

# Psychophysically determining the maximum acceptable weight of lift for polypropylene laminated bags

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**Abstract:** The objective of this study was to psychophysically determine the maximum acceptable weight of lift (MAWL) for polypropylene (PP) laminated bags. Twelve men were requested to decide their MAWLs under various task combinations involving 3 lifting ranges, 3 lifting frequencies, and 2 hand conditions. The results revealed that the MAWL was significantly affected by the frequency and range variables (all  $p < .001$ ), whereas the hand condition did not influence the MAWL. The participants exhibited relatively low MAWL values compared with subjects in previous studies, especially in infrequent lifts. The results of multiple stepwise regression revealed that certain anthropometric data (e.g., chest circumference, wrist circumference, and acromial height) accounted for the percentage of variance for the determined MAWLs, ranging from 56.2% to 83.4%. These data can be obtained simply and quickly, and are considered the superior predictors for MAWL determination when handling PP laminated bags.

**Key words:** Psychophysics, Maximum acceptable weight of lift, Handles, Prediction model, Anthropometry

## Introduction

The maximum acceptable weight of lift (MAWL) is one of the most widely used approaches for representing a person's lifting capacity and is thus employed to design appropriate jobs<sup>1</sup>. When lifting, the weight and its distribution, shape, stiffness, and handles are object characteristics that must be considered in the design of lifting tasks<sup>2, 3</sup>. Previous studies found that good handles were theorized to reduce lifting stress, whereas poor handles were theorized to increase lifting stress<sup>4</sup>. Ciriello *et al.* reported that the maximum acceptable weight was approximately 16% lower when no handles were used and suggested that the load recommendations for the MAWL based on boxes with

handles must be adjusted when applied to boxes without handles or other types of containers<sup>5</sup>).

However, numerous MAWL studies have focused only on rigid boxes with well-designed handles. In practice, many manual material handling tasks exist in manufacturing and service industries, logistics, and agriculture that require people to lift soft bags without handles, such as polypropylene (PP) laminated bags, for transporting goods; loading and unloading bags, boxes, or cartons; removing materials from a conveyor belt; and stacking goods in a warehouse<sup>6</sup>. Therefore, the aim of this study was to psychophysically determine the MAWL for PP laminated bags and to develop candidate predictors for the MAWL.

## Methods

We recruited 12 male university students to participate in this study. Their mean age, height, and body mass were

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**Table 1. Basic data of the twelve Taiwanese male participants in this study**

Items	Mean	S.D.	Range
Age (years)	23.3	0.8	22.0– 24.2
Stature (cm)	172.3	3.9	163.0–178.0
Body mass (kg)	68.4	5.2	59.2– 81.6
Acromial height (cm)	142.3	6.0	132.1–148.0
Knuckle height (cm)	75.8	2.9	68.3– 81.8
Knee height (cm)	51.0	1.9	48.5– 55.0
Chest circumference (cm)	19.0	1.5	17.5– 22.8
Wrist circumference (cm)	16.1	0.8	15.0– 17.5
Isometric strengths (kg)			
Composite strength	100.9	6.9	90.9–111.2
Back strength	56.3	14.0	32.3– 77.2
Shoulder strength	34.9	5.5	28.8– 50.5
Arm strength	30.9	4.1	23.0– 35.8

23.5 years, 172.3 cm, and 68.4 kg, respectively. Table 1 shows the details. All participants reported being moderately physically active (leisurely exercise at least twice a week), healthy and asymptomatic of illness and having no pre-existing injuries. Anthropometric measurements and standard isometric strengths were obtained by following the procedure detailed by Ayoub *et al.*<sup>7)</sup>, which was applied for all participants for further regression analysis. The subjects participated voluntarily and underwent a physical examination conducted by a physician. Informed consent was obtained from all participants, and the Ethics Committee of Chang Gung Memorial Hospital approved this study.

Each participant determined his MAWL by using the psychophysical approach<sup>8)</sup>, for each task condition. The assumption of psychophysical stress as an integration of physiological and biomechanical stress has been studied by several researchers<sup>1, 5, 8, 12)</sup>. Specific instructions were given for the MAWL determination to adjust the weight of the bag by adding or subtracting sand to the maximum amount that they could lift comfortably (i.e., without straining themselves) for an 8-h workday in an assigned task combination. The participants were familiarized with the experimental procedures prior to data collection. The training session lasted 3 days, which permitted them to gain experience in monitoring their own sensations and in adjusting the object's weight. A minimum rest period of 15 min was required between successive trials and the participants were also restricted to performing the tests 2-h every half day to avoid a carry-over effect. The initial weight of the bag was varied at random, and the participants were encouraged to make adjustments. No incentives or emotional appeals were applied to minimize emotional influence. Unlike the rigid boxes (i.e., wooden boxes) typically

used in previous studies, a PP laminated bag with a length of 50 cm and a width of 40 cm was designed and produced for this study. The maximum capacity of the bag was 50 kg and the dry sand was generally used in building and construction industry. A thin and plastic wooden plate was set inside the rectangular bag to maintain its shape. Bags of this size and the cotton yarn gloves used in the tests are used widely in Taiwan.

For each lifting task, the participants were required to lift a bag by grasping the edges on each side. Three ranges were set for the lifts: floor to knuckle (FK; knuckle height: 76 cm), floor to shoulder (FS; shoulder height: 127 cm), and knuckle to shoulder (KS). Moreover, three frequencies were set for the lifts: one-time maximum (OTM), 1 lift/min, and 4 lifts/min. Two hand contact conditions were set: with and without gloves. For the FKM task, the participants lifted the bag from the floor to knuckle height at the OTM frequency. Similar notations were used for the other tasks. The OTM lift was considered an infrequent task, whereas 4 lifts/min was considered a frequent task. Consequently, 216 MAWLs (12 participants  $\times$  3 handling ranges  $\times$  3 frequencies  $\times$  2 hand contacts) were determined. Each participant was allotted approximately 20 min for determining his respective MAWL and then performed the MAWL task for the next 20 min.

During the MAWL determination, a randomized complete-block design was used for the experiment. Each participant was considered a block; he performed all treatment combinations in random order. The MAWL data were analyzed with three-way analysis of variance (ANOVA), and the Duncan multiple-range test (MRT) was performed for post hoc comparisons. An alpha level of .05 was selected as the minimum level of significance. Significant factors affecting the MAWL were developed by conducting stepwise regression analysis. This was achieved by selecting the anthropometric data and the isometric strength values as predictors.

## Results and Discussion

The ANOVA results showed that the MAWL data were significantly affected by the lifting range ( $F_{(2,198)}=87.7$ ,  $p<0.001$ ,  $\eta^2=0.470$ ) and frequency ( $F_{(2,198)}=375.7$ ,  $p<0.001$ ,  $\eta^2=0.791$ ) variables. This result was in agreement with those reported by Lee *et al.*<sup>8)</sup> and Pinder and Boocock<sup>9)</sup>. The MAWL values did not differ between the hand contact conditions ( $F_{(1,198)}=0.201$ ,  $p=0.668$ ,  $\eta^2=0.001$ ). Moreover, the interactions were found to have a non-significant influence on determining the MAWL,

**Table 2.** Mean (SD) MAWL values determined by 12 participants compared with the results of a previous study

Task variables	This study	Duncan MRT grouping	Lee <i>et al.</i> <sup>(8)</sup>
Floor to knuckle			
One time maximum	36.3 (3.7)	A	40.5 (8.9)
1 lift/min	25.1 (1.8)	B	26.5 (5.9)
4 lifts/min	22.6 (1.1)	C	20.7 (2.0)
Floor to shoulder			
One time maximum	31.0 (4.1)	A	32.0 (5.0)
1 lift/min	23.2 (2.1)	B	22.3 (3.5)
4 lifts/min	18.9 (3.2)	B	17.5 (1.9)
Knuckle to shoulder			
One time maximum	27.0 (2.4)	A	30.6 (5.7)
1 lift/min	21.9 (2.5)	B	20.9 (4.7)
4 lifts/min	18.9 (2.1)	C	17.3 (2.2)

except for that between frequency and height.

The means and standard deviations of the MAWL values for all task conditions, as well as the Duncan MRT result, are listed in Table 2. A comparison of the MAWL data against those presented by Lee *et al.*<sup>(8)</sup> is also displayed in the table. Compared with the previous Taiwanese data, the MAWL values of infrequent FK and KS tasks in this study were 4.2 kg and 3.6 kg, respectively, lower than those reported by Lee *et al.*<sup>(8)</sup>. This may be attributed to the boxes used by Lee *et al.* having handles. Garg and Saxena<sup>(10)</sup> indicated that the average MAWL for six boxes with different dimensions that were tested without handles was lower (ranging from 4.0% to 11.5%, with an average decrease of 7.2%) compared with that for boxes with handles. Ciriello *et al.* reported that the maximum acceptable weight was approximately 16% lower when no handles were used<sup>(5)</sup>. However, this was insufficient for gaining an understanding as to why the effect of the handles was not observed in the FS task (with a difference of 1 kg). Moreover, it seems that the handle effect existed only in the infrequent task (i.e., OTM in this study). Smith and Jiang<sup>(11)</sup> reported that the MAWL for bag lifting was higher (2.2 kg) than for box lifting in FS tasks with a frequency of 6 lifts/min. Our results were consistent with theirs when performing the frequent tasks. The results implied that handle effect may interact with other task variables in lifting. Further comparative studies in the handle effect may be required to clarify these ambiguities.

Table 3 lists the R-squares of the significant factors for predicting the MAWL by using the participants' anthropometric data and isometric strength values as inputted for all 9 task conditions. Because an effect of gloves on the MAWL was not found, the prediction models were devel-

**Table 3.** Candidate predictors for predicting the MAWL values of nine task combinations according to the participants' anthropometric data

Task variables	Predictors	R <sup>2</sup>	Increased R <sup>2</sup>	<i>p</i>
Floor to knuckle				
One time maximum	Chest circumference	0.666	—	0.001
	Wrist circumference	0.794	0.128	0.042
1 lift/min	Chest circumference	0.678	—	0.001
4 lifts/min	Chest circumference	0.701	—	0.001
	Wrist circumference	0.834	0.133	0.025
Floor to shoulder				
One time maximum	Chest circumference	0.435	—	0.020
	Wrist circumference	0.562	0.127	0.139
1 lift/min	Chest circumference	0.601	—	0.003
4 lifts/min	Chest circumference	0.625	—	0.002
	Wrist circumference	0.785	0.160	0.029
Knuckle to shoulder				
One time maximum	Chest circumference	0.654	—	0.001
	Acromial height	0.752	0.098	0.092
1 lift/min	Chest circumference	0.520	—	0.008
	Wrist circumference	0.628	0.108	0.141
4 lifts/min	Acromial height	0.725	0.097	0.133
	Chest circumference	0.613	—	0.003
4 lifts/min	Wrist circumference	0.702	0.089	0.135
	Acromial height	0.791	0.089	0.101

oped without considering the glove condition. In this study, the body mass was added to the MAWL as a dependent variable to identify the significant predicting factors from previous studies<sup>(7, 12)</sup>. Anthropometric data (cumulative R<sup>2</sup> ranged from 0.562 to 0.834) were considered to have superior predicting power compared with those reported in previous studies<sup>(8, 12)</sup> in which boxes were equipped with well-designed handles. However, all strength values were not selected as the significant predictors. Among these significant factors, the chest circumference (CC) was the most preferentially selected predictor for all 9 lifting tasks, with the accounted variance ranging from 43.5% for the FSM task to 67.8% for the FK1 task. The significant relationship between the CC and MAWL observed in this study was in agreement with that reported by Lee and Chen<sup>(12)</sup>.

The wrist circumference (WC) was also a significant factor for MAWL prediction in this study. To the best of our knowledge concerning related past studies, the WC has seldom been selected as a factor in a MAWL prediction model for boxes with handles. In addition to the CC, a generally accepted significant predictor, the WC may be another critical index for predicting MAWL in cases without handles (e.g., PP laminated bags). Furthermore, the acromial height (AH) was determined to be a suitable predictor for KS tasks, as shown in Table 3. This result is

in agreement with the regression model developed by Lee and Chen<sup>12)</sup>.

## Conclusions

Twelve Taiwanese male students were recruited to determine their MAWL values when lifting PP laminated bag under various task combinations. Results also showed that the CC, WC, and AH accounted for 56.2% to 83.4% of the MAWL variations. These candidate factors are presented for use in predicting the lifting capacities for various lifting ranges and frequencies. Therefore, tasks can be pre-screened and assigned to specific populations according to measured anthropometric data. The usefulness of the measure for providing the predictive factors for other populations (e.g., industrial workers, women, and older people) warrants further investigation.

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