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Asymmetric Lifting Capabilities for Different Container Dimensions

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This study recruited 14 young male participants to examine human 4-h maximum acceptable weight of lifting (MAWL) and maximum weight of lifting (MWL) for different modes of asymmetric lifting and containers. The results showed that asymmetric lifting with trunk rotation decreased MAWL and MWL by 9.1 and 17.3%, respectively, and asymmetric lifting with body turn decreased MAWL and MWL by 6.1%, when compared with the symmetric lifting. The decreasing effects of container width and MAWL and MWL were greater than those of container length. Participants selected MAWL of ~33–37% of their MWL capability.

lifting capacity asymmetric lifting container

1. INTRODUCTION

Lifting a load to a destination off the mid-sagittal plane is referred to as an asymmetric lifting. An asymmetric lifting task usually requires a lifter to twist the trunk to some degrees off the sagittal plane while lifting. Several studies have demonstrated the potential disadvantages for twisting trunk while lifting. For example, an asymmetric lifting would increase the shear and compression loading on the intervertebral discs and the muscle activities of the trunk [1, 2, 3, 4]. Second, an asymmetric lifting would decrease maximum isometric trunk strength [5], isoinertial peak lifting force, velocity and average upward acceleration [6] or human lifting capability [7, 8, 9, 10, 11, 12]. Third, an asymmetric lifting can cause poor posture stability and asymmetric muscular loads on the spine [5].

Human psychophysical maximum acceptable weight and force for manual materials handling tasks have been examined for decades. In 1991, Snook and Ciriello developed manual materials handling guidelines, maximum acceptable weights and forces that derived from studies conducted in a 21-year time span before 1991 [13]. Recently, Ciriello, Dempsey, Maikala, et al. revealed secular changes, a drop in absolute psychophysically determined maximum acceptable weights and forces, over 20 years, though the effects of task variables were similar to earlier results [14]. This study aimed to examine maximum acceptable weight of lifting (MAWL) for symmetric and two asymmetric lifting tasks (asymmetric lifting with trunk rotation and asymmetric lifting with body turn), and for three container dimensions (varying in frontal and sagittal dimensions) for a 4-h work period. A further objective was to examine the percentage of participants' MAWL to their maximum weight of lifting (MWL). Our hypothesis was that participants' MAWL would differ significantly with different lifting modes and container dimensions, and the participants' MAWL for a 4-h work period would be much lower than their MWL.

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2. METHOD

2.1. Participants

Fourteen young male university participants, experienced in manual materials handling tasks, were recruited for this experiment. Their mean (*SD*) anthropometric data were, age 20.5 (0.9) years, body weight 66.5 (13.3) kg and height 171.0 (3.4) cm. All participants were in good physical health. They gave their written consent to participate in this experiment.

2.2. Description of Task Variables

This study examined participants' MAWL for lifting a container from the floor onto a 74-cm-high table at a frequency of 4 lifts/min for a 4-h work period. Participants were tested over three lifting modes and three container dimensions. The three lifting modes included symmetric lifting, 90° asymmetric lifting with trunk rotation, and 90° asymmetric lifting with body turn. For symmetric lifting, participants lifted the container sagittally from the floor onto a 74-cm-high table. For 90° asymmetric lifting with trunk rotation, participants first twisted their trunk and held a container initially located at their right side, then lifted the container onto a table in front of them. For 90° asymmetric lifting with body turn, participants first performed an initial symmetric lifting, followed by a 90° body turn to the left (footstep change), and then placed the container onto the table. Figure 1 presents the schematic top view of the three lifting modes. For all three lifting modes, the participants were permitted to take one or two steps as needed for body stability while placing the container onto the table. The horizontal distance from the table edge to the middle of the initial location of the ankles was ~90 cm. The sagittal distances of the container's center of gravity from the ankles were ~42.5 and 50 cm for 35- and 50-cm-wide containers, respectively.

The three container dimensions (length × width × height) in this study were 70 × 35 × 15 cm, 50 × 50 × 15 cm and 50 × 35 × 15 cm. The 50 × 35 × 15-cm container provided a standard basis. The dimensions of the 70 × 35 × 15- and 50 × 50 × 15-cm ones were designed to examine the effects of container length and width on the participants' lifting capability, respectively. All three containers had secure wooden handles (3 cm in diameter) on the upper middle half of the container width sides.

2.3. Procedure

The participants wore flat-soled sport shoes during the experiments. Before the experiment, the participant was asked to rest for at least 10 min on a seat before his resting heart rate was taken with a polar heart rate monitor (Polar Accurex II, Polar CIC, USA). Then,

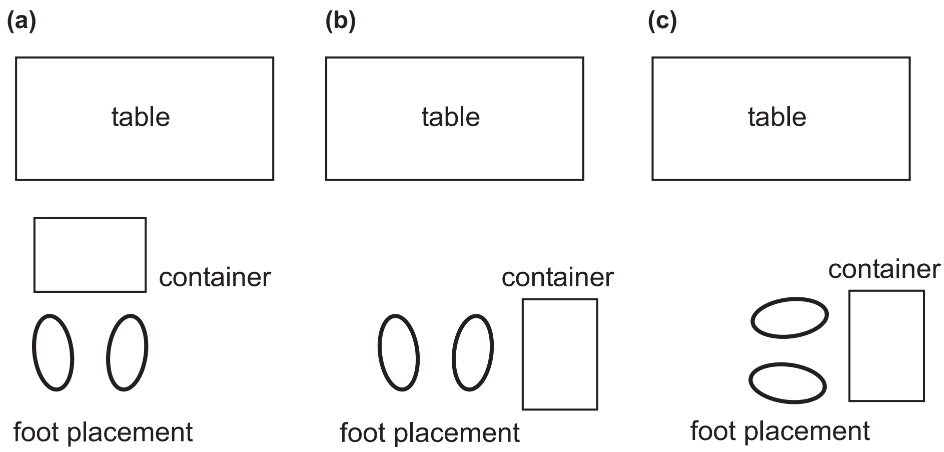

Figure 1. Top schematic view for (a) symmetric lifting, (b) 90° asymmetric lifting with trunk rotation and (c) 90° asymmetric lifting with body turn.

the participant stretched to warm up. Next, the participant performed one of nine (three lifting modes × three lifting containers) possible experimental conditions. The sequence for performing the nine experimental conditions was random for each participant. The initial weight (lead shot) inside the container was randomly assigned, ~5–25 kg. The participant was asked to lift the container using a free-style lifting posture at a frequency of 4 lifts/min monitored with a pace timer which generated an audible signal for the participant. He was encouraged to adjust the weight (by adding or subtracting lead shot) inside the container to the maximum that he could accept at a frequency of 4 lifts/min for 4-h work without strain or discomfort, without feeling tired, weakened, overheated or out-of-breath. Psychophysical weight adjustment lasted for 30 min. After the participant confirmed that he had adjusted the weight to his MAWL, he was asked to perform the lifting task for another 5 min to reach a steady heart rate and then the test ended. The participant's heart rate was recorded right after the end of each test. No more than one experimental condition was tested for each participant in a day. Before formal experiments, each participant had a 10-day training period to become familiar with the psychophysical weight adjustment procedure.

This study also measured each participant's MWL capacity from the floor onto the 74-cm-high table under all nine possible experimental conditions. The lifting posture for MWL measurements was identical to that for MAWL. To obtain the participant's MWL capacity for a given condition, he was initially asked to lift a container loaded with some lead shot from the floor onto a 74-cm-high table. If the participant could lift the container onto the table, he was asked to increase the load by adding more lead shots, in increments of 2–10 kg, until he could not perform the task. Initial load increments were large but they were reduced as the participant approached his estimated MWL capacity. At least 2 min of rest were provided between two consecutive progressive tests. The participant's MWL capability could normally be obtained after several progressive tests.

3. RESULTS

Table 1 shows the means and standard deviations of MAWL and MWL, MAWL to MWL percentages and the difference between working heart rate and resting heart rate (Δ heart rate) for all nine experimental conditions. This table demonstrates that symmetric lifting resulted in higher MAWL and MWL than the other two asymmetric lifting modes. The 50 × 35 × 15-cm container gave higher MAWL and MWL than the other two containers. Additionally, participants selected MAWL of ~33–37%

TABLE 1. MAWL (kg), MWL (kg), MAWL/MWL (%) and Δ Heart Rate (beats/min) for All 9 Experimental Conditions

		MAWL	MWL		
Mode	**Container (cm)**	***M* (*SD*)**	***M* (*SD*)**	**MAWL/MWL**	**Δ Heart Rate**
Symmetry	50 × 35 × 15	17.8 (2.3)	53.4 (5.4)	33.3	29.4
	50 × 50 × 15	15.5 (1.6)	45.2 (5.4)	34.2	29.1
	70 × 35 × 15	16.4 (1.7)	49.1 (6.3)	33.4	29.7
Trunk rotation	50 × 35 × 15	15.8 (1.7)	43.7 (6.1)	36.1	27.2
	50 × 50 × 15	13.9 (1.6)	37.7 (6.0)	36.8	28.5
	70 × 35 × 15	15.3 (1.2)	40.8 (6.0)	37.5	34.5
Body turn	50 × 35 × 15	16.3 (2.3)	49.5 (6.1)	32.9	31.2
	50 × 50 × 15	14.7 (1.5)	42.6 (5.4)	34.5	31.3
	70 × 35 × 15	15.5 (1.4)	46.5 (5.5)	33.3	29.8

Notes. MAWL—maximum acceptable weight of lifting, MWL—maximum weight of lifting, Δ heart rate—difference between working and resting heart rates.

TABLE 2. Analysis of Variance (ANOVA) for Maximum Acceptable Weight of Lifting (MAWL), Heart Rate and Maximum Weight of Lifting (MWL) (*F* Values)

Variable	*df*	MAWL	Heart Rate	MWL
Participant	13	20.73*	23.18*	46.01*
Mode	2	25.97*	0.62	135.83*
Container	2	39.22*	0.22	95.50*
Mode × container	4	1.00	1.59	0.83
Error	104			

Notes. *significant at $P < .05$.

TABLE 3. Means and Relative Percentages of MAWL (kg) and MWL (kg) for Different Lifting Modes and Dimensions of Containers

	MAWL		MWL	
Variable	***M***	**%**	***M***	**%**
Mode				
symmetric	16.5	100	49.2	100
trunk rotation	15.0	90.9	40.7	82.7
body turn	15.5	93.9	46.2	93.9
Container (cm)				
50 × 35 × 15	16.6	100	48.8	100
50 × 50 × 15	14.7	88.5	41.8	85.6
70 × 35 × 15	15.7	94.5	45.5	93.2

Notes. MAWL—maximum acceptable weight of lifting, MWL—maximum weight of lifting.

of their MWL capacity. Table 2 shows that the effects of the lifting mode and container dimensions on MAWL and MWL were significant ($P < .05$).

Table 3 shows that MAWL and MWL decreased with an increase in container length and width. MAWL decreased to 88.5% (50 × 50 × 15 cm) or 94.5% (70 × 35 × 15 cm) of MAWL for the 50 × 35 × 15-cm container. The effect of container length or width on MWL was similar to that on MAWL. MWL decreased to 85.6% (50 × 50 × 15 cm) and 93.2% (70 × 35 × 15 cm) of MWL for the 50 × 35 × 15-cm container. In addition, both MAWL and MWL decreased in asymmetric lifting. MAWL for 90° asymmetric lifting with trunk rotation and 90° asymmetric lifting with body turn were 90.9 and 93.9% of that of the symmetric lifting variants, respectively. MWL for asymmetric lifting with trunk rotation and with body turn were 82.7 and 93.9% of that of the symmetric lifting variants, respectively. The difference between the two asymmetric lifting modes was significant for MAWL and MWL ($P < .05$).

4. DISCUSSION

Our data demonstrated that MAWL and MWL decreased with container width or length. In terms of biomechanics, increasing container length or width elevates muscular strain during lifting due to a longer moment arm to shoulder or low back. Our results showed that the effects of the dimensions of the container on MWL were larger than those on MAWL. For example, MWL averaged across three lifting modes decreased to 85.6% (50 × 50 × 15 cm) or 93.2% (70 × 35 × 15 cm) of MWL for the 50 × 35 × 15-cm container, while MAWL only decreased to 88.5% (50 × 50 × 15 cm) and 94.5% (70 × 35 × 15 cm) of MAWL for the 50 × 35 × 15-cm container. Previous studies showed that MAWL decrement ranged from 3 to 9% as container width increased from 30.48 to 45.72 cm; and an additional 2–5% as container width increased further from 45.72 to 60.96 cm [15, 16, 17]. Our 11.5% decrement for MAWL as the container width increased from 35 to 50 cm was a little higher than the upper boundary of the decrease range in previous studies.

This study showed that MAWL and MWL decreased by only 5.5 and 6.8% as the container length increased from 50 to 70 cm, respectively, compared to the 11.5% (for MAWL) and 14.4% (for MWL) decreases as the container width increased from 35 to 50 cm, indicating that the effect of container length on human lifting capacities was smaller than the effect of container width. This implies that a practitioner should avoid choosing a wider container in lifting task. Finally, our participants selected MAWL of ~33–37% of their MWL capacity for a 4-h repeated lifting work period.

Asymmetric lifting decreased MAWL and MWL as compared to symmetric lifting. The decrease can be attributed to the oblique direction of force application, poor postural stability and unequal muscle loading in asymmetric lifting. Additional body movement and longer travel distance of the container in asymmetric lifting may also be responsible for lower MAWL and MWL. This study revealed that asymmetric lifting led to lower MAWL while heart rate remained almost unaltered as compared to symmetric lifting. The insignificant change in heart rate was consistent with Mital and Fard's [7] and Kumar's [18] findings, though Garg and Banaag [8] reported heart rate increased with an increase in the angle of asymmetry. It seems that participants adjusted their MAWL psychophysically to achieve a near-equal circulatory load for both symmetric and asymmetric lifting.

Previous studies confirmed that asymmetric lifting resulted in lower MAWL. However, the decrease in MAWL of 90° asymmetric lifting with trunk rotation to that of symmetric lifting differed among studies due to different experimental conditions, such as lifting frequency, container, lifting range, participants and work duration. Table 4 compares the decrease (%) in MAWL of asymmetric lifting

TABLE 4. Comparison of Maximum Acceptable Weight of Lifting (kg) of Asymmetric Lifting With Trunk Rotation and the Experimental Conditions in Various Studies

Variable	Mital & Fard [7]	Garg & Badger [5]	Garg & Banaag [8]	Chen, Aghazadeh & Lee [9]	Wu [11]	Wu [12]	This Study
Angle							
symmetric	17.4	42.1	26.6	25.8	34.9	24.3	16.5
30°		34.9	24.6	23.5	33.5	23.1	
60°		36.2	22.9	20.9	31.7	22.2	
90°	15.9	33.5	21.2	18.5	30.3	21.2	15.0
Lifting frequency (lifts/min)	1, 4, 8	0.2	3, 6, 9	1, 2, 4, 8	1, 4	1, 4	4
Container (length × width) (cm)	30.48 × 45.72	51 × 25	51 × 38	52 × 37	48 × 36	48 × 36	50 × 35
	30.48 × 60.96	51 × 38					50 × 50
	35.56 × 30.48	51 × 51					70 × 35
	35.56 × 30.48 cg offset 10.16						
	35.56 × 30.48 cg offset 20.32						
Lifting range (cm)	0–81	0–81	0–81	0 to knuckle height	0–76	0–68	0–74
Participants	occidental males	occidental males	occidental males	occidental males	oriental males	oriental males	oriental males
Work duration (h)	8	8	1	8	1	1	4

Notes. cg—center of gravity.

with trunk rotation and the experimental conditions of various studies. MAWL decrease data were averaged across the lifting frequencies and containers for each study. Our 9.1% decrement for MAWL was close to Mital and Fard's [7] 8.5%.

The asymmetric lifting with body turn has an apparent biomechanical advantage over asymmetric lifting with trunk rotation due to lesser trunk twist, which might be safer for the trunk. However, asymmetric lifting with body turn also requires one or two more foot steps in the lifting process. This study showed that although participants accepted more weight (0.5 kg) in asymmetric lifting with body turn than in asymmetric lifting with trunk rotation, this difference was trivial and impractical. By analyzing MWL data, we found that the difference in MWL between asymmetric lifting with trunk rotation and body turn was more considerable than the difference in MAWL. A person using asymmetric lifting with body turn could lift 5.5 kg more weight than when using asymmetric lifting with trunk rotation.

Finally, practitioners should fully understand that the psychophysically determined MAWL data was normally much higher than the corresponding recommended weight limits of the revised NIOSH equation [19]. The large discrepancies between MAWL data and the corresponding recommended weight limits can be attributed to a multiplicative model and choosing the most conservative (i.e., most protective) criterion when developing the revised NIOSH equation. For example, the effect of a multiplicative model in the revised NIOSH equation on reducing the recommended weight limits can be easily understood by a multiplication result of only 0.26 assuming all six factor multipliers are equal to 0.8. Additionally, the 23-kg load constant in the revised NIOSH equation was chosen on the basis of the maximum acceptable weight limit for 75% of female workers under ideal conditions. Both are responsible for the large discrepancies between MAWL data and the corresponding recommended weight limits.

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