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Determination of Safe Carrying Load Limit for Women Carrying Water

Rohit Sharma* **and Ranjit Singh**

Faculty of Engineering, DEI, Dayalbagh, Agra, UP, India

Abstract

Fetching and carrying water is women's work in rural India, which results in poor health of women. So, a physiological, biomechanical and psycho-physiological study was conducted among the Women Carrying Water (WCW) for determining maximum acceptable carrying load. A total of 20 subjects were selected from the villages of Haryana, who perform water carrying activities for fulfilling their daily basic needs of water. In the present work, for physiological study both the field and laboratory data were collected. Information regarding Blood Pressure (B.P), hemoglobin content, weight, height, age, ponderal index, lean body weight etc. was also recorded. Biomechanical stresses shows that carrying water is safe only for head mode. For shoulder and waist mode carrying water should be stopped for reducing the risk of injuries. In psychophysiological evaluation out of 7 subjects all rated 15 kg load as the moderate but for shoulder and waist mode only 4 and 3 subjects rated as the moderate and all other subjects rated it as the heavy and very heavy. By considering the stresses such as cardiovascular, muscular and biomechanical and also by psychophysiological evaluation it is concluded that carrying load for the head mode should be around 15 kg and for shoulder and waist mode should not be more than 10 kg at the walking speed of 3.5 km.hr^{-1}.

Keywords: Physiological; Biomechanical; Psycho-physiological; EMG; Heart rate; Walking speed; VO_2max; carrying load

Introduction

Humans are all alike in facing the basic constraint of time and in needing water to drink every day. As well, water is needed for drinking, sanitation, bathing and food preparation. Adding all water needs together, the United Nations High Commissioner for Refugees [1] suggests that 15 litres per person per day is required while the Human Development Report of UNDP sets a standard of 20 litres per capita per day, and Gleick [2] argues for higher minimum 50 litres (approximately) per day per person. Whatever the exact level of this basic need, the residents of developed countries (and the majority of Indian citizens) can simply turn the tap and satisfy it immediately, but in approximately 18.6 % of rural Indian households somebody (usually female) has to spend an average of 47 minutes per day in fetching water for fulfilling their basic water needs.

Traditionally, fetching water has been a woman's job. It does not matter if the women are old, young or pregnant, crucial household needs have to be met after weary day. For women there are no developed countries, they work for longer hours, the plight of poor rural women is rather worse. Every dawn brings with it a long search of fuel fodder and water. They generally fetch 15 to 40 litres of water in one time from a source within 1 kilometer of the user's dwelling and fetch up to 80 litres of water for fulfilling their and family needs. Fetching and carrying water is women's work in rural India. In the villages of the desert district of Banaskantha, women spend up to six hours in a day bringing water from distant sources to their homes. They carry about 20 to 30 liters on their heads on each trip, often walking barefoot [3]. In Haryana where all the villages are provided with safe drinking water through community water supply since 1990, fetching water was found drudgery prone activity [4]. In the year 1999-2000, AICRP (All India Coordinated Research Project) team of FRM conducted ergonomic evaluation of fetching water with the objective to see the risk involved in this activity. Fetching water is an extremely strenuous activity undertaken by rural women and it consumes an enormous amount of their time and energy and reduces it for the rest of work. Physical loading of the body within an individual's capacity for adaptive responses may lead to tissue strengthening; however, frequent loading beyond capacity for adaptation or repair may lead to injury through fatigue failure, accumulation of fatigue damage [5] or early degenerative changes in bone and soft tissues [6]. However, water carrying is a physical activity and assumptions have been made that water carrying is detrimental to health and associated with musculoskeletal disorders, such as spinal pain or other joint problems [7,8]. Such assumptions are supported by strong evidence that the physical demands of work such as handling heavy materials, bending, twisting and lifting, are risk factors for onset of simple low back pain [5, 9] and other musculoskeletal disorders [10,11]. However, very few studies have specifically investigated water carrying as it is performed by women in developing countries and used appropriate methodologies to investigate its association with health generally or musculoskeletal disorders specifically [12,13,14]. Some women may experience high rates of perceived exertion and pain sufficient to limit their capacity to carry water containers [15]. Reduced capacity of women to collect water due to pain or fatigue may have serious implications for the health of their families.

Objective of Study

For protecting the WCW from the hazards of carrying water and also for making the life of WCW easy, it is very important to define a safe load limit for WCW. So, the main objectives of this study was to estimate the safe load to carry for women carrying water by considering the following parameters (1) Physiological responses of WCW including heart rate response and EMG study, (2) Biomechanical study, (3) Psycho-physiological study of WCW for different loads with different modes of carrying.

***Corresponding author:** Rohit Sharma, Faculty of Engineering, DEI, Dayalbagh, Agra, UP, India, E-mail: r25sharma@gmail.com

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Methodology

Data collection

To study the water carrying activity 20 healthy women subjects aged (30.2 ± 8.3) were selected at random from the villages of Kaithal District, Haryana; having a population of about 1, 72, 861. About 60% of the population is working in unorganized sectors and has a literacy of 20% among women. Most of the subjects were local habitual staying in village of Haryana for more than 15 yrs. or since birth. About 80% of the women were married having at least one child. So, the carrying water is their daily job for fulfilling the requirement of water for different uses. The personal information of WCW was obtained through Standard Nordic Questionnaire [16] such as age, weight, height etc.

Basic data of subjects are presented in Table 1. Data collected was for both field and laboratory study. LBW and PI were calculated from anthropometric measurements of the subjects (24.2 ± 6.8; 23.4 ± 1.6). Information regarding hemoglobin content, dietary intake was recorded for checking the physical fitness of the WCW. Information regarding work terrain, walking speed, distance travelled, time spend and mode of carrying water was also recorded through a specially designed questionnaire.

Before starting the study, the subjects were informed of the purpose and procedures of the study and consented to participate. Different size of aluminium container (Handa) filled with water were used for carrying.

Dietary intake of women carrying water (WCW)

The WCW consumes less calorie intake per day. But as their whole day job is mostly sedentary in nature, except for the morning water carrying activity which was calculated from the random samples. Higher fat content for the WCW is evident. The average hemoglobin content of WCW was 12 gm/dl (SD ± 1.38) which was closer to the normal population. The lower calorie intake might be the reason for the poor physical fitness of the WCW.

Work terrain

The work plane for water carrying activity was mostly horizontal except in certain cases where small slopes had to be encountered by the WCW. Paths were well defined but the passages were too narrow at certain points allowing only one person to pass through at a time.

Walking speed, Time spent, Distance travelled

The problem of shortage of drinking water is very acute for majority of the low income group and women spending 3-4 hrs a day in fetching water, having to walk for a long distances.

The average speed of walking as observed for the WCW was 3.1 $km.hr^{-1}$ during onwards journey of fetching water, while the average walking speed obtained by the WCW during backward journey was 3.5 $km.hr^{-1}$, slightly higher. This higher speed might be due to several reasons like 1) availability of water during morning for limited hours, 2) good number of people waiting in a queue to get water, 3) Because she carried a load and wanted to ease herself by finishing the task as early as possible. Based on the field study same speed was selected for the laboratory simulation. On an average they fetched 22 vessels of water daily in summer (16 in morning and 6 in the evening). She spent 6-7 minute per trip to fetch water to home. Hence the time spent on fetching was varying from 132-154 minutes carrying load of 20-30 kg per trip. The approximate distance traveled per cycle of fetching water was about 0.30 km. This depicts that she had to travel about 6.6 km. in a day only for fetching water.

Variable	Women carrying water	
	Mean	SD
Age (yr)	30.2	±8.3
Weight (kg)	50.4	±10.7
Height (cm)	150.2	±5.2
Fat (%)	24.6	±5.8
Lean body weight (kg)	24.2	±6.8
Ponderal index	23.4	±1.6
Body surface area (m^2)	1.7	±0.3

Table 1: Physical Characteristics of the women carrying water (N=20).

Physiological study

To understand the physiological demands in fields for different activities, heart rates were measured by using a waist mounted ECG Monitor (HRM-4A Jogger Heart Rate Monitor, Respironics H.K.Ltd. Hongkong). The monitor was initially calibrated against the Dynograph recording in the laboratory and the correlation obtained was 0.9984.

The oxygen consumption was determined by the open circuit method. A Douglas bag of 50 liter capacity was used for collecting the expired air during each load. The bag and accessories like 2-way stopcock and hose pipe were placed on the side table so that their weights were not carried by the subject. The oxygen content of the expired air was determined with the help of a paramagnetic oxygen analyzer (Taylor India Limited). The instrument was frequently checked and calibrated against the calibration gas mixture (Oxygen- 16%, Carbon dioxide- 4%, balance Nitrogen) and also with normal outside air.

For laboratory study 7 subjects out of 20 were randomly selected, and the subjects were asked to run on a treadmill (AT-6 SCHILLER) with a speed 3.5 $km.\ hr^{-1}$. Their heart rates were determined through the continuous recording of a Beckman Dynograph, where Manubrium-Xiphoid (M-X) lead was used for picking up the ECG signal using a pair of Ag-AgCl surface electrodes. The output from Dynograph was then fed to Analogic 610 data analyzer through which continuous monitoring of the heart rate was achieved.

Subjects were asked to carry loads of different amounts ranging from 10 to 30 kg for 20 minute work. Cardiorespiratory responses were observed for each subject after every 5^{th} minute. Information regarding B.P. with the help of BP apparatus (Hg-manometer) was also recorded. Subjects were then asked to carry loads (10 to 30 kg) of their choice for one hour duration, for determining the final acceptable load. Heart rate was monitored throughout the experiment and O_2 consumption for each load was taken at the 5^{th} minute of work. Each load carrying activity was followed by 10 minutes of recovery and 30 minutes of rest. In case the subject's heart rate had not come down to the resting level after 30 minutes of rest, more rest pause was given.

The subjects reported at 9 am and were asked to sit down calmly for 20-30 minutes to exclude the physical and emotional influences on the heart rate. Prior to the experiment subjects were made aware of the experimental protocol and were made familiar with the instruments.

Electromyography (EMG): For the present study, the electromyography technique was used in order to assess the efforts exerted by the different muscles during load carrying with different modes. A Beckman Dynograph (Model R 612, six channel) recorder was used to record the EMG signals from four different muscles, neck, right trapezoid, right deltoid and erector spinae (right). The muscles chosen were those which were mainly responsible for the process of load carrying [17].

The EMG signals from different muscles were picked up by means of Ag-AgCl surface electrodes affixed to the skin. The amplitude of the signals reflected the degree of muscular involvement and it was therefore possible to assess the degree of muscular load from the EMG. Measurements of higher signal amplitude usually reflect higher muscular force for a given muscular activity.

Before starting the experiments, all the channels of Dynograph were calibrated at 1 mm of pen deflection equal to 0.5 mv. All the recordings were done at 1 mm = 0.5 mv.

The outcome from Dynograph was stored in a TEAC 7-ch recorder. The signals stored in the tape recorder were later on analyzed for the Root Mean Square (RMS) values by using Analogic 610 signal analyzer. A kernel filter of 32 points was used for smoothing the raw signal.

It was observed through the specially designed questionnaire that out of 20 subjects studied, the most commonly adopted mode of water carrying was the head mode (51.7%) and the least adopted was the waist mode (Table 2). It was further observed that women were also carrying water by combined modes like head and close to waist, and close to waist and hand mode. In this study only the three major modes viz. head, shoulder and waist modes were considered for the physiological analysis of the subjects.

Mode	Percentage of mode (%)
Head	51.7
Shoulder	24.2
Close to waist	11.8
Head & close to waist	11.4
Close to waist & hand	0.9

Table 2: Percentage of women habituated in different modes of water carrying.

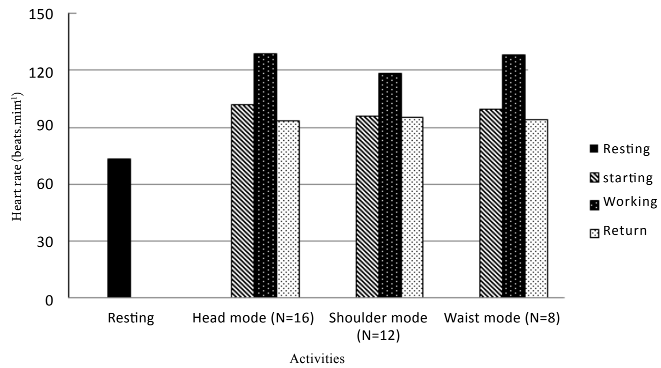

Figure 1: Average resting, starting, working and return heart rate (beats.min^{-1}) in different modes of water carrying in field.

Psycho-physiological evaluation

It was observed that for psychophysical evaluation a minimum of 15 minute of work was necessary for light weights. After carrying each load subjects were asked about the psychophysical rating to find out the responses regarding heaviness of the load. The responses of subjects were noted such as very light, light, moderate, heavy, very heavy, very very heavy for the different loads.

Statistical analysis

Data analysis was performed using SPSS statistical software, version 17.0. T-test was performed for the significance of the data and correlation analysis for correlating the data.

Results and Discussion

Significant differences ($p<0.001$) were observed in the body weight, body fat, and lean body weight among the WCW. Based on the PI values, fat content, LBW, dietary intake and surface area it can be inferred that the body builds of the WCW were more towards meso-endomorphic type.

Physiological stress

Physiological stress of subjects was determined on the basis of various parameters like average and peak heart rate, energy expenditure, maximum volume of oxygen while performing the activity. Each subject's resting HR was assessed from her ECG recording. The average resting, starting, working and return heart rates (beats.min^{-1}) in different modes of water carrying in the field are shown in Figure 1. The maximum working heart rate was observed in case of head 128.7 (± 14.02) beats.min^{-1} followed by the waist mode 128.2 (± 14.26) beats.min^{-1} and shoulder mode 118.3 (± 12.31) beats.min^{-1} respectively. It was observed that the most commonly adopted mode was the head mode. Load of 20-30 kg was carried on the head for longer distances at a speed of 3.5 km.hr^{-1}. The women did not carry such heavy loads by shoulder or waist modes for long distances.

Measurement of Physiological stress was calculated with the help of suggested prediction equations given below:

O_2 consumption (l.min^{-1}) = 0.01095 x HR (beats. min^{-1}) – 0.61694 ($r^2 = 0.983$) (1)

Where, HR = Heart Rate, r^2 = correlation coefficient

Energy expenditure (kj/min) = 0.159 x AHR – 8.72 (2)

where, AHR = Average Heart Rate

The energy expenditure for three different modes worked out to be 29.15, 26.98 and 29.25 KJ.min^{-1} for head, shoulder and waist mode respectively. But the maximum volume of oxygen for the 3 modes was calculated as 54.1, 46.7 and 54.1% VO_2 max for the head, shoulder and the waist mode. The load carried for all three modes ranged from 20-30 kg at a walking speed of 3.5 km.hr^{-1}. The average working heart rates in the field for different loads are shown in Table 3.

Validation of acceptable load for water carrying activity-20 minute activity: After the field study, out of 20 subjects 7 subjects were randomly selected for laboratory study. The subjects were asked to perform the water carrying activity in the laboratory at the same speed for the load range of 10-30 kg with all the three modes of carrying and the physiological responses were noted. The observed values of the physiological parameters on the seven subjects carrying different loads in different modes were tabulated in Table 4, and the mean and standard deviation were computed. Physiological responses of the subjects were noted at 0 kg load by walking on treadmill (3.5

km.hr^{-1}) and it was observed that Heart rate was 104.2 beats.min^{-1} and O_2 uptake was 38% VO_2 max, which indicates that even at 0 kg workload the physiological cost to perform the job by the WCW group, was strenuous because of high walking speed. In case of head mode minimum energy expenditure was observed at 10 kg load demanding O_2 consumption of 38.62% VO_2 max. While carrying 30 kg load on head the O_2 consumption increased to 64.56% VO_2 max.

In case of shoulder mode the minimum O_2 uptake was observed to be 47.05% VO_2 max at 10 kg while the maximum was 61.75% VO_2 max at 25 kg and the highest O_2 uptake (62.55% VO_2 max) for 15 kg workload. This might be due to the higher subjective variations observed for that load.

Similarly, in case of waist mode the minimum O_2 consumption (48.66% VO_2 max) was observed for 10 kg and maximum (63.02% VO_2 max) in the case of 20 kg load.

To understand the cardiac stress the heart was monitored at every minute throughout the experiment (20 min) while carrying different loads in different modes.

According to Maritz [18] the working heart rate of 105 beats min^{-1}, with a range of 95 to115 beats min^{-1} would be accepted for 8 h industrial work shift. Brouha [7] re-stated that the working heart rate should not exceed 110 beats.min^{-1} otherwise there is a chance of cumulative fatigue. It was also concluded in a study by Ayoub and mital [11] on manual material handling that the value of VO_2 max should not be exceeding 35%VO_2, which cause cardiovascular strain.

Mode	Average load carried (kg)	Avearge heart rate (beats.min^{-1})	O_2 consumption (estimated)	
			(l.min^{-1})	%VO_2 max
Head	20-30	129.6	0.792	54.1
Shoulder	20-30	117.9	0.686	46.7
Waist	20-30	128.5	0.790	54.1

Table 3: Average working heart rate in the field while carrying different modes of load.

Load (kg)	Heart rate (beats.min^{-1})	SD	Energy expenditure (kj. min^{-1})	% VO_2 max
0	104.2	±12.98	11.48	38.0
Head mode				
10	116.2	±13.78	11.98	38.62
15	119.2	±10.6	12.04	43.24
20	126.9	±11.95	15.94	51.65
25	133.1	±14.20	17.42	57.02
30	133.8		19.75	64.56
Shoulder				
10	130.7	±9.15	14.20	47.05
15	145.3	±14.22	19.42	62.55
20	145.8	±8.01	16.50	53.70
25	156.9	±25.62	19.00	61.75
Waist				
10	129.8	±10.12	15.02	48.66
15	148.2	±14.23	17.98	60.20
20	156.2	±8.68	18.98	63.02

Table 4: Physiological responses of women carrying water in different loads.

By using the relationship (equation 1) between the heart rate and oxygen consumption it was derived that for 110 beats.min^{-1} the O_2 consumption should be around 39.97% VO_2 max, but if O_2 was reduced to 35% VO_2 max the heart falls to 103.3 beats.min^{-1}. From the table it was observed that the average heart rate for 0 loads was 104.5 beats. min^{-1} which is above 103.3 beats.min^{-1} for 35% VO_2 max.

Hence, the criteria of using the 35% VO_2 max for determining the acceptable load is not valid for the water carrying activity. It was therefore decided to use the criteria of 110 beats.min^{-1} for predicting the acceptable load for all three different modes of water carrying.

Blood pressure (BP): In case of head mode there is a gradual increase in systolic pressure but diastolic pressure more or less remained the same. In case of shoulder and waist mode, no definite pattern in the systolic blood pressure was observed. This might be due to the small number of subjects studied and variations in their physical efficiency. The diastolic pressure remained more or less unchanged throughout the experiment.

EMG study-20 minute activity: The average electrical activity (RMS volts) for four different muscles in case of carrying water continuously for 20 min are presented along with the SD in Table 5.

Head mode: In case of neck (r) muscle the RMS values during work were significantly above 0 load, except the significance between 0 vs 25 kg. The significance level varied from 0.05 to 0.001 percent from lower to higher load. In case of neck muscle EMG values for 30 kg was not considered due to inherent artifacts in the signal. In case of trapezoid (r) the minimum RMS value (0.0384 volts) was obtained at 0 load while the maximum was achieved at 30 kg load (0.1223 volts). The t values obtained between the RMS values for different loads indicated the high degree of significance level in most of the cases except 10 vs 25 kg and 15 vs 20 kg loads. From Table 5 (N=7) it was also observed that there was a drop in trapezoid (r) muscle at head 20 and 25 kg load in comparison to head 15 kg load. This slight drop might be considered as subjective phenomenon which was again increased at 30 kg load. In case of deltoid muscle there was a rising trend in RMS values from 0 to 25 kg load but a certain drop in the average EMG was noted for 15 kg load. While carrying loads during the experiment, the subjects were allowed to use both the hands freely to support the load. The drop in EMG in certain cases might be due to less involvement of that specific group of muscles while the hand was in the relaxed condition. This phenomenon was observed in deltoid muscle. In case of erector spinae significant differences ($p<0.01$) were observed only between 0 vs 15 kg, and 0 vs 25 kg load.

Shoulder mode: All the muscles were significantly active when compared against the 0 load, but RMS values within the same muscle do not show much significant differences for different loads. Significant differences were observed only in case of 10 vs 20 kg and 15 vs 20 kg and 15 vs 20 kg load for neck, and 10 vs 25 for trapezoid (r) muscle. No significant difference was observed between the RMS values for different loads in any other combination.

Waist mode: Significant differences were observed for trapezoid (r) and deltoid (r) muscle in comparison to 0 load. Significant differences were also observed in case of neck muscle between 10 vs 15, 10 vs 20 and 15 vs 20 kg load with gradual increase in work load. No significant differences were observed in case of deltoid and erector spinae group of muscle.

Validation of acceptable load for water carrying activity- 60 minute activity: Out of 7 subjects 3 completed the work of carrying 10 kg on head, while 1 carried 15 kg for 60 min and other 3 subjects carried 10 kg for the duration of 50, 45 and 32 min each. This shows that even the 10 kg load was found to be heavy as majority of the subjects could not continue the work for 60 minutes at the walking speed of 3.5 km.hr^{-1}.

It was observed that in case of shoulder mode of water carrying only 1 out of 7 subjects could complete the task while carrying the minimum load of 10 kg. Two subjects worked for 50 mins, one each for 40, 35 and 10 min. It is evident from the study that in case of waist mode none of the workers completed the task for 1 hr. One subject performed the job for 45 mins, 1 each for 42, and 40 mins, 2 performed for 35 mins and 1 did not perform the job.

In this study it was observed that as the load increased the number of subjects who participated gradually reduced. This reduction in the number of subjects was obviously due to their physiological inefficiency.

To understand the cardiac demand for 60 min for different modes, the heart rate for 3 different modes were recorded at every minute for the entire duration. In case of head mode the 5th and 60th min heart rates were 112.8 and 118.7 beats.min^{-1} respectively. The respective values for shoulder were 132.6 and 139.1 (40th min) beats.min^{-1}, while for the waist mode were 129.7 and 131.9 beats.min^{-1} for 5th min and at the end of the work.

Load (kg)	Neck	Trapezoid (r)	Deltoid	Erector spinae
0	0.0246	0.0384	0.0144	0.054
	±0.0020	±0.0013	±0.0039	±0.0008
Head mode				
10	0.0274	0.0592	0.0523	0.0407
	±0.009	±0.0049	±0.0041	±0.0046
15	0.0361	0.0841	0.0331	0.0401
	±0.0011	±0.0107	±0.0065	±0.0021
20	0.0332	0.0761	0.0802	0.0462
	±0.0021	±0.0108	±0.0145	±0.0029
25	0.0283	0.0619	0.1342	0.0349
	±0.0041	±0.0126	±0.1366	±0.0041
30		0.1223		
		±0.0137		
Shoulder mode				
10	0.0384	0.0512	0.0422	0.0362
	±0.0036	±0.0047	±0.0060	±0.0022
15	0.0370	0.0498	0.0466	0.0805
	±0.0030	±0.0063	±0.0101	±0.0064
20	0.512	0.0672	0.0535	0.0460
	±0.0042	±0.0091	±0.0106	±0.0050
25	0.0436	0.1153	0.0641	
	±0.0055	±0.0103	±0.0022	
Waist mode				
10	0.0241	0.0391	0.0400	0.0590
	±0.0012	±0.0037	±0.0041	±0.0212
15	0.0310	0.0592	0.0518	0.0499
	±0.0036	±0.0047	±0.0080	±0.0070
20	0.0590	0.0762	0.0570	0.0272
	±0.0050	±0.0268	±0.0059	±0.0041

Table 5: Electrical activity (RMS volts) for 4 different muscles while carrying different loads in different modes-20 minute work.

It can be concluded that the head mode demands less cardiac cost in comparison to the other two modes, Although the cardiac cost demand for the other two modes remained more or less similar, in long run (15 mins onwards) the shoulder mode demands more cardiac involvement than the waist mode. Therefore in case of long term jobs the degree of physiological stress is minimal in head mode followed by the waist and shoulder mode.

EMG study- 60 minute activity: To understand the muscular involvement while carrying acceptable loads in three different modes for 60 min the average RMS (volts) values for 4 different muscles were calculated.

In case of neck (r) muscle the minimum activities were observed for 0 load (0.0246 volt) and shoulder (0.0293 volt) mode respectively, indicating minimum involvement of neck muscle in all three modes of load carrying. The values for shoulder and waist mode was 0.0502 (± 0.0068) and 0.0412 (± 0.0086) volts respectively. In case of trapezoid (r) the minimum and maximum activities were observed in 0 load (0.0382 volt) and in head (0.0541 volt) mode. The values for shoulder and waist mode was 0.0502 (± 0.0067) and 0.0418 (± 0.0082) volts respectively. The data therefore indicates the maximum involvement of trapezoid (r) muscle in head mode. In practice it was observed that workers used their right hand more than the left hand to support the load on the head. In case of deltoid (r) muscle the minimum and maximum values were obtained in 0 load (0.0141 ± 0.0038 volts) and head mode (0.0423 ± 0.0078 volts) respectively. The higher value for the head mode is due to the increased involvement of the right hand for supporting the load carried on the head while walking. The behavior of erector spinae (r) muscle was quite different. The highest response was observed in 0 load (0.0533 ± 0.0007) followed by waist (0.0421 ± 0.0063 volts), shoulder (0.0416 ± 0.0023 volts) and head mode (0.0380 ± 0.0016 volts).

By summing up all the EMG value (neck + trapezoid (l) + deltoid (r) + erector spinae (r) it was observed that from the view point of muscular responses the most stressful was the shoulder mode (0.1566 volts) followed by waist (0.1456 volts) and head mode (0.1332 volts).

Electromyographic signs of fatigue can be used as indicators of muscular overload. High doses of muscular involvement cause localized muscle fatigue [19] which involves muscular decrement, sensation of fatigue and pain and changes in the EMG signals. These changes are closely related to the fatigue process.

Biomechanical stress

From Table 6, it is observed that in case of head mode the shift of the vertebral column towards the right side was negligible but in shoulder mode the shift of the vertebral column towards the right side was 14.3^0, 17.1^0, 17.2^0 and 19.8^0 respectively for 10, 15, 20 and 25 kg load. This shift of vertebral column axis was necessary to counter the eccentric loading effect on the body resulting from carrying load on the left shoulder. By countering the eccentric load the resultant CG (body + load CG) is brought within the base support otherwise the body will fall down due to unstable posture. In case of waist mode the vertebral column shift towards the right side was 14.3^0, 14.0^0, 12.6^0 and 17.7^0, for 10, 15, 20, and 25 kg load respectively.

From the above table (Table 6) it is evident that with the increase in load the hip and shoulder axis tilts more towards the anticlockwise direction with respect to their normal axis while carrying loads in shoulder and waist mode. From the lateral vertebral column shift, shift in the hip and shoulder axis it could therefore be concluded that carrying load by shoulder and waist mode are potentially dangerous from the view point of spinal injury. Long term carrying of water in these two modes might cause permanent spinal deformity resulting in severe musculoskeletal disorders and even lower limb paralysis. This is also evident from the physiological study.

Although considering the high degree of muscular stress, cardiac demand and shift in body axis shoulder mode should not be recommended but considering the present work culture a maximum of 10 kg load at a speed of 3.5 km.hr^{-1} may be recommended for shoulder mode as suggested earlier in the physiological study.

Psycho-physiological evaluation

All the subjects rated 10 kg as a light weight and 15 kg as a moderate load for the head mode. Three subjects rated 20 kg as a very heavy load while four rated it as very very heavy. 25 kg and 30 kg load was rated as being heavy to very very heavy by the subjects. In case of shoulder mode three subjects rated 10 kg as light load while three rated it as moderate and one as being heavy. In case of 15 kg four subjects rated it as moderate, two as heavy and one as being very heavy. 20 kg and 25 kg load was rated as being heavy to very very heavy by the subjects. None of the subjects carried 30 kg load by shoulder mode. In case of waist mode 10 kg was rated as a light load by four subjects while three rated it as a moderate load. 15 kg and 20 kg load was rated as being moderate to very heavy by the subjects Load 25 and 30 was observed to be too heavy to be carried by the waist mode.

Mode	Vertebral column shift angle (degree) against axis in 0 load condition	Hip axis angle with reference to the horizontal	Shoulder axis angle with reference to the horizontal
Head			
10 kg			
15 kg	1.7		
20 kg	2.8	7.3±0.82	
25 kg	3.1	3.6	
Shoulder			
10 kg	14.3±4.26	7.9±2.93	5.31.68
15 kg	17.1±4.12	9.3±8.02	7.5+-3.10
20 kg	17.2±2.36	13.6±6.15	7.61.32
25 kg	19.8±1.76	14.8±1.61	6.72.46
Waist			
10 kg	14.3±2.68	14.5±4.90	8.72.05
15 kg	14.0±4.16	14.7±3.50	6.53.62
20 kg	12.6±3.60	12.8±3.40	6.12.42
25 kg	17.7±4.10	15.7±6.80	9.92.56

Table 6: Changes in the vertebral column-longitudinal, hip and shoulder horizontal while carrying different loads in different modes.

Mode	Loads (kg)				
	10	15	20	25	30
Head					
Very light					
Light	7				
Moderate		7			
Heavy				3	2
Very heavy			3	3	2
Very very heavy			4	1	3
Shoulder					
Very light					
Light	3				
Moderate	3	4			
Heavy	1	2	3	1	
Very heavy		1	2	2	
Very very heavy			2	4	
Waist					
Very light					
Light	4				
Moderate	3	3	1		
Heavy		2	2		
Very heavy		2	4		

Table 7: Psychophysical rating in different modes (N=7).

It is therefore concluded that most of the subjects preferred 10 kg load as that was the minimum which the subjects could carry for the maximum time duration by all the modes. In case of shoulder and waist mode subjects could carry minimum (10 kg) load for 1 hr., but complain about tiredness by end of the job.

It was observed from Table 7 that out of head, shoulder and waist modes the head mode demanded the minimum physiological, muscular and biomechanical involvement followed by the waist and shoulder mode. The body was more stable in head mode while more unstable in case of waist mode. However the recommended load by shoulder and waist mode should not exceed 10 kg at a walking speed of 3.5 km.hr^{-1}.

Considering the severe muscular stress, shift in body axis, heart rate determining the acceptable load [20,21,22] it can be concluded from that the maximum acceptable load for the head mode should be around 15 kg and that for shoulder and waist mode should not be more than 10 kg at the speed of 3.5 km.hr^{-1}. It was also estimated in a study conducted on adult female construction workers and household workers that the MAWL is around 15 kg [23]. Considering the cardiovascular, muscular and biomechanical stresses the water carrying by shoulder and waist mode should be discontinued.

Conclusion

It is therefore concluded that most of the subjects preferred 10 kg load as that was the minimum which the subjects could carry for the maximum time duration by all the modes. In case of shoulder and waist mode subjects could carry minimum (10 kg) load for 1 hr but complain about tiredness by end of the job. Based on the heart rate, oxygen consumption and EMG responses by four different muscles and psychophysiological rating for carrying different loads for 20 minute and 1 hr, the recommended load for water carrying by the head mode was suggested as 15 kg. Considering the cardiovascular, muscular and biomechanical stresses the water carrying by shoulder and waist mode should be discontinued. From the view point of oxygen consumption and biomechanical stresses it is advisable that carrying water by shoulder and waist mode should be discontinued.

In this study further validation of these loads has not been carried out and it needs to be performed in future studies.

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