A COMPARISON OF DIFFERENT MODES OF LOAD CARRIAGE : AN EVALUATION

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ABSTRACT

The objectives of this study were: (a) to find the maximum acceptable weight which can be carried for 8 hours using a psychophysical method for front, side (one hand and two hands) and back carrying, and (b) to develop models which could predict the acceptable maximum weight in carrying using isometric strength and anthropometric data. A series of laboratory experiments were conducted to find the maximum acceptable weight in front, side and back carrying. Six college students participated in the experiment. It was found that subjects were willing to carry the heaviest load using two-hand side carrying (average maximum acceptable weight: 7.76 kg). Back carrying was the close second with 6.62 kg. Also, there was a significant difference ($p< 0.01$) in maximum acceptable weight for carrying between one-hand (4.40 kg) and two-hand side carrying.

I. INTRODUCTION

Manual load studies for efficient transport of goods are some of the earliest studies in ergonomics (Bedale, 1924; Renbourn, 1954; Malhotra and Gutpa, 1965; Das and Saha, 1966; Soule and Goldman, 1969; Datta and Ramanathan, 1970; 1971; Winsmann and Goldman, 1969; Kinoshita, 1985; Legg and Mahanty, 1985). Despite the fact that many psychological factors as well as physiological factors affect human capability in manual transport, most of these studies were limited to physiological studies. Only two of the above studies (Winsmann and Goldman 1969; Legg and Mahanty, 1985) assessed perceptual responses in addition to the physiological responses for efficient carrying. Subjective feelings must also be considered since any ergonomic design recommendation needs to be both subjectively acceptable and metabolically efficient. The two above studies which included perceptual responses, however, did not differentiate among specific body regions (Pandolf et al., 1975; Pimental and Pandoff, 1979; Robertson et al., 1982). Therefore, it is not possible to assess discomfort sensations from strap pinching, different bone or muscle pressures with different types of military rucksacks in load carrying.

Cultural differences are also not considered in load applications. Manual load transport often involves different carrying methods, and these methods can affect maximum load capabilities. Use of an A-frame with back carry has had loads of up to 175 kg reported (Daniels, 1966). In South-East Asia and India carrying loads of 90 to 175 kg have been reported (Renbourn, 1954; Sen and

Nag, 1975; Soule et al., 1978). Besides cultural differences, these load capabilities are partly attributed to the efficiency of the carrying method. The yoke or headpack-strap are common methods in these regions (Datta and Ramanathan, 1970;1971; Hetay et al., 1978).

In all of the above studies, preliminary observation would conclude that some form of back carrying is the most efficient way among manual carrying methods. However, this does not establish which back-carrying method is the most efficient and individually acceptable (culturally acceptable?). Therefore, the objectives of this study were: (a) to find the maximum acceptable weight which can be carried for 8 hours using psychophysical methodology for front, side (one hand and two hands) and back carrying, and (b) to develop models which could predict the acceptable maximum weight in carrying using isometric strength and anthropometric data.

II. METHOD

An experiment was conducted in the laboratory to find the maximum acceptable weight for carrying for an 8-hour work day. Four different carrying methods, back carrying, front carrying, and side carrying (one and two hands) were investigated.

2.1. Subjects

Six male subjects were recruited for the study from the local student population at Louisiana State University. The subjects' ages ranged from 22 to 27 years with a mean of 23.8 years and a standard deviation (SD) of 2.2 years. Their mean height was 171.7 cm, the mean weight was 59.7 kg, and SD's were 7.0 cm and 5.7 kg, respectively. All were in good physical condition at the time of the experiment. None had a personal medical history of any back problem. Each subject was tested for his arm, shoulder, leg and composite strength, before the carrying experiment began. Table 1 shows the anthropometric data for all the subjects.

Table 1. Anthropometric data for subjects.

	Mean	Range	S.D.
Age (Years)	23.83	22.0 - 27.0	2.23
Weight (kg)	59.67	51.4 - 65.7	5.71
Height (cm)	171.67	164.0 -182.0	6.95
Acromial Height (cm)	140.62	131.1 -154.5	7.97
Standing Iliac Crest Height (cm)	101.07	92.2 -110.5	6.27
Knuckle Height (cm)	77.28	67.5 - 90.1	8.19
Knee height (cm)	51.07	45.8 - 55.5	3.85
Forearm Grip Distance (cm)	34.33	29.1 - 38.5	3.72

2.2. Experiment

The subjects were tested in two sessions. In the first session, the subjects participated in a series of isometric strength tests. Arm strength, shoulder strength, leg strength and composite strength were recorded for each subject. All the strength measurements were completed before the carrying experiments in session 2.

In the second experiment session, the subjects participated in a series of carrying including front carrying, side carrying and back carrying. Since it was not easy to test subjects over an entire eight-hour work day, psychophysical methodology was used to estimate the maximum weight acceptable to the subjects for carrying over an eight-hour period. Thus, the experiment for each type of carrying was conducted for 20 minutes instead of eight hours. The subjects were asked to carry weight in a sack at walking speeds of 1.6km/h and 2.4km/h on the treadmill, each for 20 minutes.
Lower walking speed of 1.6 km/hr was selected because it was the lowest setting on the treadmill used. Initially, the value selected for higher walking speed was twice this value, that is 3.2 km/hr. But, the subjects felt rushed while carrying the load at this speed. Most of the subjects said they felt that this speed was not representative of speed used in industrial tasks and therefore was unrealistic. Hence, the higher walking speed was set at the average of 1.6 and 3.2 km/hr, that is at 2.4 km/hr at which they subject felt more natural.

a) Front Carrying

In the front carrying test, each subject was asked to carry a rucksack in front of his body on the treadmill using two hands. Subjects used two straps as a handle to hold the rucksack. Subjects were told that, if at any time they felt the sack was too heavy, weight could be taken out. Conversely, if they felt that the sack was too light, weight could be added. Each subject was told to assume that he would have to carry the final weight for 8 hours a day. When the 20 minutes were over, the sack was weighed.

b) Side Carrying

In the side carrying test, each was asked to carry a rucksack at his side on the treadmill. One-hand carrying and two-hand carrying were tested. Subjects also used the straps as a handle for the rucksack. In a one-hand carrying, the dominant hand was used for carrying. Other procedures were the same as that for the front carrying test.

c) Back Carrying

In the back carrying test, the rucksack was placed on a special platform so that a subject could squat on the floor and place the rucksack on his back with the experimenter's help. The task for the back carrying experiment was the same as other carrying experiments.

2.3. Equipment

The equipment used in the testing included a strength monitor, Model Dynadex ST-1, manufactured by the Dynadex Co. for isometric strength measurement, and a treadmill, Quiton Model Q55 manufactured by Quinton Co. A generic type student rucksack was used to hold the weights while lifting (also called a backsack).

III. RESULTS

Table 2 shows the summary (mean, standard deviation and range) of the strength measurements for all the subjects. Table 3 shows the average weights acceptable to all subjects for carrying over an eight-hour period determined during the carrying experiments using the different carrying methods. This table also shows the ranges and standard deviations for the acceptable weight. It was found that the subjects were willing to carry the heaviest load

Table 2 : Subjects' Strength Measurements (N).

	Mean	Range	S.D.
Static Arm	274.20	158.87 - 356.00	65.87
Stooped Back	543.94	336.86 - 741.82	150.02
Static Composite	753.09	470.36 -1102.26	204.99
Static Shoulder	381.14	289.25 - 492.62	79.65
Static Leg	762.06	498.40 - 943.4	146.51

Table 3. Average Weight (kg) Carried by Six Subjects in Each Task

Task	Speed (km/h)	Mean	Range	S.D.
Back Carrying	1.6	6.09	4.04 -10.34	2.23
	2.4	7.25	5.00 - 9.20	1.53
Front Carrying	1.6	3.05	2.27 - 3.46	0.42
	2.4	3.17	2.78 - 3.35	0.22
Side Carrying One Hand	1.6	4.62	3.52 - 5.74	0.75
	2.4	4.17	3.46 - 4.60	0.51
Side Carrying Two Hands	1.6	7.59	6.02 -10.90	1.51
	2.4	7.92	6.25 -10.68	1.62

using two-hand side carrying method (average maximum acceptable weight: 7.6 kg). Back carrying was the close second with 6.1 kg. As expected, there was a significant difference ($p < 0.01$) in maximum acceptable weight of carrying between one-hand side carrying (4.6 kg) and two-hand side carrying.

It was also noticed that changing speed from 1.6 km/h to 2.4 km/h did not cause any noticeable change in the acceptable weight in most carrying methods (within 5% range). It is interesting to find that in back carrying there was an increase of 1.2 kg (21%) when the speed was increased.

Table 4 also shows that the actual force required was less than 15% of the isometric strength in most cases. Side carrying with two hands, however, showed the highest percentages. Rohmert (1968) reported that persons can sustain an exertion level if the required exertion level is about 15% of their maximum muscle force. The finding from our study confirms Rohmert's finding.

Table 4. Percentage of strength required to carry weight against the isometric strength.

		PERCENTAGE OF STRENGTH OF EACH BODY PART				
Carrying Method	Speed (km/h)	ARM	BACK	COMPOSITE	SHOULDER	LEG
Back	1.6	21.8%	10.8%	7.8%	15.4%	7.8%
	2.4	26.0%	13.1%	9.4%	18.6%	9.3%
Front	1.6	11.0%	5.7%	4.0%	7.8%	4.0%
	2.4	11.3%	5.7%	4.1%	8.1%	4.1%
Side One Hand	1.6	16.5%	8.3%	6.01%	11.8%	5.9%
	2.4	14.9%	7.5%	5.4%	10.7%	5.3%
Side Two Hands	1.6	26.9%	13.6%	9.8%	19.3%	9.7%
	2.4	28.3%	14.3%	10.3%	20.3%	10.2%

Table 5 shows the result of a correlation analysis conducted to examine the effect of anthropometric and strength variables on the maximum acceptable weight in different carrying tasks. Several of the correlations between the acceptable weights for tasks and these variables were very low. The arm strength showed a correlation of $r^2 = 0.471$ with the acceptable weight in front carrying at 1.6 km/hr carrying speed. Back strength also showed very low correlation with back carrying tasks (e.g. $r^2 = 0.004$ for back carrying at 1.6 km/hr speed) even though back strength would be expected to be an important factor in determining acceptable weight in back carrying. These types of results may have been obtained because the data are derived from a combination of subjective and physical measurement approaches. Therefore, no single variable turned out to be a stand-alone predictor based upon high correlation.

A stepwise regression procedure was used to develop models that can predict maximum acceptable weight for different carrying methods. This was performed on a microcomputer using the SAS program. The criterion used to select or reject a variable was a partial F value of 3.0.

Polynomial models using the acceptable front carrying weight were attempted. The models are listed in the Table 5. This table shows relatively high r^2 values for each model (average r^2=0.92).

Table 5. <u>Regression Models</u>

Task	Model	R**2	F Value	p
Back Carrying 1.6 km/h	$Y = 23275 - 8131.22X_1^2 + 2925.51X_1^3 - 306.27X_1^4 - 38432X_1^{-2}$	0.9707	8.27	0.2544
Back Carrying 2.4 km/h	$Y = -102993 + 43016X_1^2 - 15846X_1^3 + 1673.29X_1^4 + 660702X_1^{-4}$	0.9977	108.23	0.0720
Side Carrying One Hand 1.6 km/h	$Y = 5698.52 - 1973.87X_1^2 + 706.88X_1^3 - 73.63X_1^4 - 9459.38X_1^{-2}$	0.7442	0.73	0.6940
Side Carrying One Hand 2.4 km/h	$Y = -28068 + 11826X_1^2 - 4375.67X_1^3 + 464.16X_1^4 + 177184X_1^{-4}$	0.9952	52.35	0.1032
Side Carrying Two Hands 1.6 km/h	$Y = 9939 - 3470.64X_1^2 + 1248.38X_1^3 - 130.66X_1^4 - 16372X_1^{-2}$	0.9999	1811.19	0.0176
Side Carrying Two Hands 2.4 km/h	$Y = -101565 + 42074X_1^2 - 15434X_1^3 + 1622.95X_1^4 + 661534X_1^{-4}$	0.8021	1.01	0.6233

Note : X_1 - Front Carrying 1.6 km/h
X_2 - Front Carrying 2.4 km/h

IV. DISCUSSION AND CONCLUSIONS

There was a significant difference ($p < 0.01$) in maximum acceptable weight of carrying between one-hand side carrying and two-hand side carrying despite the use of the dominant hand in the one-hand side carrying. This could be attributed to the fact that people prefer to carry with two hands rather than one hand in side carrying to have a better balance.

An analysis of variance (ANOVA) for the acceptable carrying weight data was computed using the random effects model. Using a SAS package, both main effects and interaction effects were calculated for significance (alpha=0.05). The variables tested included the anthropometric (age, body height, body weight), task (method of carrying, speed of carrying), and strength variables. As expected, the method of carrying had a significant main effect ($p<0.0001$). Body height was also a significant main effect ($p<0.0015$), but not body weight ($p<0.3100$). The two other significant main effects were isometric shoulder strength ($p<0.0010$) and arm strength ($p<0.0158$). Speed of carrying was not a significant main effect ($p<0.4440$). This might have been because the two speeds (1.6 and 2.4 km/h) were too close for a major difference in energy demand. Somewhat surprisingly, there was no significant interaction effect among any of the variables.

This research shows that front carrying cannot be used to estimate the acceptable weight in other types of carrying. The difference in the acceptable weights between back carrying and one-hand side carrying found in this study is consistent with the result of an earlier physiological study (Malhotra and Gupta, 1965).

A most interesting, though preliminary, result for use as injury-preventive data is the comparison of current isometric lift and lift-and-carry maximum load limits. Examination of Table 2 vis-a-vis Table 3 gives some indication of this ratio. This ratio is demonstrated in Table 4. The results from this experiment indicate that the composite strength test alone cannot be used to predict an employee's performance for lifting and carrying tasks in an industrial setting.

This general area of research concerning carrying is still incomplete. There is an impetus for continuing these studies because lifting and carrying are common activities in service and distribution industries (shipping, trucking, and warehousing). Further development of this study could help increase the quality of personnel selection criteria which, today, are largely based on static lift capabilities.

In addition, it is noted that to-date existing research has shown disagreements in the best manual materials handling practices. To some extent, though undefined, cultural practices seem to have influenced preferred methods of lifting and carrying. It is doubtful, for example, that Western nations' cultural influences will ever adopt carry-on-head, or for that matter, back-carry (in the industrial environment). Further lifting and carrying studies need to focus on the most common industrial applications.

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