

Effects of box handle position and carrying range on bi-manual carrying capacity for females

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Abstract: This study utilizes a psychophysical approach to examine the effects on carrying capacity for bi-manual carrying tasks involving different handle positions and carrying ranges. A total of 16 female subjects participated in the experiment in groups of two people, and each group of subjects performed the tasks in a random order with 12 different combinations of carrying task. The independent variables are handle position (upper, middle, lower) and carrying range (F–F: floor height carried to floor height, F–W: floor height carried to waist height, W–W: waist height carried to waist height, W–F: waist height carried to floor height), the dependent variable is the maximum acceptable carried weight (MAWC), heart rate (HR), and the rating of perceived exertion (RPE). The results show that the handle position has a significant effect on MAWC and overall RPE but no significant effect on HR. Carrying range has a significant effect on the MAWC and HR, but no significant effect on overall HR. The handle position and carrying range have a significant interaction on the MAWC and HR. The RPE for different body parts shows significant differences, and the hands feel the most tired. Overall, this study confirms that the lower handle position with the W–W carrying range is the best combination for a two-person carrying task.

Key words: Bi-manual carrying, Handle position, Carrying range, Maximum acceptable weight of carried, Psychophysics

Introduction

In manual material handling (MMH) activities, in addition to lifting and lowering, the carrying task is one of the most common modes of handling objects, and often occurs in many industrial and daily life activities^{1–3}. The carrying task, however, results in more frequent lower back injuries than do lifting or lowering, but the heavier burden of the carrying task can more easily lead to adverse effects on the human body⁴.

Common carrying tasks are mostly done by a single

person, though two persons participate in some limited conditions, such as when the goods are too heavy, the volume is too large, there are site restriction or automated facilities are not available to assist^{5,6}. Usually with a two-person carrying team, the maximum acceptable weight of the object carried is affected by the individual's carrying capacities, their height difference, the weight distribution, the carrying method, the presence or absence of handles, operating factors and environmental factors.

Previous studies have shown that overexertion is one of the main causes of lower back injuries received during manual materials handling⁷. In order to understand the personnel handling capacity, the psychophysical method is the one most frequently used by researchers. Scholars have used the psychophysical method to study the team

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lifting efficiency, and have confirmed that the team lifting capacity is less than the combined capacity of the individual team members^{6, 8–12}. Some scholars also have evaluated the effects on the maximum acceptable weight of the object carried due to height difference^{10, 13}, carrying frequency^{9, 14}, load mass distribution¹⁵, carrying method and the presence or absence of handles¹⁶.

Previous studies have demonstrated that individual carrying capacity is affected by the handle position^{17, 18}, and that different carrying ranges have significant effects on the physiological costs¹⁹. However, there has been no previous research on how the bi-manual carrying task is related to handle position and carrying range. We assume that the box handle position and carrying range will have a significant effect on the bi-manual MAWC; therefore, this study uses the psychophysical method to examine the effect of the handle position and carrying range on the bi-manual carrying capacity of females over an 8-h work period.

Method

Subjects

This research was approved by the Ethics Committee of the Ergonomic Center at Huafun University. A total of 16 female university students (age 20.4 ± 1.41 yr, stature 158.3 ± 5.08 cm, weight 54.6 ± 7.66 kg) were recruited and paired into 8 groups according to their stature. The stature difference in each group was within 5 cm to minimize the effect on team carrying capacity¹⁰. Subjects retained the same partner throughout the experiment. The subjects received a presentation introducing the experimental purpose and procedure before the experiment. In addition, subjects were asked to sign an agreement for participation in this research after it was ensured that they had no musculoskeletal or cardiovascular symptoms. Table 1 shows the anthropometric and isometric data of subjects.

Experimental design

This study uses a randomized complete block factorial design, with blocking on each group, to examine the effects of different carrying ranges and box handle positions on the bi-manual carrying capacity of females. The independent variables were carrying range and box handle position. The handle position had three levels, upper, middle and lower, as shown in Fig. 1. The carrying range had four levels, floor carried to the floor (F–F), floor carried to waist height (F–W), waist height carried to waist height (W–W), and waist height carried to the floor

Table 1. Mean anthropometric and isometric strength data for subjects (N=16)

Human Characteristics	Mean	SD
Age (yr)	20.4	1.41
Height (cm)	158.3	5.08
Weight (kg)	54.6	7.66
Acromial height (cm)	129.3	4.65
Elbow height (cm)	96.9	3.32
Knuckle height (cm)	60.6	3.62
Right hand grip strength (kg)	25.3	3.95
Left hand grip strength (kg)	24.7	3.07
Shoulder (kg)	17.3	2.78
Arm (kg)	17.7	2.07
Leg (kg)	46.9	6.92
Stooped back (kg)	37.6	8.67
Composite (kg)	45.2	7.30



Fig. 1. Photograph of the experimental box with three different box handle positions (upper, middle, lower) on each side.

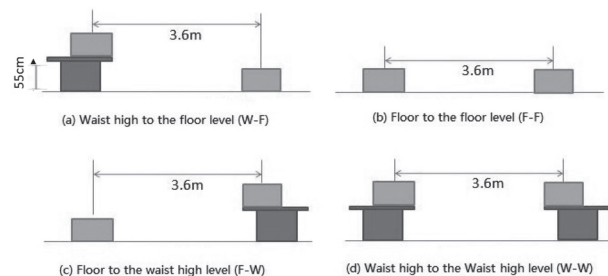


Fig. 2. Diagram of four different carrying ranges (W–F, F–F, F–W, W–W).

(W–F), as shown in Fig. 2. The three dependent variables were psychophysically determined maximum acceptable weight carried (MAWC), heart rates (HR) and ratings of perceived exertion (RPE). The bi-manual carrying task was performed in parallel, with the two subjects facing each other with both hands holding the cutout handles on the two sides. The subjects were instructed to lift the box at the knuckle height and hold under all experimental conditions. The carrying task was performed at a frequency of 2 min^{-1} , and the carrying distance was 3.6 m. The height of the table was 55 cm. The average temperature

and relative humidity of the laboratory were 22–24°C and 55–75%. Each group performed 12 carrying tasks in a random order. On any given day, data for only one experimental treatment was collected for each group. As a result, a total of 96 bi-manual team carrying tasks (8 groups × 3 handle positions × 4 carrying ranges) were performed. As shown in Fig. 1, the wooden boxes used in these bi-manual carrying tasks were 70 cm long, 40 cm wide and 40 cm high, with three sets of cutout handles of 12 cm × 3 cm on each side: the upper handle located 6.5 cm under the edge, the middle handle located 20 cm under the edge, and the lower handles located 33.5 cm under the edge. All the handle centers were 11 cm away from the side. The subjects' heart rates were monitored using a Heart Rate Monitor (Exersentry Model TM 3A).

Experimental procedures

The psychophysical method²⁰⁾ was used for each group to determine bi-manual maximum acceptable weights for each experimental treatment. The subjects were allotted four 1 h training sessions to practice carrying tasks until they were familiar with the experimental procedure. After the four training sessions, the subjects formally participated the experiment. Before the test, each subject was required to read the psychophysical instructions, similar to those used by¹⁶⁾, and then perform a 10-min warm-up exercise. When the test began, the subjects were asked to adjust the weight of the box by adding or subtracting lead weights to the maximum they could carry in box at knuckle height with three ranges of handles that were 3.6 m apart. The subjects were instructed to work on an incentive basis, working as hard as they could without straining themselves, and without becoming unusually tired, weakened, overheated or out of breath²⁰⁾. The subjects were encouraged to make weight adjustments. They were also allowed to discuss the maximum acceptable weight with their partner during the waiting time. To minimize emotional influence, no incentives or emotional appeals were applied. The entire adjustment process took about 30 min for each task. Once the weight was decided, the subjects were asked to continue carrying the box for another 10 min. The subjects' heart rate was recorded every 30 s during the last 10 min and the mean values over 10 min were used for analysis. At the end of each team carrying task, the subjects were asked to rate the perceived exertion (RPE) of the palms, fingers, wrists, arms, shoulders, legs, back and whole body²¹⁾.

Table 2. ANOVA of MAWC, HR and RPE for bi-manual carrying

Source of variation	MAWC	HR	Overall RPE
Subject (S)	**	**	**
Handle position (P)	**	-	**
Carrying range (R)	**	*	-
P×R	**	*	-

** $p < 0.001$, * $p < 0.05$, $\alpha = 0.05$

Statistical analysis

The dependent variables were the MAWC, HR and RPE. The independent variables were the carrying range and handle position. To identify significant effects of the dependent variables, analysis of variance (ANOVA) statistical analysis procedures were employed. When variables were identified as statistically significant, Duncan's multiple range test was used for post hoc comparison to determine the source of the statistically significant effect. An alpha level of 0.05 was selected as the minimum level of significance.

Results

Maximum acceptable weight of carried

Analysis of variance results as shown in Table 2 found that the handle position and carrying range had significant effects on MAWC. Further Duncan multiple range test (Table 3) verified that the largest weight of MAWC is the lower handle, follow by the middle handle, smallest as the upper handle, and three of them have significant difference. For the carrying range, the MAWC of W–W was the largest, followed by W–F, F–W, and the MAWC of F–F was the smallest. MAWC of the W–W was significantly higher than the MAWC of the F–W and F–F, which did not differ among themselves. However the MAWC of both W–W and W–F were not significantly different. The ANOVA in Table 2 shows that handle position and carrying range had a significant interaction effect on MAWC ($p < 0.001$).

Heart rate

The ANOVA results in Table 2 shows that the handle position had no significant effect on mean heart rate. However the heart rate values were significantly affected by carrying range. Further analysis of the Duncan test (Table 3) indicated that carrying range F–F has the highest mean heart rate, significantly higher than the mean heart rate of W–W, while there was no significant difference among

Table 3. Duncan test summary of MAWC (kg), HR (bpm) and overall RPE of bi-manual carrying

Independent variable		MAWC (SD)	Duncan test	HR (SD)	Duncan test	RPE (SD)	Duncan test
Handle position	Upper	39.42 (3.14)	C	97.84 (10.76)	A	17.1 (2.11)	A
	Middle	40.96 (4.10)	B	98.30 (12.16)	A	16.7 (2.47)	C
	Lower	44.15 (3.14)	A	98.53 (12.10)	A	16.83 (2.47)	B
Carrying range	F–F	39.23 (3.72)	B	99.54 (10.69)	A	16.80 (2.20)	A
	F–W	39.52 (3.67)	B	98.15 (13.12)	AB	17.03 (2.37)	A
	W–W	43.80 (4.84)	A	96.00 (11.60)	B	16.73 (2.37)	A
	W–F	43.48 (4.09)	A	99.21 (11.27)	A	16.94 (2.45)	A

Table 4. DUNCAN test with body part RPE as the variables

Variable	Level	Mean	Duncan grouping	Significant level
Body part	Palms	17.76	A	$\alpha=0.05$
	Fingers	17.50	A	
	Arms	17.48	A	
	Wrists	16.83	B	
	Whole body	16.74	B	
	Shoulders	16.73	B	
	Back	16.23	C	
	Legs	15.74	D	

** $p<0.001$, * $p<0.05$, $\alpha=0.05$

Table 5. ANOVA summary of each body part’s RPE

Research variable	Fingers	Wrists	Arms	Shoulders	Back	Legs	Whole body	Palms
Subjects	**	**	**	**	**	**	**	**
Handle position	—	—	—	*	—	—	—	—
Carrying range	—	—	—	—	—	—	—	—

** $p<0.001$ * $p<0.05$ —: no significant effect

F–F, W–F and F–W, also no significant difference between W–W and F–W. The ANOVA results in Table 2 also show that the handle position and carrying range have significant interaction effect on the mean heart rate ($p<0.05$).

Rating of perceived exertion

The handle position has a significant effect on the overall RPE (Table 2), further Duncan test revealed that the overall RPE for the upper handle is larger than the lower handle, and the lower handle is larger than the middle handle.

However the carrying range has no significant effect on the overall RPE value. The interaction effect of handle position and carrying range on overall RPE value was not significant. Based upon data analysis, the most tired body part was the palms (17.76), followed by the fingers (17.50), arms (17.48), wrists (16.83), the whole body (16.74), shoulders (16.73), and back (16.23), while the legs were

the least tired (15.74). The ANOVA results show that the RPE values for the body parts differed significantly from one another. The Duncan test in Table 4 show that the palms, fingers, arms were significantly more tired than the wrists, whole body and shoulder, and these three again were significantly more tired than the back and legs.

The ANOVA results for the subjects, handle position and carrying range effects on each body part’s RPE values are summarized in Table 5. As can be seen, in addition to subjects, the handle position has a significant effect on the shoulders RPE, but the other factors had no significant effect. Further analysis found that the shoulder RPE of the upper handle was higher than the middle and the lower position.

Discussion

Effect of handle position

As expected, the handle position significantly affected MAWC and RPE values, and the MAWC of the carrying box with lower handles (44.15 kg) was higher than that of the carrying box with middle handles (40.96 kg) and upper handles (39.42 kg). The subjective rating of perceived exertion also confirmed that carrying the box with the upper handles was more tiring than carrying it with the lower handles. According our observation, when the subjects were carrying the box with the lower handles, because the palms, wrists and arm can be close to the box and bear the pressure together; the palms, which were originally in a single position under pressure, can share the load with the larger arm muscles. In addition, the observations also found that when subjects carried the box with the lower handles, the abdomen of subject was more close to the box, and shortened the distance between body and load. Thus the MAWC when carrying the box with the lower handles was larger than that of carrying it with the upper and middle handles.

Effect of carrying range

As stated above, the carrying range had a significant effect on the MAWC and HR values. The results show that the MAWC of carrying the box in the W–W range (43.80 kg) was higher than that of carrying in the F–F range (39.23 kg). The physiological criteria also indicated that carrying box in the F–F range produced a higher heart rate than the other ranges. As can be seen from experiment, when the subjects carried the box in the W–W range because the handle height (table height 55cm + handle height 5 cm) is very close to the knuckle height, (mean knuckle height=60.6 cm)so when the subjects performing the carrying task, their waist did not need to bend to lift the load and the weight of their upper body while raising the MAWC. In contrast, for the F–F level the MAWC has the smallest value because during the carrying, subjects need to bend their waist to lift the load and also lift the weight of their upper body, which makes the waist overloaded, so that carrying the MAWC values is the lowest, producing a higher heart rate than W–W level. Although the heart rate values were significantly affected by carrying range, as can be seen in Table 3, the mean HRs are lower than 115 beats/min, which is considered a reasonable physiological load for an 8-h work day²³.

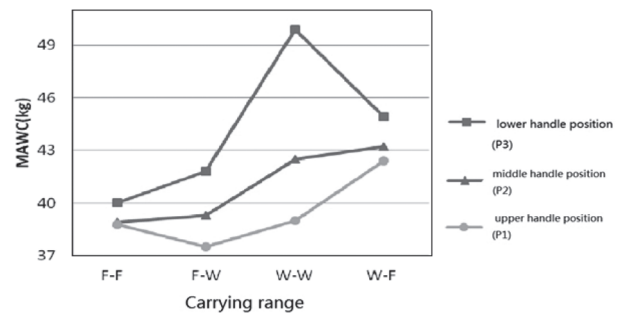


Fig. 3. Interaction effects of the handle position and carrying range on the MAWC.

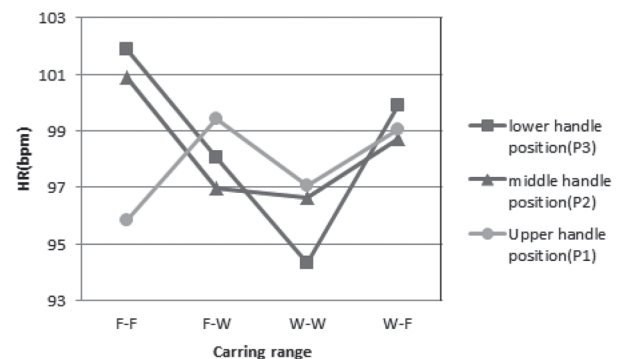


Fig. 4. Interaction effects of the handle position and carrying range on the HR.

Interaction effects of handle position and carrying range

As can be seen in Table 2, handle position and carrying range have significant interaction effects on MAWC and heart rate. Therefore, optimum handle position and carrying range cannot be selected independently of one another without considering the combined effect of these two factors for different carrying tasks. For the F–F carrying range, as can be seen from Figs. 3 and 4, although the MAWC for the lower handles (40.0 kg) was slightly larger than that for the upper handles (38.8 kg), the heart rate for the lower handles (101.9 beats/min) was significantly higher than that for the upper handles (95.81 beats/min). Previous study indicated that lifting from near the floor requires a significantly greater energy expenditure than lifting from greater heights²⁴. For the W–W carrying range, the MAWC of the lower handles (49.90 kg) was significantly larger than that for the middle (42.50 kg) and upper (39.00 kg) handles, and the heart rate for the lower handles was significantly lower than those for the middle and upper handles. One reason for this may be that for subjects to carry the box with the upper handles they must first lift the box up from the waist height level, and then

down to the knuckle height; then when they have almost reached the destination the subjects must again lift the box up to the waist height level of the desktop, requiring use of the upper handle to raise the box higher, followed by the middle handle, finally the lower handle. This higher lifting height of the upper handle is more physiologically demanding and decreases the handling weight. In contrast, using the lower handle was less physiologically demanding because there was less lifting height, so the heart rate was lower than those for the middle and upper handles. Therefore, the lower handle has the largest MAWC.

For the F–W and W–F carrying ranges, as can be seen from Figs. 3 and 4, although the MAWC for the lower handles was larger than that for the middle handles, the heart rates for the lower handles were higher than those for the middle handles. This is because carrying box with the lower handles required the subjects to bend at the waist to lift the box when performing F–W tasks, and to bend at the waist to lower the box when performing W–F tasks, which was more physiologically demanding than carrying box with the middle handles.

Overall, the bi-manual carrying box with lower handles over the W–W carrying range has the largest MAWC and the lowest HR and RPE values. In addition, in the F–F conditions it is better to use the upper handles, and in the F–W and W–F conditions, it is better to use the middle handle. In other words, this study confirms that a box should provide handles in the appropriate positions in order to reduce musculoskeletal stress and in turn to increase worker carrying capacity. This is in accord with previous research²²⁾.

Study limitation

The present study has a few important limitations. First, only female subjects were recruited for the experimental research. The reason for selecting female subjects was because most female students lived in the university. Though the purpose of this study was to examine the effects of handle position and carrying range on the bi-manual carrying capacity, male workers would engage more at many workplaces materializing activities, rather than female workers. Therefore, further study on the male subjects is necessary. A further limitation was that “the box should provide handles in the appropriate positions” is hard to achieve in practice. It is thus recommended that except the special design for the specific objective, the table heights should be designed according to manual handling condition to enhance industrial health.

Conclusion and suggestion

Carrying boxes with handles at a high location is a common task in daily life and occupational activities. However, this study finds that the upper handle was not the best position for different carrying ranges with two-person team carrying tasks. The significant interaction effects of handle position and carrying range on MAWC and heart rate indicated that the optimum handle position depended upon different carrying ranges. In general, the lower handle was the best for the W–W carrying range, the middle handle was the best for the F–W and W–F carrying range, and the upper handle was the best for the F–F carrying range. Overall, the study confirms that the lower handle position with W–W carrying range was the best combination for a two-person carrying task.

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