International Journal of Occupational Safety and Ergonomics (*JOSE*) 2012, Vol. 18, No. 3, 387–391

Effects of Range and Mode on Lifting Capability and Lifting Time

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This study examined the effects of 3 lifting ranges and 3 lifting modes on maximum lifting capability and total lifting time. The results demonstrated that the maximum lifting capability for FK (from floor to knuckle height) was greater than that for KS (from knuckle height to shoulder height) or FS (from floor to shoulder height). Additionally, asymmetric lifting with initial trunk rotation decreased maximum lifting capability compared with symmetric lifting or asymmetric lifting with final trunk rotation. The difference in total lifting time between KS and FS was not significant, while FK increased total lifting time by ~20% compared with FS even though the travel distance was 50% shorter.

lifting strength manual materials handling

1. INTRODUCTION

The overexertion of manual lifting is responsible for a large proportion of daily and industrial accidents [1]. The most frequent accident resulting from the overexertion of manual lifting is low back injury [2]. Designing the magnitude of load in a lifting task below human maximum lifting capability is one solution to alleviating the risk of overexertion of manual lifting.

Human maximum lifting capability can be examined in static or dynamic form. It is the basis for many strength databases and screening procedures [3]. In practice, many lifting tasks in a real workplace require workers to exert their dynamic lifting strength. Hence, information on human maximum dynamic lifting capability is important: it can be directly applied to real occupational settings.

In literature, human maximum dynamic lifting capability has been widely examined for various task variables, such as range, container, and mode or team size. Lee reported human lifting capability for FK (from floor to knuckle height) was ~50 and 40% higher than those of KS (from knuckle height to shoulder height) and FS (from floor to shoulder height), respectively [4]. Lee showed that participants' maximum asymmetric lifting capability for FK increased by 25% when they rested the container on the leg compared to not doing so [5]. Lee demonstrated that maximum lifting capability decreased by 6.9% as the container length increased from 50 to 70 cm, and by 13.2% as the container width increased from 35 to 50 cm, and participants lifted 7.2 and 16.1% less weight when lifting asymmetrically compared to symmetric lifting [6]. Sharp, Rice, Nindl, et al. revealed maximum teamwork lifting capability as the percentage of the sum of the individual lifting capabilities was significantly under 100% [7, 8, 9, 10], and was dictated by the weaker of the members [11].

This study aimed to examine human maximum lifting capability and total lifting time for three lifting ranges and three lifting modes. The basic assumption of this study was that human maximum lifting capability and total lifting time differed across lifting ranges and modes.

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2. METHOD

2.1. Participants

Twelve young and healthy males volunteered to participate in this experiment. They had lifting experience within 2 months prior to this experiment. Their characteristics (*M* ± *SD*) were

age (years)	23.2	(1.4)
stature (cm)	174.0	(6.2)
weight (kg)	72.0	(12.0)
shoulder height (cm)	143.7	(6.7)
knuckle height (cm)	75.4	(3.7)
chest circumference	93.5	(8.8)
waist circumference (cm)	83.3	(9.7)
arm circumference (cm)	28.1	(3.3)
forearm circumference (cm)	26.2	(2.1)
thigh circumference (cm)	48.8	(7.7)
leg circumference (cm)	38.1	(4.4)

The participants wore sneakers in this experiment. They signed a consent form.

2.2. Experimental Apparatus

The apparatus of this experiment included a wooden container and an electric stopwatch. The container was 30 cm in length, 30 cm in width and 30 cm in height. A pair of flexible nylon handles (1 cm in diameter) was attached to the middle of the "width" sides of the container. Lifting time was measured with the electric stopwatch (model S129 from Seiko, Japan).

2.3. Experimental Design

A two-factor factorial design was used in this study. Lifting range and lifting mode were the independent variables. FK, FS and KS were the lifting ranges. The exact knuckle and shoulder heights for each participant depended on their anthropometric data. They were determined when the handle of the box was at his knuckle and shoulder heights, respectively. Symmetric lifting, 90° asymmetric lifting with initial trunk rotation, and 90° asymmetric lifting with final trunk rotation were the lifting modes. For symmetric lifting, the participant lifted the container sagittally and placed it at the destination height. For 90° asymmetric lifting with initial trunk rotation, the participant maintained the position of his feet in the sagittal plane and rotated his trunk, pulled and lifted while resting the container on the lateral side of the leg, then turned the trunk and put the container at the destination height. For 90° asymmetric lifting with final trunk rotation, the participant first lifted the container symmetrically, then turned 90° to the left using trunk rotation, and then put the container at the destination height. The participant did not move his feet during lifting for any of the three lifting modes. The horizontal distance from the edge of the destination to the middle of the participant's ankles was 90 cm. Maximum lifting capability and total lifting time were the dependent variables. Total lifting time was chosen since it reveals some information on the rate of force development during lifting.

2.4. Experimental Procedure

Each participant was briefed on the purpose of this study and was randomly assigned his own test sequence for all nine possible lifting conditions. For each lifting condition, the participant was asked to warm up for at least 3 min. The initial weight inside the container was fully balanced and randomly loaded with lead shot. Then, the participant tried to lift the container. If he succeeded, he was asked to increase the weight by adding more lead shot, in increments of 2–10 kg depending on his own judgment and capability, and to try again until he could not lift the container anymore. Initial load increments were large but they decreased as the participant approached his maximum lifting capability. Total lifting time was recorded with the electric stopwatch. For FK and FS, the participant was asked to lift the container with the semisquat lifting technique. The participant had at least a 2-min rest between two consecutive progressive trials. There were no motivational factors. The participant's maximum lifting capability could normally be achieved after approximately five to seven tries. The participant tested three lifting conditions a day. Before the formal experiment, each participant had a 2-week period to familiarize himself with all nine lifting conditions.

3. RESULTS

Table 1 shows the means and standard deviations of the participants' maximum lifting capabilities and total lifting times for the nine lifting conditions. This table shows that the maximum lifting capability of FK was the highest among the three ranges, followed by FS and KS. In addition, asymmetric lifting with initial trunk rotation decreased maximum lifting capability compared with symmetric lifting and asymmetric lifting with final trunk rotation, regardless of lifting range. Table 2 shows the results of the analysis of variance (ANOVA). It shows that the effects of participant, range, mode, and the interaction of range and mode were significant on maximum lifting capability; however, the effect of repetition was not significant. Duncan multiple range tests showed that the lifting capabilities associated with the three lifting ranges differed significantly among each other ($p < .05$), and the lifting capability of asymmetric lifting with initial trunk rotation was significantly lower than that of symmetric lifting and asymmetric lifting with final trunk rotation ($p < .05$).

Table 1 also shows that FK was associated with the longest total lifting time, followed by FS and KS. Table 2 shows the effects of participant, range, and the interaction of range and mode on total lifting times were significant. Duncan multiple range tests showed the total lifting time of FK was significantly longer compared with FS and KS ($p < .05$). However, the difference in total lifting times between FS and KS was not significant ($p > .05$)

4. DISCUSSION

Human maximum lifting capability differs significantly across lifting ranges and lifting modes. The large differences in maximum lifting capabilities across the three lifting ranges are mainly attributed to different exertion types and responsible muscles. FK lifting involved a short lifting distance and engaged the muscles of the whole body; hence, it was associated with the highest maximum lifting capability. Conversely, FS lifting involved a long lifting distance and KS lifting mainly engaged arm muscles in lifting; hence, these two lifting ranges significantly

TABLE 1. Means (Standard Deviations) of Participants' Maximum Lifting Capabilities and Lifting Times for 9 Lifting Conditions

	Maximum Lifting Capability (kg)			Total Lifting Time (s)		
Variable	FK	KS	FS	FK	KS	FS
Symmetric lifting	80.8 (11.6)	36.7 (5.1)	41.1 (6.8)	2.8 (0.5)	2.4 (0.4)	2.4 (0.3)
Asymmetric lifting with final trunk rotation	81.0 (11.6)	36.2 (4.9)	41.0 (6.8)	3.2 (0.7)	2.3 (0.4)	2.4 (0.3)
Asymmetric lifting with initial trunk rotation	59.2 (10.7)	34.6 (4.3)	36.4 (6.3)	3.0 (0.4)	2.4 (0.4)	2.4 (0.4)

Notes. FK—from floor to knuckle height, KS—from knuckle height to shoulder height, FS—from floor to shoulder height.

TABLE 2. Summary of Analysis of Variance (ANOVA) Results

		Maximum Lifting Capability		Total Lifting Time	
Variable Source	*df*	*F*	*p* > *F*	*F*	*p* > *F*
Participant	11	52.9	<.001	8.0	<.001
Repetition	1	0.5	.471	0.3	.551
Range	2	1786.2	<.001	50.5	<.001
Mode	2	119.6	<.001	0.7	.466
Range × mode	4	52.9	<.001	3.1	.016
Error	195				

decreased the participants' maximum lifting capability.

This study did not show any difference in maximum lifting capability between asymmetric lifting with final trunk rotation and symmetric lifting. The participants' initial posture for asymmetric lifting with final trunk rotation was identical to that for symmetric lifting. This might be responsible for the approximately equivalent maximum lifting capability in the two lifting modes. However, this result was inconsistent with Lee's earlier study, which found a 6–9% decrement in maximum lifting capability between the two lifting modes across different containers [6]. The discrepancy might be attributed to the difference in the dimensions of the container and the position of feet in the two studies. The width and length dimensions of the container in this study (30 × 30 cm) were much smaller than Lee's (50 × 35 cm to 70 × 50 cm) [6]. Hence, the participants of this study did not need, and were not permitted, to take additional foot steps when putting the container at its destination, which eliminated the main shortcoming for asymmetric lifting with final trunk rotation of more body movement during lifting, and reduced the difference of maximum lifting capability between the two lifting modes.

Asymmetric lifting with initial trunk rotation decreased maximum lifting capability. The decrement was great (~27%) for the lifting range of FK. The decrement in maximum lifting capability for asymmetric lifting with initial trunk rotation can be attributed to the involvement of lateral force exertion and poorer posture and body stability in the initial lifting posture.

For maximizing muscle strength, the rate of force development should be minimized in accordance with the rules of biomechanics. This mechanism of a slow rate of force development is also helpful in protecting the musculoskeletal system from injury. Total lifting time revealed some information on the rate of force development. This study indicated that the total lifting time of KS was approximately equal to that of FS, while the total lifting time of FK was 20% longer than that of FS even though the travel distance of FK was half of FS. The longer total lifting time of FK decreased the rate of force development that was responsible for the great maximum lifting capability, ~1.6- to twofold of FS, associated with FK.

This study examined the effects of three lifting ranges and three lifting modes on maximum lifting capability and total lifting time. It showed that lifting range and mode significantly affected human maximum lifting capability. The order for the lowest to the highest lifting capability for the three lifting ranges remained unchanged regardless of lifting mode. Asymmetric lifting with initial trunk rotation significantly decreased, by ~25%, maximum lifting capability compared with symmetric lifting or asymmetric lifting with final trunk rotation. The total lifting time for FK increased by ~20% compared with that for FS even though the travel distance was 50% shorter. The results of this study can help in understanding human maximum lifting capability and in establishing the upper limit of lifting. However, applying the results of this study to real work situations demands caution. The results can only be applied to tasks and lifters similar to those discussed here, which constitutes the limitation of this study.

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