisfaction.

3. Results and Discussion

In this technical aspect, the criteria used as a reference in the design are those that have a value of more than 60%. These criteria are high-quality and waterproof material; the sling is easily adjusted and has a comfortable back system. Table 3 lists the percentage of respondent who state the criteria is important. The size is adjusted to the posture of Indonesian female climbers as shown in Table 4.

Table 3. Technical aspects.

Criteria	Amount (%)	Technical Response
Made of high-quality ingredients	64.7	Excellent quality of material
The sling is easily adjustable	88.2	Strap feature
Comfortable shape according to body shape	37.5	Size according to anthropometry
Not colourful	6.3	Colour design
There is a source of energy for charging battery life	5.9	Modification and innovation
Has a thick sling	5.9	Sling
Dark in colour	6.3	Colour design
Back cushion is not too big	25	Size according to anthropometry
Smaller than body dimension	37.5	Size according to anthropometry
Strap position is not too high	31.3	Size according to anthropometry
Made from water-impermeable material	94.1	Waterproof material
Made of lightweight material	5.9	Lightweight material
Has a durable zipper	5.9	Durable ingredients
Has lot of compartment	5.9	Minimum 5 compartments
Having a comfortable back system	100	Size according to anthropometry

Table 4. Size of mountain bags after redesign.

Backpack Section	Body Dimension	Dimension (cm)	Backpack Size (cm)
Height	Seated shoulder height [P50]	69.070	69.070 H 69
Width	Shoulder width [P50]	41.734	41.734 H 42*
Back base width	Shoulder width [P5]	26.796	26.796 H 26*
Back base height	Seated shoulder height [P50]	61.600	61.600 H 61
Main strap length	Seated shoulder height [P95]	81.330	81.33+ 32.486 = 113.82 H 114
	Chest thickness [P95]	32.486	
Main strap width	Upper shoulder width [P5]	21.634	(21.634-10.680)/2 = 5.477 H 5*
	Head width [P5]	10.680	

* significantly differ from existing backpack size

The dimensions to be changed is the part of the mountain bag related to the back system. They're the height and width of the back base, the length, and width of the main sling. Figure 1 is a picture of the proposed mountain bag design.

Figure 1. Proposed mountain bag design.

Figure 2 is a comparison between working pulses during an experiment using an old design backpack and a proposed design of participant #2. Every participant has different working pulses range. We use t test to determine the significance of participants working pulse difference between old and proposed backpack. Based on these results, it can be seen that the average work rate per minute of the proposed mountain bag design has a significant difference with the old design. With an average proposed design, the mountain bag is lower than the old design. It is indicated that the proposed design mountain bag has a lower physical workload than the old design. It means that the risk of fatigue is smaller than the old design, although the pattern of the rate of change is not significantly different. Figure 3 shows the comparison value of %CVL of old draft mountain bags and the proposed design.

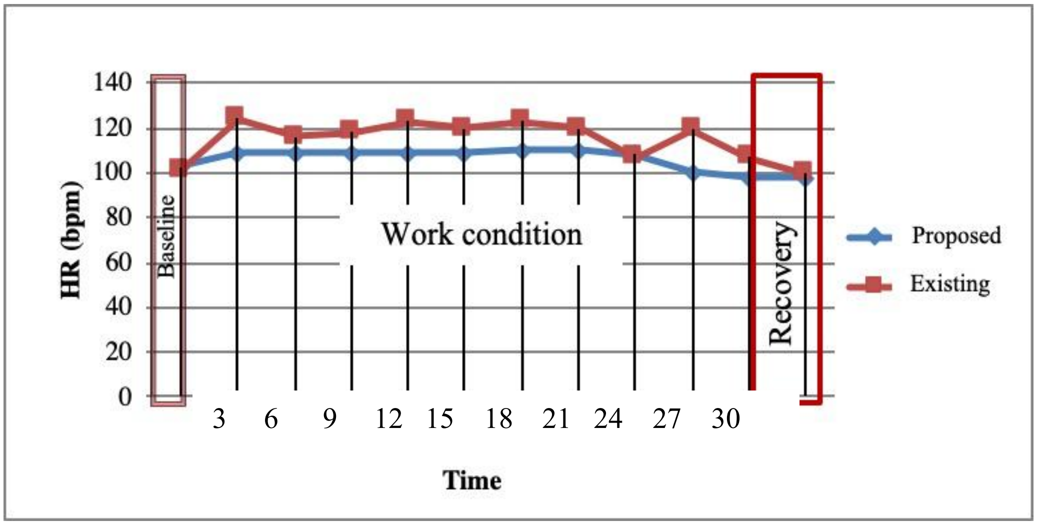

Figure 2. Example comparison of work pulse rate of participant #2.

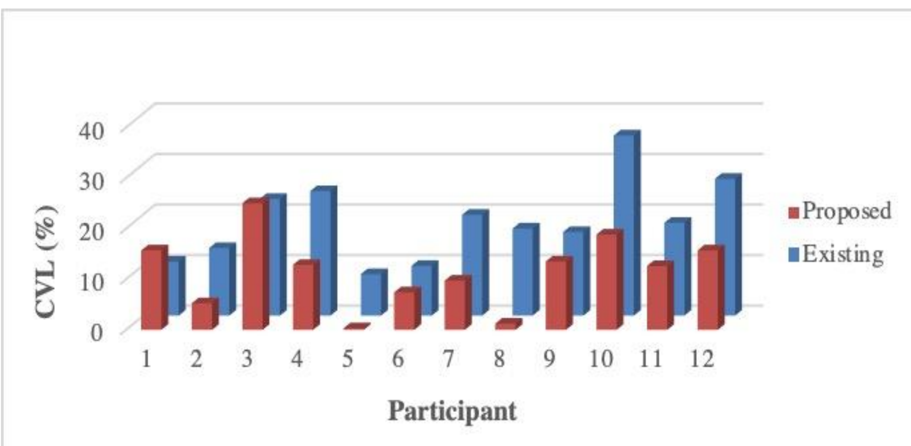

Figure 3. Comparison of cardiovascular load.

Based on the calculation of %CVL, it can be seen that the average value of %CVL using a proposed design mountain bag is smaller than the old design. It means that the proposed design mountain bag has a lower risk of fatigue than the old design.

Figure 4 shows the comparison of the RPE values, which are subjective physical workload assessments. RPE assessment reveals that there is no significant difference between the existing and proposed design mountain bags. However, the average RPE value of a proposed design mountain bag is smaller than the old design. It indicates that the physical workload of the proposed draft mountain bags is smaller than the old designs.

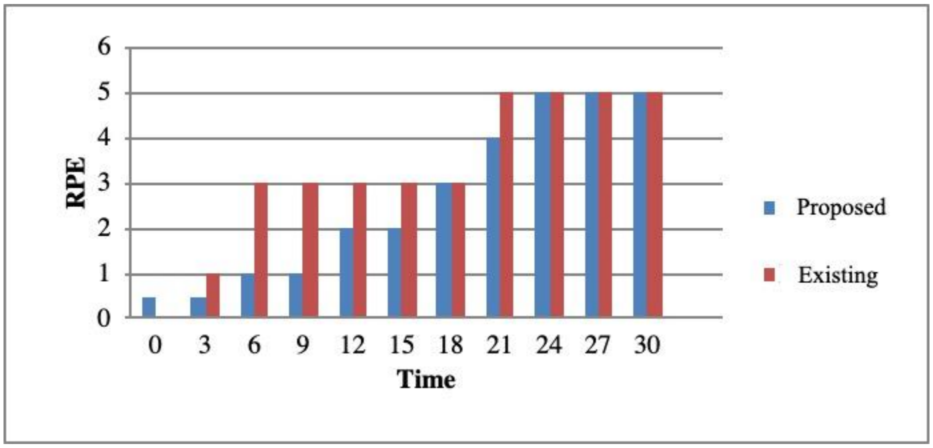

Figure 4. Comparison of RPE for participant #2.

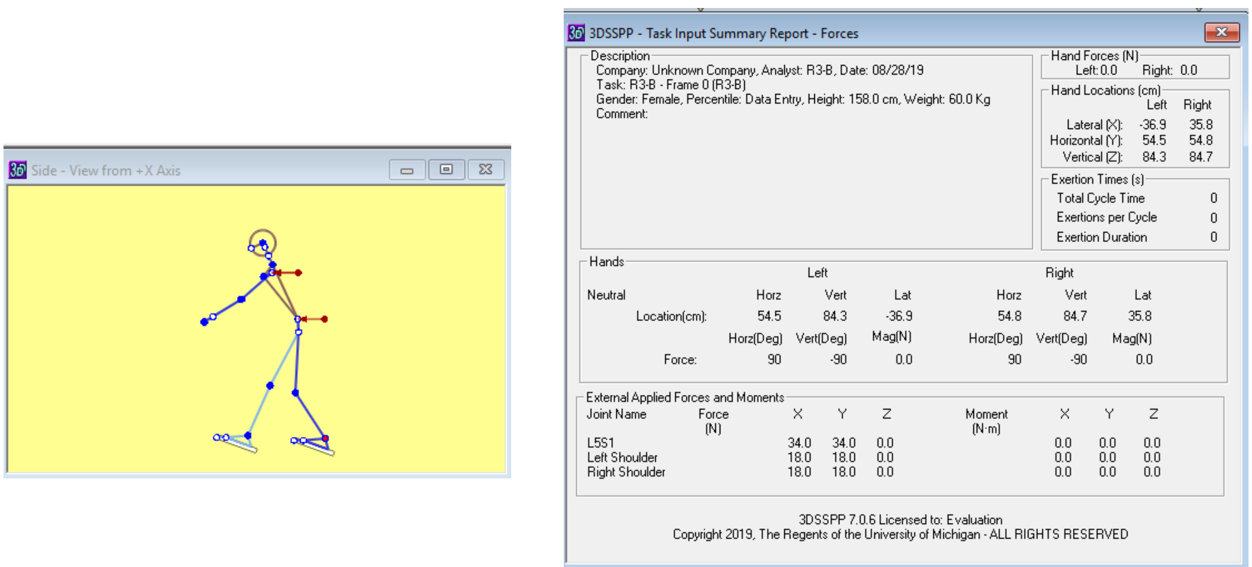

Figure 5. 3D SSPP Biomechanics Test.

Figure 5 is the result biomechanical test with 3D SSPP and the total compression force value (N) at L5/S1. The result shows that there are significant differences between the two designs. The value of the total compression bag of a proposed design is smaller than the old design; this can be interpreted as the proposed designed mountain bag having a smaller chance of experiencing MSDs complaints than the old design.

Table 5 contains the results of the USE questionnaire for the existing and proposed mountain bag design. Based on the usability comparison of the old design and the proposed design, it can be seen that there is no significant difference between the two designs. Even so, the average reusability of proposed designs is greater than the old designs. It means that the proposed design mountain bag is more capable of Indonesian female climbers than the old design.

Table 5. Results of the USE Questionnaire.

Design	**Usefulness**	**Ease of Use**	**Ease of Learning**	**Satisfaction**	**Usability (%)**
Existing	0.69	0.76	0.86	0.71	75.38
Proposed	0.73	0.78	0.92	0.82	81.04

4. Conclusions and Recommendations

The wants and needs of consumers with the highest percentage of mountain bag value criteria, namely, back system, frame, main strap, material, and colour. The size of the mountain bag design after calculating the width of the bag is 42 cm, the width of the back base is 26 cm, the height of the bag is 69 cm, height of the back base is 61 cm, the length of the central rope is 101 cm, and the width of the main rope is 5 cm.

The physiological aspect shows that the average working pulse and percentage of the proposed design CVL are smaller than the old design. So that the proposed design is less likely to feel work fatigue. At the Rating Perceived Exertion value, the old design is smaller than and the proposed design. RPE is a measurement of physical workload subjectively, so it has participants' presumptions that have the same feelings towards product valuation.

In the biomechanical value, the proposed design of the mountain backpack has a smaller value than the old design. So, it has a smaller risk of experiencing MSDs complaints. In the usability factor, the proposed design mountain bag has a higher value than the old design. The proposed design mountain bag can be interpreted as more able to be used by participants than the old design.

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