한손 연속작업의 심리육체학적 모델링
(Psychophysical modeling for one-handed combined tasks)

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Abstract

Most studies in manual material handling (MMH) have paid more attention to single MMH activities - lifting, lowering, carrying, holding, pushing or pulling and have ignored combined activities. Also, many studies have been involved with two-handed MMH activities rather than to one-handed MMH activities. Very few studies are reported on the determination of workers' capacities for combinations of one-handed MMH activities (e.g. lifting a box, then carrying the box, and lowering the box). The objective of this study was to utilize the psychophysical approach to examine the combinations of lifting, carrying and lowering activities from a simulated industrial task involving one-handed and two-handed combined tasks and to develop mathematical models for combined tasks. Ten male students served as subjects for the study. The capacities that were determined as the maximum acceptable weight workloads for 1 hr work period for one-handed and two-handed combined tasks - lifting a box from floor to knuckle height, carrying the box for 4.3 m, and lowering the box from knuckle to floor height - were determined psychophysically under three frequencies: six handlings per minute, one handling per minute and one handling per five minutes. Combined MMH capacities models for one-handed tasks were developed. The advantages and disadvantages of different models are discussed.

1.Introduction

Most studies of whole-body exertion have been concerned with vertical two-handed lifting or horizontal pushing and pulling (Ayoub and McDaniel, 1974; Chaffin, 1974; Yates *et al.*, 1980), with very few reports on one-handed strengths for lifting (Davis and Stubbs, 1980; Warwick *et al.*,1980; Fothergill *et al.*, 1991) and carrying (Mital and Manivasagan, 1983). In a one-handed carrying study, Mital and Manivasagan (1983) investigated the maximum acceptable amount of carrying for infrequent performance.

It is common for people to do a combined activity in which lifting, carrying for a certain disance and lowering something like consumer products, containers and tool boxes, etc. Part of the study was conducted by Jiang (1984) using psychophysical methodology to find the maximum acceptable weight of two-handed manual material handling activities. However, no actual weight/force data are available for one-handed combined tasks, especially for repetitive tasks. And much less is known about the load limits for one-handed combined tasks although combined activities (lifting, carrying and lowering) are still being performed routinely in industry or in our normal life.

The objective of this study was to utilize the psychophysical approach to examine the one-handed and two-handed combined tasks and find the relationship between the capacities of one-handed and two-handed combined tasks. Physiological response was measured by monitoring the heart rate during the experiment.

2. Methods and results

2.1. Subjects

Ten male students, ranged in age from 20 to 30 with a mean age of 23, were selected as subjects for this study. The subjects' mean height was 173.9 cm (s.d.=6.31cm) and mean weight was 75.1 kg (s.d.=8.39kg). All subjects were free from back pain, and no musculoskeletal abnormalities were noted. Isometric arm, back, leg, shoulder, and composite strengths of the subjects were measured based on the equipment and protocol used by Asfour (1980) and were comparable with the other studies (Ayoub, 1978; Jiang, 1984; Fox, 1993). The subjects had six training and familiarization sessions before the experimental data were collected.

2.2. Experimental design

After the subject had six training and familiarization sessions, the data base for each subject's physical condition was collected using strength tests, the anthropometric measurements and the physical work capacity (PWC). To ensure that each subject received the same instructions for the test or experiment, each subject was requested to read the instructions for the strength test and psychophysical approach before he started the test or experiment.

A randomized complete block design was utilized. Each subject was considered as a block.

2.3. Anthropometric measurements and PWC test

Height, weight and 22 other anthropometric measurements were taken for each subject. The protocol for anthropometric measurement was adopted from Ayoub (1980), Asfour (1980), and Lohmann *et al.* (1991). The PWC (VO_2 max) was determined for each subject on a bicycle ergometer using submaximal techniques (Fernandez, 1986; Kim, 1990; and Fox, 1993). The subject rode a bicycle ergometer for four minutes at each of three different workloads. Oxygen consumption and heart rate data were collected during the fourth minute of each workload, assuming that the subjects had reached steady state. The oxygen consumption (in liters/minute) and heart rate data for each of the workloads were then used in a least squares regression to estimate VO_2 max, using the subject's predicted maximum heart rate (220-age). The mean value of PWC was 44.17 ml/kg-min and was comparable with the other studies (Jiang, 1984; Fox, 1993).

2.4. Procedure and results

Using the psychophysical methodology, subjects were asked to determine the amount of weight they could lift, carry, and lower comfortably with one hand or two hands for an actual one-hour work period. Each activity was conducted under three different frequency conditions (six handlings per minute, one handling per minute and one handling per five minutes) and two replications. Six handlings/min was considered as a frequent task, one handling/min was considered borderline for frequent and infrequent tasks, and one handling/5 min (0.2 handling/min) was considered as an infrequent task for this study. The one-hour period was selected rather than an eight-hour work shift because it more closely approximates an intermittent work schedule that would be encountered when carrying activities occur (Jiang *et al.*, 1986).

Each subject determined the maximum amount of weight they were willing to lift, carry, and lower with their preferred hand or two hands for one-hour at various task variable combinations. The order of task was randomly selected. Each subject was asked to perform combined manual materials tasks with a 49cm X 16cm X 20cm tool box for one-handed tasks or 46cm X 30cm X 30cm box for two-handed tasks that required the subjects to pick up the load, carry the load, and put the load down. The initial weight in the tool box was selected randomly, with either very light or very heavy weights concealed in a false bottom of the container (up to 12kg and 7kg for two-handed task and one-handed task, respectively). Then, frequency was identified, and subjects were allowed to walk through the distance of 4.3m at the identified frequency for several. The 4.3 m carrying distance represented a medium carrying distance in industry. Subjects were encouraged to make adjustments to initial weight by adding or removing weights, in order to arrive at the maximum acceptable weight for that task without getting tired or exhausted. Walking speed was not controlled. Adjustment of the weight was allowed throughout the hour, and heart rate was monitored continuously during the experiment, however, minute heart rate was recorded for four minutes at the end of one hour for frequencies of 1/min and 6/min. If the subject adjusted the load during the last ten minutes at the end of one hour, the subject was asked to continue the work with the adjusted load for fifteen more minutes from the time of the last adjustment and the minute heart rate was recorded at the end of that fifteen minutes for four minutes. A four minute average was taken for heart rate. For the frequency of 1/5min, the 55th and 60th minute of heart rate were recorded and the average was taken as the heart rate of that task. The final weight at the end of the period was considered the maximum acceptable weight of combined task for that particular frequency. Each experimental condition was completed twice by each subject (one replication) and the order in which the subject performed the condition was randomized for each set of experiments. The subjects MMH capacities and corresponding heart rate data are shown in Table 1.

3. Model Development

Two sets of models were developed for combined task capacities. The two sets of models are as follows.

(1) Prediction model for one-handed combined task capacities using two-handed combined task capacities as a predictor

(2) Prediction model for the capacity of one-handed combined task using two-handed combined task capacity and frequency rate

Table 1. Means and Standard deviation of Response Measures

	6/min		1/min		1/5min	
	one-handed	two-handed	one-handed	two-handed	one-handed	two-handed
maw	13.9 (2.71)	16.7 (2.33)	27.0 (5.53)	35.9 (7.91)	32.4 (7.48)	42.5 (9.68)
heart rate	120.0 (11.0)	147.2 (16.0)	100.1 (6.6)	110.4 (9.1)	105.6 (6.4)	116.8 (8.7)

* the value in parenthesis are standard deviations.
* maw : maximum acceptable weight (kg).
the unit for heart rate is bpm.

The goodness of the models was indicated as R^2 values and PRESS statistics. R^2 is a descriptive measure of the strength of the regression relationship, a measure of how well the regression line fits the data. The press statistics is defined as follows (Allen, 1971):

$$PRESS = \sum_{i=1} (Y_i - Yh_i)^2$$

where Y_i = observed value for the i-th observation
Yh_i = the estimator of $E(Y_i)$ excluding the i-th observation
The PRESS value indicates the amount of prediction sum of squares error.

3.1. Modeling for one-handed combined task capacities using two-handed combined task capacities as a predictor

The capacity of one-handed combined task was over 75% of the capacity of two-handed combined task on the same frequency rate. Table 2 shows the correlation between the capacities of one-hand tasks and two- handed tasks. From the Table 2, there was some correlation between one-handed and two-handed task capacities at the same frequency rate, so, there might be a positive, linear relationship between the capacities of one-handed and two-handed tasks. The prediction models for the capacity of the one-handed combined task were developed by using the capacity of the two-handed combined task as a predictor for each frequency. Table 3 shows the developed model for each frequency using the capacity of two-handed combined task as a predictor and corresponding R^2 values and PRESS statistic. Each model showed high R^2 value (0.9361 for 6/min, 0.7019 for 1/min, and 0.8330 for 1/5min) and had just one predictor (the capacity of two-handed task) for simplicity. However, each model in Table 3 had a limit that it was restricted to use only for a certain frequency rate.

3.2. Modeling for one-handed combined tasks capacities using two-handed combined task capacities and frequency rate

To overcome that limit of the models in Table 3, another model was developed for one-handed combined task capacity using two-handed combined task capacity and frequency rate as predictors. In this model, the proportional frequency rate (PFR) was used. For example, if the frequency rate was 6/min, 6 was used as PFR and for the 1/5min frequency rate, 0.2 was used as PFR. Model 4 shows the prediction model for the one-handed combined task capacity using two-handed combined task capacity and frequency rate.

4. Discussionu

The advantage of the first set of models (models 1 through 3) was that these models were very simple to use because of just one predictor. Also, in spite of simplicity, these models had fit the current data set and simulated future data set in terms of R^2 values, and PRESS values. If the two-handed combined task capacity is known, the one-handed combined task capacity could be predicted for the same frequency rate. However, these models were

Table 2 Correlation between the capacities of one-handed task and two-handed task

		one-handed task		
		6/min	1/min	1/5min
two-handed task	6/min	0.9495 [a] (0.0001) [b]	0.5403 (0.1069)	0.2297 (0.5233)
	1/min	0.3304 (0.3512)	0.8387 (0.0024)	0.7054 (0.0227)
	1/5min	0.3856 (0.2711)	0.7366 (0.0151)	0.9132 (0.0002)

[a] pearson correlation coefficient
[b] Prob > |R| under Ho: Rho = 0

Table 3 Prediction Models for the Capacity of One hand Combined task using the Capacity of Two hands Combined task for each frequency

Frequency	Model	R^2	PRESS	Model
6/min	C1 = -5.272 + 1.1420 x C2	0.9361	4.23	Model 1
1/min	C1 = 5.955 + 0.5860 x C2	0.7019	82.17	Model 2
1/5min	C1 = 2.241 + 0.7055 x C2	0.8330	84.04	Model 3

where : C1 = capacity of one-handed combined task for each frequency rate (kg)
C2 = capacity of two-handed combined task for each frequency rate (kg)

Table 4 Prediction Model for the Capacity of One hand Combined task using the Capacity of Two hands Combined task and PFR

Model 4: $\ln(C1) = 2.314 + 0.027 \times C2 - 0.0257 \times PFR$
$R^2 = 0.9233$ PRESS = 0.4135

where: C1 = capacity of one-handed combined task (kg)
C2 = capacity of two-handed combined task (kg)
PFR = 6 when frequency rate is 6/min
1 when frequency rate is 1/min
0.2 when frequency rate is 1/5 min
Ln= natural log (e=2.7182)

limited to use only their own frequency rate.

The model 4 overcame the shortage of the models 1 through 3 by adding frequency rate as a predictor to avoid using different models for different frequency rates. Model 4 showed a high R^2 value and the PRESS value was also impressive. However, since a small sample size (10 subjects) was used for the model development in this study, for the best predicted results, these models should be applied within the range of independent variables of present study. The best ranges for the two-handed task capacities for this model is from 13kg to 52kg, and ranges for the frequency rates is from 6/min to 1/5min.

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