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Tzu-Hsien Lee[a] & Chia-Yun Tseng[a]
[a] Department of Management and Information Technology, Southern Taiwan University of Science and Technology, Tainan, Taiwan

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Grip Force and Heart Rate Responses to Manual Carrying Tasks: Effects of Material, Weight, and Base Area of the Container

Tzu-Hsien Lee
Chia-Yun Tseng

Department of Management and Information Technology, Southern Taiwan University of Science and Technology, Tainan, Taiwan

This study recruited 16 industrial workers to examine the effects of material, weight, and base area of container on reduction of grip force (ΔGF) and heart rate for a 100-m manual carrying task. This study examined 2 carrying materials (iron and water), 4 carrying weights (4.4, 8.9, 13.3, 17.8 kg), and 2 base areas of container (24 × 24 cm, 35 × 24 cm). This study showed that carrying water significantly increased ΔGF and heart rate as compared with carrying iron. Also, ΔGF and heart rate significantly increased with carrying weight and base area of container. The effects of base area of container on ΔGF and heart rate were greater in carrying water condition than in carrying iron condition. The maximum dynamic effect of water on ΔGF and heart rate occurred when water occupied ~60%–80% of full volume of the container.

liquid solid carriage manual materials handling

1. INTRODUCTION

A manual carrying task is a human daily activity, also common in industrial operations. According to a survey, a manual carrying task, a proportion of ~15.7% of manual materials handling, is the third most frequent task in manual materials handling [1]. Statistics reveal that manual carrying tasks are risky for the musculoskeletal system, especially with regard to the upper limbs and vertebral spine [2]. In addition to the risk for the musculoskeletal system, carrying a load manually also imposes on the cardiovascular system. However, despite the significance of manual carrying tasks on musculoskeletal and cardiovascular systems, databases on manual carrying tasks are less extensive as compared with manual lifting and lowering tasks [3].

Designing the maximum acceptable weight of carrying has been of longstanding interest in studies of manual carrying tasks to reduce the risk of musculoskeletal injury. In the past decades, a number of studies have endeavored to determine the maximum acceptable weights of carrying for alleviating the musculoskeletal overexertion injuries of manual carrying tasks [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Yet, only a few studies have involved human cardiovascular workloads of manual carrying tasks, and most of them were on the resulting responses of heart rate or oxygen consumption of an individual while carrying their maximum acceptable weights [5, 13, 14, 15]. In addition, to our best knowledge, nearly all manual carrying task studies were conducted under the condition of solid carrying; the dynamic effect of liquid carrying on cardiovascular responses has never been revealed in studies.

This study intended to examine the material effect on manual carrying tasks to gain information on human responses to the dynamic effect of liquid in carrying. In this regard, two variables (carrying weight and base area of container) affecting the dynamic effect of liquid while carrying were also included in this study. Hence, the purpose of this study was to examine the effects of material, weight, and base area of container on the grip force

Correspondence should be sent to Tzu-Hsien Lee, Department of Management and Information Technology, Southern Taiwan University, No. 1, Nan-Tai Street, Yung-Kang 710, Tainan, Taiwan. E-mail: thlee@mail.stut.edu.tw.

reduction (ΔGF) and heart rate response while performing manual carrying tasks.

2. METHOD

2.1. Participants

This study recruited 16 male industrial workers as participants. All participants were in excellent physical condition and regularly engaged in manual materials handling tasks in their daily pursuits. They were compensated for their participation. The participants signed an informed consent statement. Their mean age was 36.0 years (*SD* 10.0), mean body mass was 66.9 kg (*SD* 6.2), and mean height was 170.2 cm (*SD* 6.0).

2.2. Apparatus

The apparatus of this study included a carrying container, dynamometer, and heart rate monitor. The carrying container was a commercial oil container whose three dimensions were 24, 24, and 35 cm. The dynamometer (Takei Kiki Kogyo, Japan) and heart rate monitor (OMRON, model TF1, Japan) were used to record grip force and heart rate, respectively.

2.3. Experimental Design

A completed randomized factorial design, with each participant as a block, was employed. Three independent variables were studied: carrying material, carrying weight, and base area of container (base length × base depth). Two levels of carrying material were examined: water (liquid) and iron (solid, iron sand, 0.3 mm in diameter). Four levels of carrying weight were examined: 4.4, 8.9, 13.3, and 17.8 kg. They occupied ~20%, 40%, 60%, and 80% of full volume of the container, respectively, in carrying water condition. Two levels of base area of container were examined: 24 × 24 cm and 35 × 24 cm. They were produced by using the square face (24 × 24 cm) and rectangle face (35 × 24 cm) of the carrying container as base, respectively. There were a total of 16 experimental treatments (2 carrying materials × 4 carrying weights × 2 base areas of container) for this study. The dependent variables were grip force reduction (ΔGF) and heart rate after participants performed carrying tasks.

2.4. Experimental Procedure

The experimental sequence for the 16 treatments was randomized for each participant. For each test,

(a) (b)

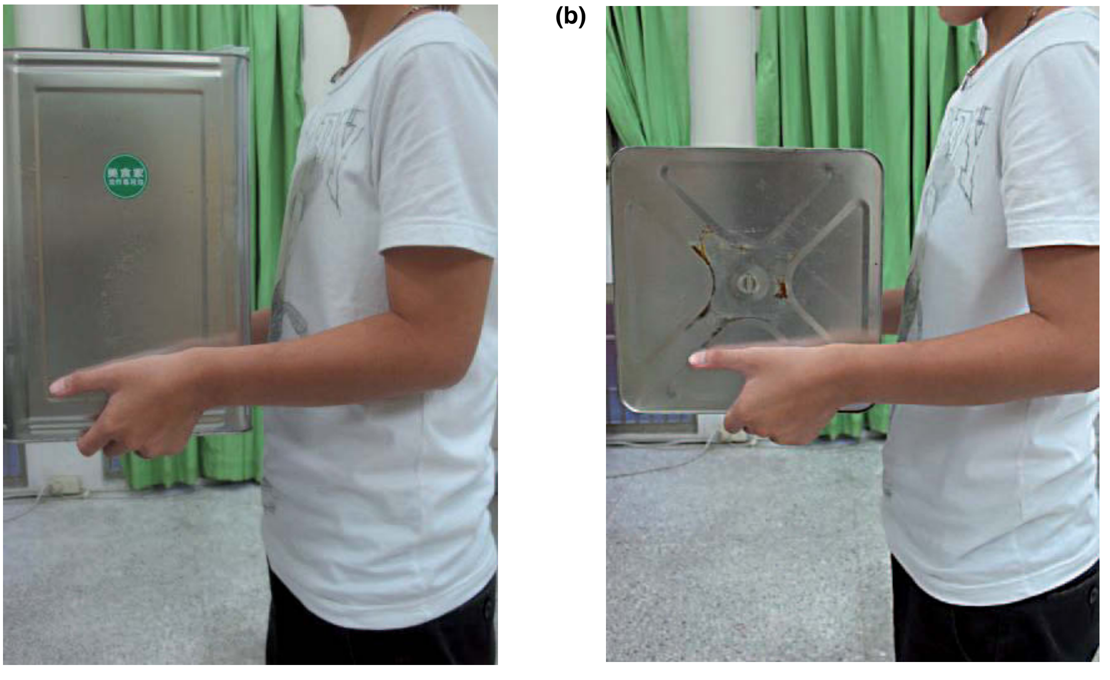

Figure 1. Carrying postures for (a) 24 × 24 cm base area of container and (b) for 35 × 24 cm base area of container of this study.

the grip force of the dominant hand of the participant was taken in a standing and arms hanging posture with the grip span of the dynamometer set at 6 cm. Then, the participant was asked to lift the container from the floor to elbow height (elbow angle at 90°), keep the container clear off body, hold the container and walk 100 m, then lower the container down to the floor. Figure 1 shows the carrying postures of this study. The participant performed the aforementioned procedure at normal task speed. The task time of the 100-m carrying was ~80 s. The grip force of the dominant hand and heart rate were recorded immediately after the participant finished the carrying task. On any given day, two experimental treatments, at an interval of 30 min, were assigned for each participant. Each participant replicated all 16 experimental treatments twice.

2.5. Data Analysis

Analysis of variance (ANOVA) was performed on the experimental data. Duncan's multiple range tests were further applied to determine the differences of means among levels of independent variables; $\alpha = .05$ was taken as the level of significance for all statistical tests.

TABLE 1. Grip Force Reduction (kg), *M* (*SD*)

	24 × 24 cm Base Area of Container		35 × 24 cm Base Area of Container	
Weight (kg)	Water	Iron	Water	Iron
4.4	1.18 (0.82)	1.25 (1.06)	1.21 (0.83)	1.18 (0.99)
8.9	1.53 (1.12)	1.71 (1.28)	1.93 (1.06)	1.57 (1.17)
13.3	3.53 (1.41)	3.06 (1.22)	4.39 (1.32)	3.79 (1.06)
17.8	5.21 (1.33)	5.10 (1.14)	6.09 (1.05)	5.32 (1.05)

TABLE 2. Heart Rate (bmp), *M* (*SD*)

	24 × 24 cm Base Area of Container		35 × 24 cm Base Area of Container	
Weight (kg)	Water	Iron	Water	Iron
4.4	88.7 (5.2)	88.5 (4.4)	89.8 (4.5)	89.1 (5.0)
8.9	91.6 (5.1)	91.3 (5.7)	94.8 (6.2)	91.6 (5.5)
13.3	99.3 (6.4)	98.8 (6.4)	103.6 (8.0)	99.6 (6.5)
17.8	105.3 (8.4)	105.5 (6.5)	110.8 (7.9)	106.8 (7.0)

TABLE 3. Summary of Analysis of Variance (ANOVA) on Grip Force Reduction (ΔGF) and Heart Rate (HR)

		F	
Variable	*df*	ΔGF	HR
Participant	15	11.12*	35.89*
Replication	1	2.80	0.28
M	1	8.79*	16.75*
W	3	492.47*	437.62*
B	1	17.38*	29.82*
M × W	3	2.30	1.05
M × B	1	4.12*	12.60*
W × B	3	4.54*	2.06
M × W × B	3	0.68	1.05
Error	480		

Notes. *$p = .05$; M = material, W = weight, B = base area.

3. RESULTS

Tables 1–2 summarize the means and standard deviations of ΔGF and heart rate, respectively. Clearly, ΔGF and heart rate increased with carrying weight. Table 3 shows the ANOVA results. ANOVA revealed that material, weight, base area, material × base area interaction, and weight × base area interaction significantly affected ΔGF. Additionally, material, weight, base area, and material × base area interaction significantly affected heart rate. Table 4 summarizes the means and standard deviations of ΔGF and heart rate for the independent variables, and results of Duncan's multiple range tests. For ΔGF response, Table 4 shows that the ΔGF of water was significantly greater than that of iron, ΔGF significantly increased with weight, and

TABLE 4. Means and Standard Deviations of Grip Force Reduction (ΔGF) and Heart Rate (HR), and Results of Duncan's Multiple Range Tests for Independent Variables

Variable	ΔGF	Grouping	HR	Grouping
Material				
iron	2.87 (1.94)	A	96.4 (9.0)	A
water	3.13 (2.13)	B	98.0 (10.0)	B
Weight (kg)				
4.4	1.21 (0.92)	A	89.0 (4.8)	A
8.9	1.69 (1.16)	B	92.3 (5.8)	B
13.3	3.69 (1.33)	C	100.3 (7.1)	C
17.8	5.43 (1.20)	D	107.1 (7.7)	D
Base area				
24 × 24 cm	2.82 (1.95)	A	96.1 (8.9)	A
35 × 24 cm	3.19 (2.12)	B	98.3 (10.0)	B

Notes. Means with different letters in Grouping are significantly different.

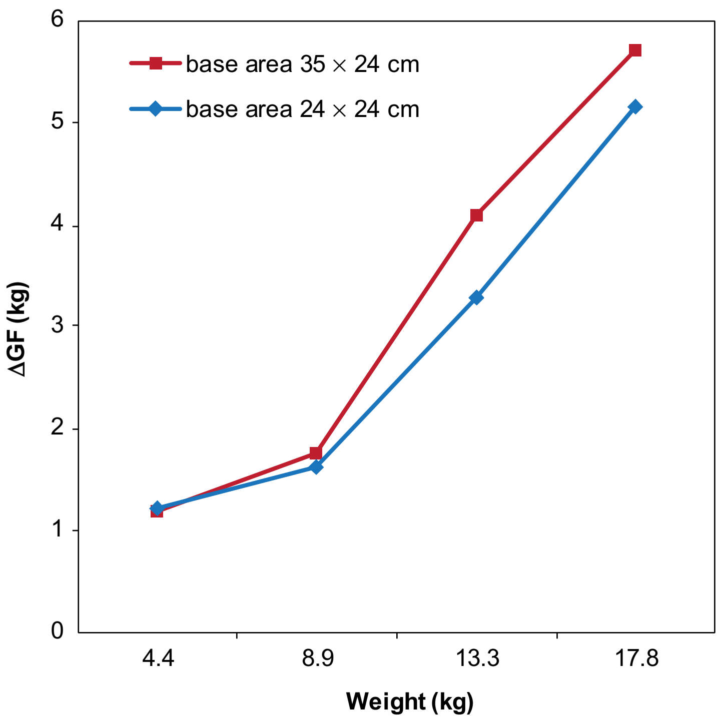

Figure 2. The interaction effect of weight × base area on grip force reduction (ΔGF).

ΔGF of 35 × 24 cm base area of container was significantly greater than that of 24 × 24 cm base area of container. For heart rate response, the heart rate of carrying water was significantly greater than that of carrying iron, heart rate significantly increased with weight, and the heart rate of 35 × 24 cm base area of container was significantly greater than that of 24 × 24 cm base area of container. Figures 2–4 show the interaction effects of weight × base area and material × base area on ΔGF, and the interaction effect of material × base area on heart rate.

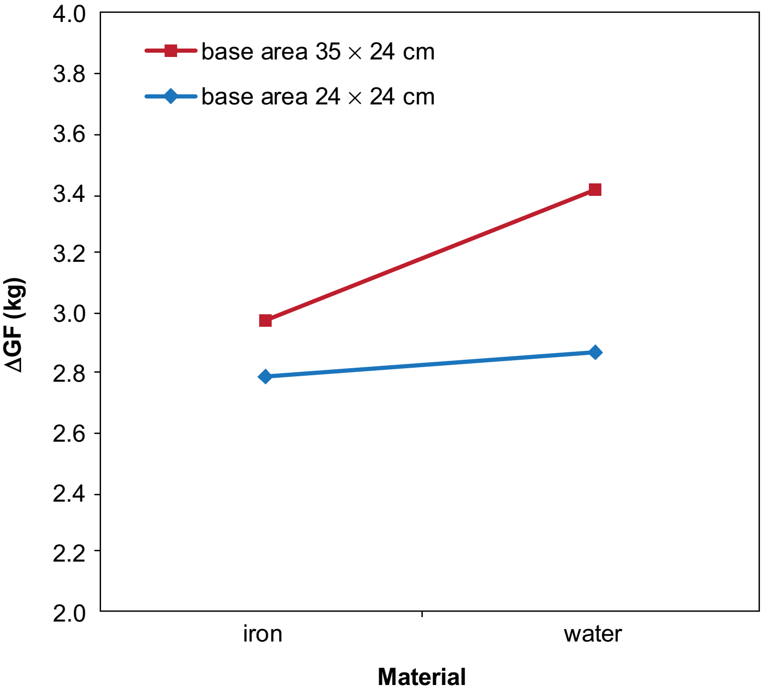

Figure 3. The interaction effect of material × base area on grip force reduction (ΔGF).

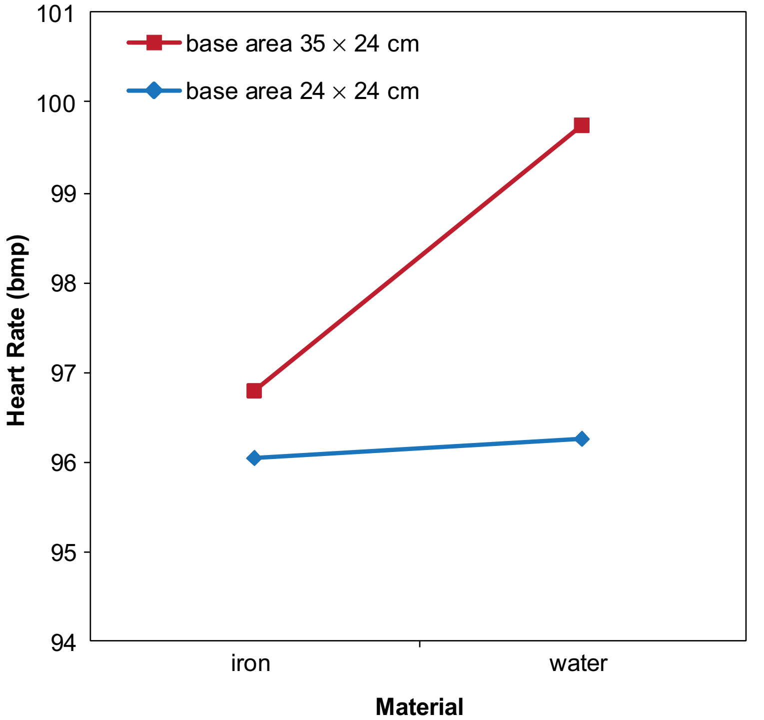

Figure 4. The interaction effect of material × base area on heart rate.

4. DISCUSSION

Carrying water significantly increased ΔGF and heart rate as compared with carrying iron. Overall, the ΔGF of carrying water (3.13 kg) was 109% of that of carrying iron (2.87 kg), and the heart rate of carrying water (98.0 beats per minute, bmp) was 102% of that of carrying iron (96.4 bmp). Mechanically, carrying water is associated with problems of sloshing and moving center of gravity, and both excitation force and damping by hands at the handles [6], the dynamic effect of water while carrying increases carriers' muscular and cardiovascular strains, and thus accounts for our findings.

Carrying weight also significantly affected ΔGF and heart rate, with ΔGF and heart rate increased with carrying weight. Overall, ΔGF increased from 1.21 (carrying weight of 4.4 kg) to 5.43 kg (carrying weight of 17.8 kg), and heart rate increased from 89 (carrying weight of 4.4 kg) to 107.1 bmp (carrying weight of 17.8 kg). This result can also be attributed to the increase in muscular and cardiovascular strains with carrying weight. However, to explain the relationship between carrying weight and ΔGF, or between carrying weight and heart rate, we can not ignore the dynamic characteristic of water. In addition to the gravity effect, carrying water added a dynamic effect as compared with carrying iron. Moreover, the dynamic effect induced by carrying water varied across different volume of water in the container. In this study, the dynamic effect of water can be analyzed by comparing the difference of ΔGF between carrying water and carrying iron, and by comparing the difference of heart rate between carrying water and carrying iron. Data in Table 1 show that the maximum dynamic effect of water occurred at 13.3 kg (difference of ΔGF = 0.47 kg) in 24 × 24 cm base area condition, while at 17.8 kg (difference of ΔGF = 0.77 kg) in 35 × 24 cm base area condition. This result showed that the maximum dynamic effect of water depended on carrying weight and base area of the container. In general, our results showed that the dynamic effect of water at 13.3 or 17.8 kg was greater than that at 4.4 or 8.9 kg. As noted in experimental design, 4.4, 8.9, 13.3, and 17.8 kg of water occupied ~20%, 40%, 60%, and 80% of full volume of the container, respectively. Since there is no dynamic effect of water when water occupies 100% full volume of the container, it is logical to deduce from this study that the maximum dynamic effect of water on ΔGF and heart rate occurs when water occupied ~60%–80% of full volume of the container.

The effect of base area on ΔGF and heart rate was consistent with that of carrying weight, with the larger base area associated with greater ΔGF and heart rate. The two base areas of the container of this study differed only in length, with the larger base area associated with the longer container. The effect of the base area of the container on ΔGF and heart rate can be attributed to the difference in length. Since a longer container allows more area for water's center of gravity to move and, meanwhile, the carriers' two hands were separated farther in the longer container condition, both increased hand effort in carrying. This could account for the increase in ΔGF and heart rate in the larger base area of container condition.

The interaction effect of carrying material and base area of container showed that the dynamic effect of water on ΔGF and heart rate increases with base area of container. The result implied that carriers should select a more compact container (smaller base area) when carrying water due to the advantage of container shape geometry. The interaction effect of carrying weight and base area of container on ΔGF in Figure 2 shows that the effect of base area of container on ΔGF depends on carrying weight. The base area effect on ΔGF (difference of ΔGF between two base areas) increased with carrying weight. This result showed that the compact container reduced ΔGF as compared with the bulky container while carrying heavy weight. Hence, carriers should be encouraged to take advantage of compact containers when carrying heavy weights.

5. CONCLUSIONS AND LIMITATAIONS

This study demonstrated that material, weight, and base area of container significantly affected reduction of grip force and heart rate for a 100-m manual carrying task. This study suggested that practitioners or workers should keep the carried load as stable and as low as possible, and select a smaller base area of a container for manual carrying tasks to reduce physical workload. It should be noted that this study did not examine the effects of carrying distance on reduction of grip force and heart rate. Hence, the explanation of the experiment results of this study demands caution. The results might not be applicable to carrying tasks of shorter carrying distance. The specific condition of this experiment constitutes the limitation of this study.

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