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Maximum Acceptable Weight of Manual Load Carriage for Young Taiwanese Males

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Abstract: This study examined the maximum acceptable weight of carriage (MAWC) for young Taiwanese males experienced in manual load carriage tasks. The elements of the examined load carriage tasks included lifting a box from the floor to the waist height, turning around while holding the box, carrying the box at the waist height for a distance, lowering the box to the floor, turning around, and walking unloaded back to the original position. Subjects performed the load carriage tasks over different levels of carriage distance, frequency, box width (sagittal dimension), and handle according to a response surface design. The results showed that subjects' MAWC decreased with carriage distance, frequency and box width, while heart rate and rate of perceived exertion (RPE) increased with carriage distance, frequency and box width. The MAWC for box with handles was on average 1.5 kg more than that for box without handles, while the effects of handle on heart rate and RPE were very trivial.

Key words: Manual load carriage task, Maximum acceptable weight of carriage

Introduction

Manual load carriage task is an inevitable activity in manufacturing environments. A complete manual load carriage task usually contains the elements of lifting a load, turning around while holding the load, carrying the load for a distance, lowering the load, turning around, and walking unloaded back to the original position. Due to the complex nature of the load carriage task, load carriers were found to experience a high incidence of low back injury in manufacturing environments[1, 2].

Psychophysical approach has been widely utilized to determine human maximum acceptable weight of handling capability for various tasks and work periods by quantifying human subjective tolerances to the stresses of the handling tasks they perform. Psychophysical approach usually gives the subjects a short period, usually 30 min, to simulate the examined task conditions and determine the maximum acceptable weight of the handled objects for the task conditions for a longer work period, such as 1-h, 4-h, or 8-h. Setting the weight of the handled object below human maximum acceptable weight of handling capability is supposed to be helpful for reducing the possibility of low back injuries. Some knowledge regarding human psychophysical capabilities and physiological responses of load carriage tasks were demonstrated in literature. For instance, Mital and Manivasagan[3] examined the effects of container shape, container volume, and carriage distance on maximum acceptable weight of carriage (MAWC) for one-handed carriage tasks. They found that the MAWC increased significantly for certain container shapes due to the advantage of geometry, and the MAWC increased with container volume but decreased with carriage distance. Ciriello and Snook[4] showed that the MAWC at the frequency of 6 and 3.75 carriages/min were approximately 61% and 77% of the MAWC at 1 carriage/min, respectively, for a 4.3-meter load carriage task. They also found that the female MAWC was around 44% to 52% of that of male MAWC. Taboun and Dutta[5] measured human physiological responses while carrying loads over different carriage distances, frequencies, weights, and box widths (sagittal dimension). They demonstrated that all these factors significantly affect subjects' oxygen consumption and heart rate with the exception of box width. Morrissey and Liou[6] examined young male MAWC for 1-h work period, and found that the MAWC decreased with carriage distance, box width and

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frequency. However, their results showed the MAWC decreased with the presence of box handles. Recently, Wu and Chen[7] repeated the study of Morrissey and Liou[6] and confirmed similar results with the exception that the MAWC increased by approximately 4.56% when the containers were equipped with handles.

The aim of this study was to examine the effects of carriage distance, frequency, box width, and handle condition on psychophysically determined MAWC capacity, heart rate and rate of perceived exertion (RPE) of young Taiwanese males. This knowledge of MAWC can be applied to relevant tasks and be helpful for reducing the possibility of low back injuries.

Methods

Subjects

Twelve young male subjects, experienced in manual load carriage tasks, participated in this study. Their mean (SD) anthropometric data were: age 21.4 (0.8) years; body weight 64.5 (10.5) kg; stature 171.5 (5.1) cm; shoulder height 141.3 (3.6) cm; chest circumference 89.0 (8.9) cm; waist circumference 76.2 (7.4) cm; rest heart rate 73.5 (3.1) beats/min. All subjects were free from any history of musculoskeletal injuries and heart problems for the past 12 months. Subjects understood the purpose of this study and gave their written consent for participation.

Experimental design

The load carriage task examined in this study contained the elements of lifting a box from the floor to the waist height, turning around while holding the box, carrying the box at the waist height for a distance, lowering the box to the floor, turning around, and walking unloaded back to the original position. Four independent variables (carriage distance, frequency, box width (sagittal plane), and handle) for the load carriage task were examined. The design for the levels of these four independent variables followed Morrissey and Liou[6]. There were five distance levels (1.0 m, 2.1 m, 3.5 m, 4.9 m, 6.0 m), five frequency levels (1 carriage/min, 1.2 carriages/min, 1.7 carriages/min, 2.7 carriages/min, 5 carriages/min), five box width levels (15 cm, 25 cm, 35 cm, 45 cm, 55 cm), and two handle levels (presence, absence). The levels of these variables were reported to span 90% of the cumulative distributions of the variables in manual load carriage tasks in manufacturing industry[4, 8, 9]. A response surface design was adopted to arrange the combinations of the levels of carriage distance, frequency, and box width for reducing the experimental scale[10]. One benefit of the response surface design is that the central region (or middle) of the levels of the independent variables forms a complete factorial design[11]. Figure 1 illustrates the design structure for the 15 conditions of the level combinations of carriage distance, frequency, and box width in a response surface design. These 15 experimental conditions are listed in Table 1 (the first eight conditions form a complete factorial design). Two levels of handle factor (presence and absence) were further applied to each condition. Hence, a total number of 30 experimental conditions were considered in this study. The dependent variables were the subject's MAWC capability, working heart rate and overall RPE while performing the load carriage tasks.

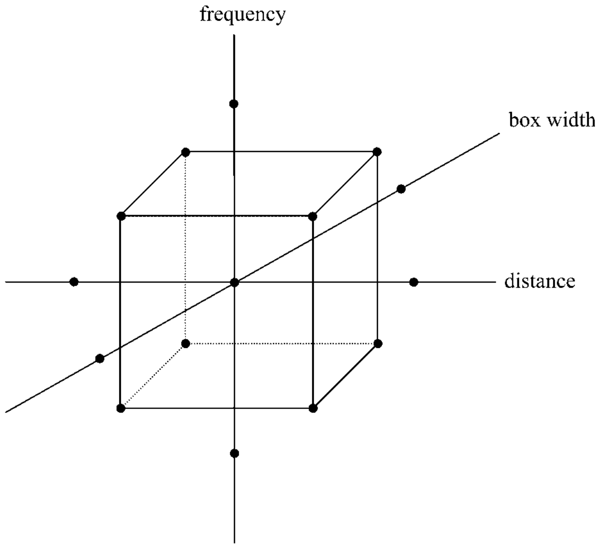

Fig. 1. The design structure of a response surface design for three factors with five levels each.
The 15 black dots represent 15 experimental combinations of the levels of carriage distance, frequency, and box width. For example, the center point represents the combination of the middle levels of carriage distance, frequency and box width (3.5 m carriage distance, 1.7 carriages/min and 35 cm box width).

The carriage boxes were made of wood. The length and height dimensions of all five boxes were 50 cm and 15 cm, respectively. Two cylindrical handles were centered on the upper middle half of the box's width sides. The diameters of the cylindrical handles were about 3.8 cm. The subject carried the box with two hands placed on handles when the experimental condition was 'handle' and on central bottom edges of the box when the experimental condition was 'no handle'.

Experimental procedure

Each subject was asked to prohibit from any excessive exercises on the day of his attendance. The subject was asked to rest on a seat for about 10 min before his resting heart rate was taken using a polar heart rate monitor (Polar Accurex II, Plolar CIC, Inc. New York, USA). Our psychophysical approach for examining the subject's MAWC was similar to those used by Morrissey and Liou[6], Wu and

Table 1. The mean(SD) of subjects' MAWC (kg), heart rate (beats/min) and RPE for all 30 experimental conditions

Distance (m)	Box width (cm)	Frequency (carries/min)	MAWC		Heart rate		RPE	
			Handle	No handle	Handle	No handle	Handle	No handle
2.1	25	2.7	17.7 (2.8)	15.8 (2.5)	95.5 (10.0)	97.9 (12.4)	10.4 (1.5)	10.5 (1.9)
4.9	25	2.7	15.4 (2.1)	14.0 (2.0)	97.0 (4.7)	97.0 (6.4)	10.2 (1.5)	10.6 (1.2)
2.1	25	1.2	19.7 (3.8)	18.3 (4.0)	86.8 (6.0)	88.0 (4.4)	9.2 (1.2)	9.0 (1.0)
4.9	25	1.2	17.5 (3.4)	15.8 (2.8)	93.7 (4.6)	93.9 (5.0)	9.9 (1.5)	9.5 (1.4)
2.1	45	2.7	15.6 (1.8)	14.2 (1.3)	97.0 (9.1)	97.6 (8.6)	10.0 (1.3)	10.5 (1.2)
4.9	45	2.7	14.1 (1.3)	12.9 (1.0)	98.1 (6.9)	100.7 (12.7)	10.7 (1.6)	11.3 (2.0)
2.1	45	1.2	17.9 (2.1)	16.5 (2.0)	86.8 (7.6)	92.4 (5.0)	9.7 (1.1)	9.6 (0.7)
4.9	45	1.2	15.9 (2.0)	14.3 (1.6)	93.4 (8.0)	95.5 (6.8)	9.8 (1.5)	10.1 (1.5)
3.5	15	1.7	19.3 (2.6)	17.7 (1.8)	92.1 (7.5)	93.4 (6.6)	9.7 (0.8)	10.0 (1.4)
3.5	35	5.0	12.4 (0.9)	11.1 (1.0)	104.9 (7.5)	109.7 (7.7)	12.0 (2.0)	12.1 (1.9)
1.0	35	1.7	19.2 (3.0)	17.2 (2.4)	90.6 (9.3)	93.0 (9.0)	9.6 (1.3)	9.5 (1.2)
3.5	35	1.7	16.8 (2.3)	15.5 (1.9)	90.6 (7.6)	93.8 (6.7)	9.8 (1.4)	9.8 (1.3)
6.0	35	1.7	15.5 (1.7)	14.1 (1.1)	95.8 (6.0)	97.3 (9.0)	10.5 (1.1)	11.0 (1.2)
3.5	35	1.0	20.4 (2.9)	18.7 (3.1)	89.6 (8.2)	90.3 (12.8)	9.4 (1.7)	9.3 (1.4)
3.5	55	1.7	15.4 (1.9)	14.5 (1.7)	94.7 (9.7)	97.2 (10.0)	10.6 (1.7)	10.7 (2.0)

Chen[7], Jiang *et al.*[12], and Ciriello *et al.*[13]. For each test, the subject was randomly administered one load carriage task from all 30 possible experimental conditions. The initial weight of the box (lead shot) was randomly assigned (either high or low) and symmetrically balanced. The carriage frequency was monitored with the beeps from a metronome. The walking speed was not controlled. The subject was asked to imagine that he was performing piece-work, and was encouraged to psychophysically adjust (by adding or removing lead shot) the weight of the box to the maximum that he could accept for a general workday (four-hours work plus one-hour rest plus four-hours work) without strain, or being discomfort, tired, weakened, overheated, or out-of-breath during the test. As the subject carried the box to the destination and walking unloaded back to the original position, an assistant returned the box manually to its original position for the next cycle. The psychophysical weight adjustment period lasted for 30 min. After the subject confirmed that he had adjusted the weight to his MAWC capability, he was asked to perform the load carriage task for an additional 5-min period for reaching a steady heart rate. The subject's heart rate and overall RPE[14] were recorded immediately after the test. Each subject performed all 30 experimental conditions in this study, and at most one condition was tested in a day. Before formal experiments, each subject had a 12-d training period to practice 12 experimental conditions randomly selected from all 30 possible experimental conditions for familiarizing the psychophysical weight adjustment approach. The location of the experiment was isolated and quiet to prevent disturbance from other people or the environment. The room temperature was maintained at 24°C. The relative humidity was 45–55%.

Statistical analysis

First, the means and standard deviations of the subjects' MAWC, heart rate and RPE for all 30 experimental conditions were calculated. Second, the analysis of variance (ANOVA) was performed on the central region (or middle) of the experimental range of the distance (2.1 m and 4.9 m), frequency (1.2 carriages/min and 2.7 carriages/min), box width (25 cm and 45 cm), and handle (presence and absence), since they form a complete factorial design, to examine the effects of these factors on subjects' MAWC, heart rate and RPE. Third, Duncan's multiple range test, quite powerful at detecting differences between means when real differences exist[10], was further performed on the complete data set (with the 30 experimental conditions) to distinguish the significant factor levels on the subjects' MAWC, heart rate and RPE.

Results

Table 1 shows the means and standard deviations of the subjects' MAWC, heart rate and RPE for all 30 experimental conditions. Table 2 shows the ANOVA results. Clearly, all four independent variables significantly affected MAWC ($p<0.0001$) while only frequency ($p<0.0001$) and distance ($p<0.0008$) significantly affected heart rate. Additionally, box width ($p<0.0386$), frequency ($p<0.0001$) and distance ($p<0.0086$) also significantly affected RPE. No significant interaction of factors was found on dependent variables with the exception of the interaction effect of frequency and distance on heart rate ($p<0.0285$). Table 3 shows the results of Duncan's multiple range tests.

Table 2. The results of ANOVA for subjects' MAWL, heart rate and RPE

Variable		MAWC		Heart rate		RPE	
Source	DF	F value	p>F	F value	p>F	F value	p>F
Subject	11	43.50	0.0001	5.58	0.0001	18.94	0.0001
Handle (H)	1	66.54	0.0001	3.36	NS	1.49	NS
Width (W)	1	70.96	0.0001	2.13	NS	4.35	0.0386
Frequency (F)	1	116.72	0.0001	39.89	0.0001	40.97	0.0001
Distance (D)	1	108.93	0.0001	11.68	0.0008	7.08	0.0086
H × W	1	0.28	NS	0.80	NS	1.49	NS
H × F	1	0.00	NS	0.17	NS	3.23	NS
H × D	1	0.01	NS	0.37	NS	0.13	NS
W × F	1	0.16	NS	0.00	NS	0.63	NS
W × D	1	1.06	NS	0.00	NS	0.87	NS
F × D	1	1.62	NS	4.88	0.0285	0.05	NS
H × W × F	1	0.20	NS	0.47	NS	0.05	NS
H × W × D	1	0.02	NS	0.04	NS	0.13	NS
H × F × D	1	0.53	NS	0.27	NS	0.01	NS
W × F × D	1	0.33	NS	0.73	NS	3.23	NS
H × W × F × D	1	0.08	NS	0.70	NS	0.63	NS

NS: non-significant, p>0.05.

Table 3. The results of Duncan's multiple range tests and the relative percentages of each reading to the highest reading of that variable

Variable	Mean (SD)	MAWC (%)	Duncan group	Mean (SD)	Heart rate %	Duncan group	Mean (SD)	RPE %	Duncan group
Distance									
1.0 m	18.2 (2.9)	100.0	A	91.8 (9.0)	95.1	C	9.5 (1.2)	88.7	C
2.1 m	17.0 (3.1)	93.4	B	92.7 (9.2)	96.0	B C	9.9 (1.3)	92.5	B C
3.5 m	16.2 (3.5)	89.0	C	95.6 (10.4)	99.0	B A	10.3 (1.8)	96.2	A B
4.9 m	15.0 (2.5)	82.4	D	96.1 (7.4)	99.5	A	10.3 (1.6)	96.2	A B
6.0 m	14.8 (1.5)	81.3	D	96.5 (7.5)	100.0	A	10.7 (1.1)	100.0	A
Box width									
15 cm	18.5 (2.3)	100.0	A	92.7 (7.0)	96.5	A	9.8 (1.1)	91.5	B
25 cm	16.8 (3.4)	90.8	B	93.7 (8.0)	97.6	A	9.9 (1.5)	92.5	B
35 cm	16.1 (3.5)	87.0	C	95.6 (10.4)	99.5	A	10.3 (1.7)	96.2	A B
45 cm	15.2 (2.2)	82.1	D	95.2 (9.0)	99.1	A	10.2 (1.5)	95.3	A B
55 cm	14.9 (1.8)	80.5	D	96.0 (9.7)	100.0	A	10.7 (1.8)	100.0	A
Frequency (carriages/min)									
1.0	19.5 (3.0)	100.0	A	90.0 (10.5)	83.8	D	9.3 (1.5)	77.5	C
1.2	17.0 (3.2)	87.1	B	91.3 (6.7)	85.0	C D	9.6 (1.3)	80.0	C
1.7	16.5 (2.7)	84.6	B	93.9 (8.3)	87.5	C	10.1 (1.4)	84.1	B
2.7	15.0 (2.3)	76.9	C	97.6 (9.0)	90.9	B	10.5 (1.5)	87.5	B
5.0	11.8 (1.2)	60.5	D	107.3 (7.8)	100.0	A	12.0 (1.9)	100.0	A
Handle									
Presence	16.9 (3.2)	100.0	A	93.8 (8.6)	97.9	B	10.1 (1.5)	99.0	A
Absence	15.4 (2.9)	91.1	B	95.8 (9.6)	100.0	A	10.2 (1.6)	100.0	A

Means with the same letter in the Duncan group column were not significantly different with each other (α=0.05).

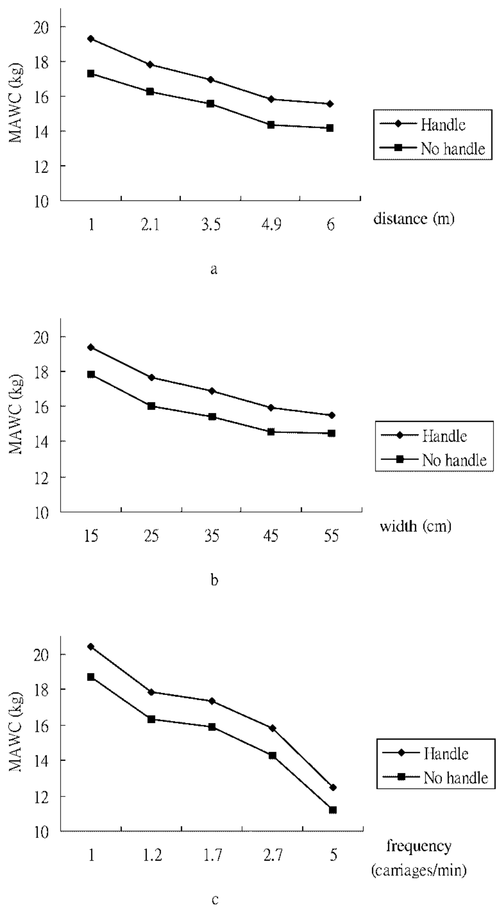

Fig. 2. The effects of carriage distance, box width, frequency and handle condition on MAWC.

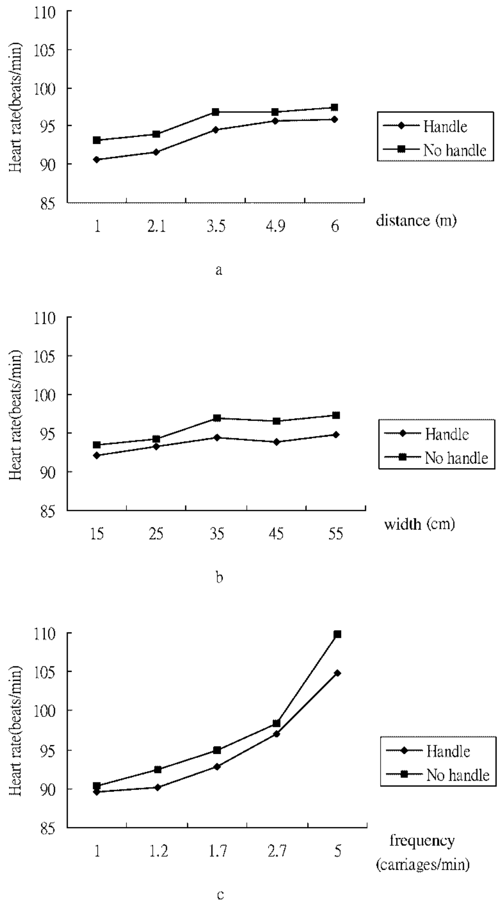

Fig. 3. The effects of carriage distance, box width, frequency and handle condition on heart rate.

Figure 2 to 4 illustrate the effects of distance, frequency, box width, and handle on MAWC, heart rate and RPE, respectively. Figure 2 shows that MAWC decreased with distance, box width, and frequency. The MAWC for box with handle was more than that for box without handle. Figure 3 and Fig. 4 show that heart rate and RPE increased with distance, box width, and frequency, respectively.

Discussion

Effect of carriage distance

Consistent with previous studies, this study demonstrated that MAWC decreased with carriage distance[4–6, 8, 12]. Table 3 shows that subjects' MAWC decreased by approximately 20%, from 18.2 kg to 14.8 kg, as carriage distance increased from 1 m to 6 m. The MAWC for the 6 m carriage distance was significantly lower than those for the 1 m, 2.1 m and 3.5 m carriage distances, but not significantly different from that for 4.9 m carriage distance. Some subjects claimed that the carrying element in the load carriage procedure limited their MAWC capabilities. A possible explanation was that the carrying element demanded enduring muscular contractions in upper extremities while walking. Wu and Chen[7] also revealed that the subjects' RPE for wrists and arms were higher than those for shoulder, back, leg and whole body in manual load carriage tasks. This study showed that the changes of heart rate and RPE with carriage distance were trivial, possibly due to a lower MAWC was selected in the longer carriage distance condition. The heart rate ranged from 91.8 beats/min (1.0 m) to 96.5 beats/min (6.0 m) and subjects' RPE ranged from 9.5 (1.0 m) to 10.7 (6.0 m).

Effect of carriage frequency

The decrement in MAWC with frequency was in agreement with the previous studies[6, 7, 15, 16]. Snook and Ciriello[16] showed that the male MAWC decreased by 37% when the carriage frequency increased from 1 carriage/min to 6 carriages/min for a 4.3 m carriage task and a 111 cm carriage height (vertical distance from floor to hands). The major disadvantage for a higher carriage frequency is that the body has not enough rest time for executing aerobic

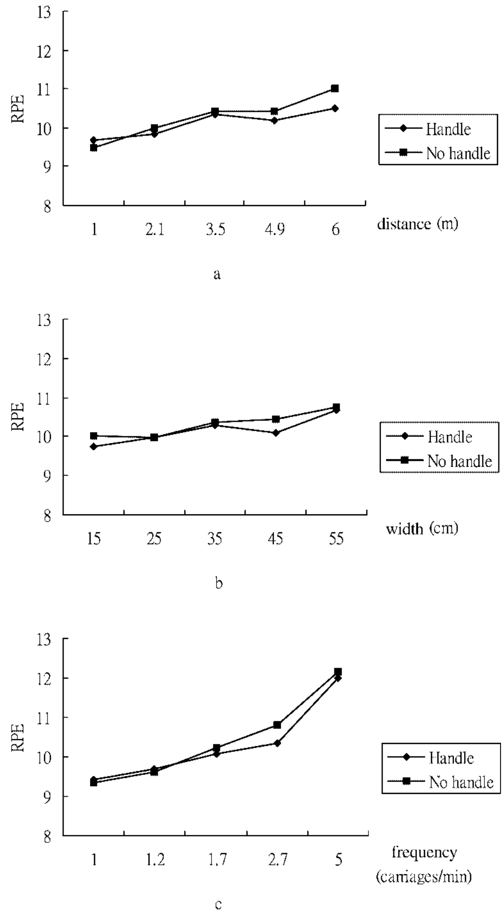

Fig. 4. The effects of carriage distance, box width, frequency and handle condition on RPE.

metabolism to recover from muscular fatigue and cardiac strain. Table 3 shows an increase of frequency from 1 carriage/min to 2.7 carriages/min decreased MAWC, on the average, by 23.1%, and a further increase from 2.7 carriages/min to 5 carriages/min resulted in a significant decrease (21.3%) in MAWC. By contrast, an increase of frequency from 1 carriage/min to 2.7 carriages/min increased heart rate by 7.6 beats/min (8.4%), and a further increase from 2.7 carriages/min to 5 carriages/min increased the heart rate by 9.7 beats/min (9.9%).

The increase of subjects' RPE with frequency was also expected. Table 3 shows that the subjects' RPE increased by nearly 29% when the frequency increased from 9.3 (1 carriage/min) to 12.0 (5 carriages/min).

Effect of box width

Similar to simple lifting tasks[17)], subjects selected a lower MAWC for a wider box in load carriage tasks. Morrissey and Liou[6)] revealed that the MAWC declined by 15% as the box width increased from 15 cm to 55 cm. Similarly, Table 3 shows that subjects' MAWC decreased by approximately 20%, from 18.5 kg (15 cm box width) to 14.9 kg (55 cm box width). However, the lower MAWC also reduced subjects' heart rate and RPE. Subjects' heart rate ranged from 92.7 beats/min (15 cm) to 96.0 beats/min (55 cm), and subjects' RPE ranged from 9.8 (15 cm) to 10.7 (55 cm).

Effect of handle

The MAWC for box with handle was on average 1.5 kg greater than that for box without handle. This finding was consistent with the simple lifting task where handle was found to result in a greater maximum acceptable weight of lifting[17)]. In this study, all subjects were asked to place their hands beneath the bottom of box in the conditions of box without handle, which damaged the security and stability of the load carriage. However, there is biomechanical benefit for placing hands beneath the bottom of box during load carriage. For example, less ulnar deviation occurs at the wrists. The handle effects on heart rate and RPE were trivial. The mean (SD) heart rate and RPE were 95.8 (9.6) beats/min and 10.2 (1.6) for box without handle, and were 93.8 (8.6) beats/min and 10.1 (1.5) for box with handle. Although the effects of handle on MAWC, heart rate and RPE were trivial, we still suggest that handles should be provided for the following reasons. First, handle design can enhance the safety of manual materials handling tasks since it provides a firm secure grip[18, 19)]. Second, handle design can eliminate some additional hand adjustments especially at the moment of box lifting from the floor or box lowering to the floor. Third, handle design can allow better box stability if subjects suffering any sudden external impacts. Since handle placement can significantly affect human performance in load carriage, further studies related to the optimal handle placement are needed.

Conclusion

This study investigated the effects of carriage distance, frequency, box width, and handle condition, on the MAWC capability of young Taiwanese males experienced in manual materials handling tasks. This study recommends that the factors of carriage distance, frequency, and box width should be carefully controlled in handling heavy materials in manufacturing environments. Additionally, handles should be equipped in the carriage box. Practitioners can refer the MAWC listed in this study in designing the load weights for similar manual load carriage tasks in manufacturing environments.

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