International Journal Of Health Medicine and Current Research
E - ISSN : 2528 - 3189
P - ISSN : 2528 - 4398

International Journal of Health Medicine and Current Research
Vol. 3, Issue 02, pp.893-899, June, 2018

DOI:
10.22301/IJHMCR.2528-3189.893

Article can be accessed online on:
http://www.ijhmcr.com

ORIGINAL ARTICLE

INTERNATIONAL JOURNAL OF HEALTH MEDICINE AND CURRENT RESEARCH

APPLYING ERGONOMIC APPROACH DECREASE BIOMECHANICAL FORCE AND WORKLOAD OF TRADITIONAL PORTERS IN BADUNG MARKET DENPASAR BALI

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ARTICLE INFO

Article History:
Received 26th March, 2018
Received in revised form
30th April, 2018
Accepted 31th Mei, 2018
Published online 30th June, 2018

Key words:
Ergonomic Approach, Biomechanical Force, Workload And Traditional Porters.

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ABSTRACT

Female Traditional porters work every evening at Badung market from 7 pm to 3.30 am. Age interval of the porters is 18-40 years. The weight of goods carried by a single porter is 60-100 kilograms plus 1-2 kilograms of the basket's weight, carried on the head. The distance of each porting activity is 100 meters. From ergonomic concept, the burden is excessive and may cause injuries such as damage of intervertebral discs, pain, excessive fatigue and head and neck muscles disorder. The symptoms are more obviously seen in those over 40 years old for most of them are not ver y capable of working, even some of them need medical treatment. To overcome this non-ergonomic work condition, a work quality improvement was done to 11 sampled porters, including on work position, carrying weight and equipment design in order to improve the unnatural work position and to give chance to them to have an active rest as well as to alter the static work system to be more dynamic. Results of this study were: (1) average of pressure force on L5/S1 before improvement was 7,967.65 ± 66 .78 N and after improvement was 2,983.26 ± 16.63 N; (2 pulse rate average before improvement was 150.61 ± 1.06 pulses/minute and after improvement was 119.51 ± 1.39 pulses/minute. The results analysis showed that applying ergonomic approach could decrease the pressure force on L5/S1 of 60.94 % ($p<0.05$) and work load by 42.59 % ($p<0.05$).

Citation: Robert Hutagalung[1*], 2018 "Applying Ergonomic Approach Decrease Biomechanical Force And Workload Of Traditional Porters In Badung Market Denpasar Bali", *International Journal of Health Medicine and Current Research*, 3, (02), 893-899.

INTRODUCTION

Ergonomics is derived from the Greek language: "Ergon" which means work and "Nomos" which means norm (Manuaba, 1983; Pheasant, 1991; Dul and Weerdmester, 1993). Ergonomics is the science, technology and the arts to deploy equipment, machinery, systems, organizations and the environment on the ability, capability and limitation of human beings so as to obtain healthy working conditions and environment, safe, comfortable and efficient so as to achieve the highest productivity (Manuaba, 2003 ; 2006; Grandjean, 1988). With ergonomics, able to suppress the negative impact of the utilization of science and technology, because with ergonomics various diseases due to work, accidents, pollution, poisoning, job dissatisfaction, human error, can be avoided or minimized.

The porters at Badung traditional market are therefore not free from getting fatigue during work. According to Manuaba (1983), the effect of improper working posture is easy fatigue if the ill posture is maintained for too long without rest. This condition is caused by unnecessary contraction of certain non-relevant muscles or of those that do not connect directly or by contraction of static muscles.

The number of female traditional porters working on irregular basis in the evening is estimated to be around 50-100 persons, and they do not have permanent customers nor certain base. While those female porters working regularly every evening are 159 porters who start to work at 7 pm until 3.30 am. The age range of the porters is 18-40 years. The estimate weight carried by a single porter is 60-100 kilograms plus 1-2 kilograms of the basket's weight, carried on the head. The distance that the porters have to carry the goods is 100 meters. According to the ergonomic concepts, the above process is described as excessive and it can be the causal factor of several injuries such as intervertebral discs damage, pain, severe fatigue, and muscles dis orders around the head and neck areas. Result of an interview done to the porters revealed that they had experienced the above conditions but had ignored them due to the work demand, inadequate knowledge, and economical factors. When their ages reached 40 years or above, the injuries would occur in more obvious manners, even some would never be able to work again or would need medical treatment (Hutagalung, 2007).

According to Adam and Hulton (1981), rupture of the spinal cord segment was associated with breakage of the upper and lower part of the intervertebral discs, which resulted from a pressure force of 10,025 Newton. While the permitted maximum limit of weight as recommended by NIOSH (National Institute of Occupational Safety and Health) is a pressure force of 6,400 Newton on L5/S1 (NIOSH, 1981; Chaffin and Andersson, 1991). Other than that, use of propulsion/power device that is actually needed to carry the goods is not efficient. This is due to the fact that the shape of the basket for carrying goods has over-sized diameter causing the distance between porter's weight force position and the goods' weight force to become longer, thus results in increase of the moment. Moreover, the non ergonomic work posture makes the propulsion/lifting capacity to move the load (goods and basket) become greater. Thus, the pressure force on the vertebrae L5/S1 increases and the workload gets heavier.

Improvement measure should be taken to overcome the above problem such as on work posture, workload and tool's design to develop a natural work posture and to provide resting time to the porters as well as to change the work system from static to dynamic.

METHODS

This study was causal comparative research with a treatment by subject design. Subjects of this st udy were 11 porters and all were females with discussing characteristics of age, body weight, height, work experience, resting pulse rate and education. Target population of this study was all female traditional porters at Badung market, Denpasar who worked both regularly and irregularly every evening of a total of 259 porters, but covered population was 159 female porters who worked daily in the evening. Variables of this study were identified and classified as follows: (a) independent variable is work quality improvement, which is combination of several improvements related to ergonomic concepts such as work posture, basket design (modification) and porting load; (b) dependant variable is aspect of workload; and (c) control variable is subject condition (age, gender, body weight, working experience, level of education, health and anthropometry) and environmental condition (wet temperature, dry temperature, humidity and wind velocity).

Before treatment, the subjects were asked to carry weight as far as 100 meters according to their usual condition from 8 pm to 2 am for one week and they were assessed on several aspects such as environmental condition, resting pulse rate, working pulse rate, followed by giving them two days of washing out period. Next, the subjects worked by applying ergonomic approach such as reducing the load according to biomechanical calculation, utilizing an ergonomic basket, giving regular rest and sweet tea. Working hours and measurement were similar to those before improvement and the results were analyzed statistically using t-test.

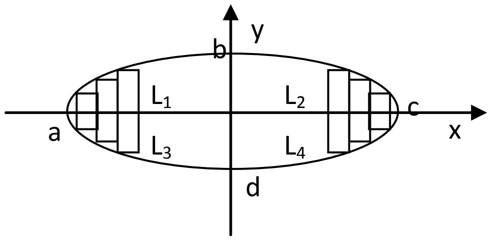

Figure 1. Area of Abdominal Pressure Acting at the Center of the Diaphragm.

These can be computed by application of the segmental approach (summing moments for each body segment) in the linkage system described in equation (1). For simplification, assume that the composite center of mass location of the body segments above the L5/S1 is known. This allows the moments to be expressed as:

$$\vec{M}_{L5/S1} = \vec{M}_{(body\ weight)} + \vec{M}_{(load)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$
$$\vec{M}_{L5/S1} = b.mg_{(body\ weight)} + h.mg_{(load)}$$

Fisher (1967) correlated these data with the hip moments M_H at various included angles between the thigh and torso θ_H. The resulting empirical prediction equation assumes the hip moments are equivalent to the L5/S1 disc moments, and can be expressed as:

$$pA = 10^{-4}\left[43 - 0{,}36(\theta_H + \theta_T)\right]\left[M_H\right]^{1,8} \text{ mmHg} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

where: pA is the abdominal pressure (mm of Hg); θ_H is the included angle at the hips; and is the load moment at the L5/S1 disc (Nm).

The moment equation for the system is:

$$\Sigma\vec{M}_{L5/S1} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$
$$0 = b(mg_{bw}) + h(mg_L) - D(F_a) - E(F_m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Since the compression and shear forces are assumed to act the disc center of rotation, and thus are not considered in the moment equation, the equation can be rearranged to solve for the unknown muscle force F_M:

$$Fm = \frac{b(mg_{bw}) + h(mg_{Load}) - D(F_a)}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

Where: F_M is the effective erector spinae muscle force necessary to stabilize the spine; *b*, *h*, *D*, and *E* are the moment arms of relevant forces (see Figure 2); mg_{bw} is the weight of the body segments above the L5/S1 level; F_A is the effective force due to abdominal pressure acting at the center of the diaphragm ($F_A = P_A$ 465 cm^2); and mg_{load} is the weight of the load in the hands. The forces acting parallel to the disc compression force (as shown in Figure 3) can be expressed by:

$$\Sigma\vec{F} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$
$$\cos x.mg_{bw} + \cos x.mg_L - F_a + F_m - F_c = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(7)$$
$$F_c = mg_{bw}\cos\alpha.mg_L\cos\alpha - F_a + F_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

$$F_c = (mg_{bw} + mg_L)\cos\alpha - F_a + F_m \qquad \text{..............................(9)}$$

Similarly, the reactive shear force across the L5/S1 disc can be solved by the third equilibrium eqution:

$$\Sigma\vec{F}_{shear} = 0 \qquad \text{..............................(10)}$$

$$\sin\alpha \,.\, mg_{bw} + \sin\alpha \,.\, mg_{Load}\ 0\ F_s = 0 \qquad \text{..............................(11)}$$

$$F_s = (mg_{(bw)} + mg_{(Load)})\cos\alpha \qquad \text{..............................(12)}$$

The action limit equation for manual handling is:

$$AL = 39{,}2\left[\frac{15}{H}\right]\left[1-\left(0{,}004\left|V-75\right|\right)\right]\left[0{,}7+\frac{7{,}5}{D}\right]\left[1-\frac{F}{F_{max}}\right] \qquad \text{..............................(13)}$$

RESULTS AND DISCUSSION

Subjects' Characteristics

Age interval of subject was 20-35 years with average 29.27 ± 3.50 years. Body weight of subjects was 44-69 kilograms with average 50.96 ± 5.05 kilograms. Height was in the range 144.50-160.00 cm with 153.28 ± 8.27 cm in average. Average of work experi ence was 7.64 ± 2.38 years with interval 4-12 years. Based on the above findings, a conclusion was made that the study subjects were proper, skilled and capable of undertaking their job. Frequency of resting pulse was 69.25-85.77 pulse/minute with average 79.14 ± 2.08 pulse/minute. From educational aspect, the number of subjects with level of education of junior high school (SMP) was 18.18 % and elementary school (SD) level was 81.82 %. Thus, level of education was considered as sufficient for doing porting job.

Subjects' Anthropometry

Subjects' anthropometry used in designing work tools (basket) was average height of upper most position of hand 181.14 ± 6.27, average of body height 153.23 ± 5.05, average of arm's length 16.36 ± 1.00, average of hand's width 8.05 ± 0.47. Mean while, for calculating biomechanics, the data above needed to be supplemented with other anthropometric data such as average of shoulder's height 126.32 ± 5.06, average of thigh's height 51.27 ± 4.15, average of knee's height 48.14 ± 2.31, average of belly's width 24.82 ± 2.09 and average of thigh thickness 12.14 ± 1.47. On the basket designing, height of upper most position of hand was measured by using 5 cm percentile, but body height, arm's length, hand's width were measured by that of 95 cm.

Simple Modeling and Pressure Force on L5/S1

Calculation of photography showed that referential point before improvement, when the load was in position of (a) Initial Ho, height before load was carried (32 cm); (b) parallel with center of moment M4, as tall as knee (35 cm) with angle $\alpha 4$ = 55 ± 0.78° ; (c) parallel with center of moment M3, as tall as L5/S1 (68 cm) with angle $\alpha 3$ = 131 ± 0.89° ; (d) parallel with center of moment M2, as tall as part between shoulder and neck (90 cm) with $\alpha 2$ = 62 ± 0.63° ; and (e) maximum height, load was on porter's head when porting activity (118 cm), with angle $\alpha 1$ = 48 ± 0.63°, while angle degree of lower arms and upper arms to horizontal surface was 15±0.78° and 60 ± 0.78° respectively (figure 2 and figure 3). The referential point after improvement, when the load was in position of (a) initial Ho, height of before load was carried (32 cm); (b) $\alpha 4$ = 60.64 ± 1.12 °; (c) $\alpha 3$ = 124.46 ± 1.13° ; (d) $\alpha 2$ = 70.64 ± 0.67°; and (e) $\alpha 1$ = 55.64 ± 0.92°, while angle degree of lower arm and upper arm to horizontal surface was 17.91 + 0.83° and 85.73 ± 0.91° respectively. Measurement of pressure force on L5/S1 before improvement was 7,637.15 ± 66.78 N and that after improvement was 2,983.26 ±1 6.63 N. The difference of pressure force on L5/S1 before and after improvement was 4,653.89 N or decreased by 60.94 %. Adam and Hulton (1981) stated that the rupture of intervertebral disc happened with a pressure force of 5,448 N. The most effective effort to reduce effect of risk is by improving work quality to make the performance of traditional porters increase (Hutagalung, 2007). According to the pressure force on L5/S1, working with workload after treatment of 29.21 kilograms. T-test result showed probability score of 0.00 ($p < 0.05$), meaning that significant change had occurred after improvement of work quality. The limit of normal lifting capacity suggested by NIOSH was in accordance with pressure force of 3,500 N on L5/S1 and maximum porting weight of 6,500 N (Van der Beek, et. al., 2000).

Therefore, the power of pressure force on L5/S1 before work quality improvement exceeded normal porting capacity of 4,237.15 N or around 124.62 % and passed over the limit of maximum porting capacity of 1,137.15 N or about 17.49 %. After improvement, L5/S1 decreased below normal or lessened by 416.74 N.

Table 1. Average Angle and t Analysis on Pressure Force on Vertebrae L5/S1.

Subject Variable	α1 (˚)	α2 (˚)	α3 (˚)	α4 (˚)	θ1 (˚)	θ2 (˚)	Gaya L5/S1 (N)	P
Before Treatment	48,00	62,00	131,00	55,00	15,00	60,00	7.637,15	
After Treatment	55,636	70,64	124,46	60,64	17,91	85,73	2.983,26	0.00
Difference	-7,64	-8,64	6,55	-5,64	-2,91	-25,73	4.653,89	

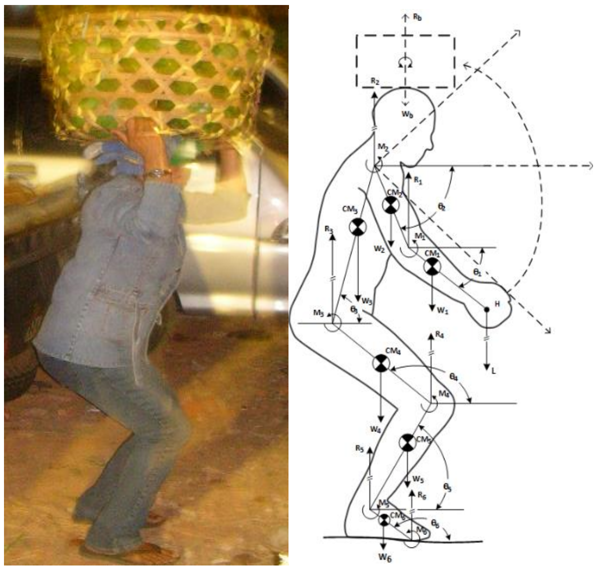

Figure 2. Model of Reaction Force and Moment Analysis on Static Force System.

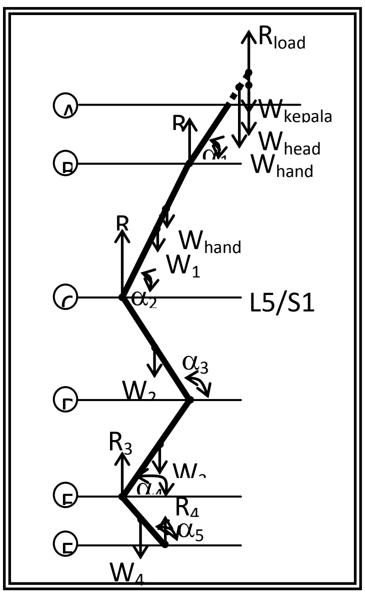

Figure 3. Reaction Force and Moment Analysis on Static Force System.

Ergonomic Design of Basket

The results of basket measurement before treatment were height 50.25 cm, upper diameter 63.55 cm, lower diameter 54.24 cm, weight 1.35 kilograms and volume 123,762.14 cm³. These measurements were not ergonomic if compared to the subjects' anthropometry, hence a new design was required. Regarding the aspects above, calculations data of an ergonomic basket were height 32 cm, diameter 32 cm, weight 1.01 kilograms and volume 25,722.88 cm³. With this volume capacity, the basket should be able to carry load at a maximum of up to 28 kilograms. The volume design matched with biomechanical calculation that maximum porting load was 30.25 kilograms

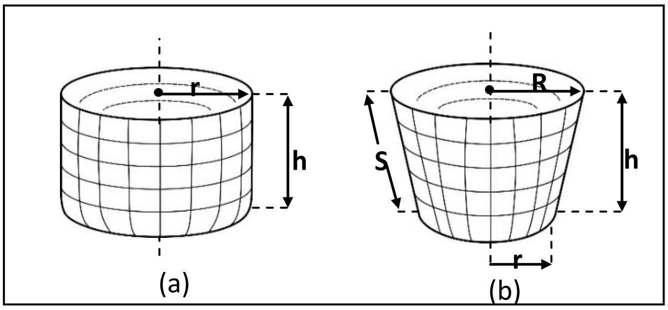

Figure 4. Ergonomic Design of Basket.

Work Environment

The result of before improvement showed that: (a) temperature around 26.40°C to 27.50°C with average 26.96 ± 0.12°C; (b) humidity around 63% to 67% with average 64.29 ± 0.38°C; and (c) wind velocity around 0.20 m/sec to 0.50 m/sec with average 0.34 ± 0.11 m/sec. After improvement, the result of measurement were (a) *26* temperature around 40°C to 27.50°C with average 26.95 ± 1.95°C; (b) humidity around 63% to 67% with average 64.33% ± 2.16°C; and (c) wind velocity around 0.2 m/sec to 0.6 m/sec with average 0.35 ± 0.01 m/se c. Manuaba (1998) stated that a simple category of work had temperature limit of 30°C to 35°C and that of moderate category had temperature limit of 29°C to 30°C. Limit of outdoors' comfort was at temperature 29°C to 31°C. Oetoko (1980) asserted that tempe rature indicator allowed on work environment minimum 21°C-30°C. Limit of outdoors' environmental comfort was at temperature 22-28°C with relative humidity 70-80% (Jaya, 2008), which means that these aspects do not affect significantly on the increasing of workload. Based on difference test of work environment by using t-independent, probability score of temperature was 0.94 or above 0.05 ($p>0.05$), of humidity was 0.77 or more than 0.05 ($p>0.05$) and of wind velocity was 1.00 or more than 0.05 ($p>0.05$), which mean there were no significant changes of before and after intervention.

Workload

The average resting pulse rate before treatment was 79.14 ± 2.08 pulses/ minute and after treatment 78.48 ± 3.01 pulses/ minute with a range of 69.25 pulses/ minute to 85.77 pulses/ minute, so the average resting pulse rate was 78.81 ± 2.65 pulses/ minute. The resting pulse rate before and after work quality improvement was not quite different. The average resting pulse rate of porters of Badung market is not quite different from that in the study by Adiputra (2008) on the work load in preparing land for cultivation on the field using hoes with four forks and one fork, which resulted in resting pulse rate of 77.31 ± 7.71 and 77.31 ± 7.71, respectively. Based on the t test, the average resting pulse rate before and after treatment was not different significantly at a probability of 0.14 ($p > 0.05$). The result of measurement showed the average working pulse rate before treatment was 150.61 ± 1.06 pulses/ minute and after treatment 119.51 ± 1.39 pulses/ minute. It shows that after the improvement of work quality, working pulse decreased to 31.09 pulse/minute or by 20.64 %. The result of t test on working pulse rate showed that the average working pulse rate before and after treatment was different significantly, at a probability score 0.00 ($p < 0.05$), indicating work load of porters before and after treatment differed significantly. According to Adiputra (2002), the greater body activities cause greater metabolism of the body, so oxygen needs become greater and pulse rate increases.

CONCLUSION

Based on the study results, it can be concluded that: Applying ergonomic approach could decrease the pressure force on L5/S1 of female traditional porters at Badung Bali market by 60.94 %. Applying ergonomic approach can reduce workload of female traditional porters at Badung market Bali by 42.59% .

ACKNOWLEDGMENTS

The writer expresses gratitude to the Director of Postgraduate Program and to the Director of Medical Program, University of U dayana, for facilities and for supporting provided to make the work possible.

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