Maximum Symmetric and Asymmetric Isoinertial Lifting Capabilities from Floor to Knuckle Height

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Abstract: Ten young male participants were recruited to test their maximum symmetric and asymmetric isoinertial lifting capabilities from floor to the knuckle height in different container dimensions varied in both width and length. The results showed that the order from the highest to lowest lifting capability for the lifting modes was symmetric lifting, asymmetric lifting with leg rotation and asymmetric lifting with trunk rotation, and for the container dimensions was 50 × 35 × 15 cm, 70 × 35 × 15 cm and 50 × 50 × 15 cm. Participants' lifting capabilities differed significantly ($p < 0.05$) among lifting modes and container dimensions. This study recommends that asymmetric lifting with leg rotation should be encouraged as compared with asymmetric lifting with trunk rotation when performing heavy asymmetric lifting tasks.

Key words: Isoinertial lifting capability, Asymmetric lifting, Container

Introduction

The primary motivation for ergonomic practitioners to explore human maximum lifting capabilities for various tasks is that they can design the demands of lifting tasks at or below human maximum lifting capabilities for reducing possible musculoskeletal overexertion injuries^{1,2}. Human maximum lifting capabilities have been widely examined in terms of isometric, isokinetic and psychophysical lifting capabilities for various static and dynamic lifting tasks, yet only a few scientific investigations reported human maximum isoinertial lifting capability.

Human maximum isoinertial lifting capability reflects the maximum lifting capability to overcome an initial static resistance and lift it to an assigned point at freely chosen speed¹. Most heavy lifting tasks in the workplace require lifters to exert their maximum isoinertial lifting capability to accomplish the lifting tasks; hence, the information of human maximum isoinertial lifting capability is very important and can be directly applied to real occupational settings. Some knowledge of task effects on human maximum isoinertial lifting capability has been demonstrated. For example, Lee³ reported lifting range

significantly affected human maximum isoinertial lifting capability. The human lifting capability for floor to knuckle height was approximately 50% and 40% higher than those of knuckle height to shoulder height and floor to shoulder height, respectively. Sharp *et al.*⁴⁻⁷ revealed the maximum isoinertial teamwork lifting capability as the percentage of the sum of the individual lifting capabilities was significantly lower than 100%, and was dictated by the weaker of the members⁸.

Asymmetric lifting is believed more harmful to the back than symmetric lifting since it involves torso twisting and bending motions and can result in higher intra-abdominal pressure, erector spinae activity, shear and compression spine loading, local stress concentration, and greater precipitation injury potential⁹⁻¹². Though human maximum asymmetric lifting capabilities in terms of isometric and psychophysical forms have been widely reported¹³⁻¹⁶, human maximum asymmetric isoinertial lifting capabilities was seldom examined. Additionally, previous studies¹³⁻¹⁶ examining human asymmetrical lifting capability conventionally asked participants to keep their feet parallel to the sagittal plane and lift the load with rotated trunk (referred to as asymmetric lifting with trunk rotation in this study), and neglected the strategy of lifting the load symmetrically, then turn direction mainly with footstep change and place the load onto the desti-

nation height (referred to as asymmetric lifting with leg rotation in this study) for accomplishing the asymmetric lifting tasks. This strategy of asymmetric lifting with leg rotation justifies the necessity of exploring the information of human maximum asymmetric lifting capability with leg rotation.

The main objective of this study was to examine the effects of symmetric lifting, asymmetric lifting with trunk rotation, and asymmetric lifting with leg rotation on human maximum isoinertial lifting capabilities. Further objective was to examine the effects of container dimension on human maximum isoinertial lifting capability. The application of this study can be applied to, for example, some palletizing tasks which required workers to turn and twist their trunks into and out of the sagittal plane while loading and unloading materials. The null hypothesis of this study was that human maximum isoinertial lifting capability has no difference between various lifting modes and container dimensions.

Method

Participants

Ten young male participants volunteered for this experiment. All participants were experienced lifters and had no musculoskeletal or cardiovascular history. They regularly performed lifting tasks within 2 months prior to their participation. Their anthropometric data were listed in Table 1. Participants gave their consent form attesting to the understanding of the purpose and risk of participating in this experiment.

Experimental design

This study selected a two-factor factorial design to examine the effects of three lifting modes and three container dimensions on participants' maximum isoinertial lifting capability from the floor to knuckle height. All

possible independent variable combinations were nine (three lifting modes $\times$ three lifting containers) for each participant. The three lifting modes included symmetric lifting, 90-degree asymmetric lifting with trunk rotation, and 90-degree asymmetric lifting with leg rotation lifting. A 90-degree asymmetric lifting task referred to the lifted container was at an initial location at 90 degrees from its final location. For symmetric lifting, the participant lifted the container sagittally from the floor onto a 74 cm high table. For 90-degree asymmetric lifting with trunk rotation, the participant maintained the position of their feet in the sagittal plane and rotated his trunk when lifting the load onto the 74 cm high table. For the 90-degree asymmetric lifting with leg rotation, the participant first faced the container and lifted it symmetrically to about table height, and then turned 90 degrees to the left, facing the table mainly using the footstep change (leg rotation), and then placed the container onto a 74 cm high table. The horizontal distance from the table edge to the middle of initial ankles was 90 cm. Figure 1 depicts the schematic top view of symmetric lifting, 90-degree asym-

Table 1. The means and standard deviations (SD) of the participants' anthropometrical characteristics

Anthropometrical characteristics	Mean	SD
Age (yr)	20.3	0.9
Stature (cm)	170.7	2.4
Weight (kg)	67.7	7.5
Shoulder height (cm)	137.9	3.3
Knuckle height (cm)	72.0	2.7
Chest circumference (cm)	90.1	5.2
Waist circumference (cm)	76.0	6.9
Arm circumference (cm)	28.1	3.3
Forearm circumference (cm)	25.6	1.8
Thigh circumference (cm)	52.2	5.4
Leg circumference (cm)	35.6	3.0

Fig. 1. Schematic top view of table, container and foot placement for symmetric lifting (a), 90-degree asymmetric lifting with leg rotation (b), and 90-degree asymmetric lifting with trunk rotation (c).

metric lifting with trunk rotation, and 90-degree asymmetric lifting with leg rotation. The participant performed the three lifting modes in three lifting container dimension conditions. The three container dimensions varied in two length (50 and 70 cm, coronal plane) and two width (35 and 50 cm, sagittal plane) dimensions. The dimensions (length $\times$ width $\times$ height) for the three containers were 50 $\times$ 35 $\times$ 15 cm, 70 $\times$ 35 $\times$ 15 cm and 50 $\times$ 50 $\times$ 15 cm. All three containers were provided with secure wooden handles (diameter 3.5 cm) on the upper middle half of the container's width sides.

Experimental procedure

Each participant was briefed the purpose of this study before the experiment. The participant wore ordinary clothing and flat rubber-sole sport shoes during the experiment. The participant was asked to stretch himself for at least 3 min prior to the experiment. Then, the participant was randomly assigned a lifting condition from all nine (three modes $\times$ three containers) possible lifting conditions. The initial weight inside the container was loaded with some lead shots in a random and balanced way. The participant was asked to lift the container from the floor onto a 74 cm high table with semi-squat lifting technique. The maximum isoinertial lifting capability in this study was the single maximal load that the participant could lift cleanly from the floor onto a 74 cm high table. When the container was lifted, the participant was permitted to take one or two steps as needed for body stability while placing the container onto the table. If the participant succeeded the lifting task, he was asked to increase the weight by adding more lead shots, in increments of 2 to 10 kg, and tried again until he failed the lifting task. The trial was considered as a failure if the participant failed to lift up the container. Initial load increments were large but were reduced as the participant approached his max-

imum isoinertial lifting capability. At least 2 min of rest was provided for the participant between two consecutive progressive trials, eliminating the effect of fatigue on maximum isoinertial lifting capability. No any motivational factors were provided to the participant. Two assistants were by the participant's sides for preventing the participant from possible dropping of the container or loss of body stability. The participant's maximum isoinertial lifting capability can normally be obtained after approximately five to seven tries. The tests of nine lifting conditions were performed in a random order for each participant, and at most three maximum isoinertial lifting capabilities were tested for each participant in a day. Before the formal experiment, the participant was given a 10 d period to familiarize all nine lifting conditions and experimental procedure. All the collected data were subjected to SAS software for statistical analysis.

Results

Table 2 shows the means, standard deviations (SD), Duncan groupings, and relative percentages of participants' maximum isoinertial lifting capabilities (kg) for all nine combinations. The results of analysis of variance showed that the effects of participant ($F_{9,72}=68.4$, $p<0.0001$), lifting mode ($F_{2,72}=101.8$, $p<0.0001$) and container ($F_{2,72}=66.2$, $p<0.0001$) on maximum isoinertial lifting capability were significant while the interaction effect of mode and container ($F_{4,99}=0.98$, $p>0.4259$) was not. The experimental data demonstrated that the order from the highest to lowest maximum isoinertial lifting capability for the three lifting modes was symmetric lifting, asymmetric lifting with leg rotation and asymmetric lifting with trunk rotation, regardless of container dimension. Duncan multiple range tests showed that the lifting capabilities associated with the three lifting modes differed

Table 2. The mean (SD), Duncan groupings, and relative percentages of participants' maximum isoinertial lifting capabilities (kg) for all nine combinations of lifting mode and container dimension

Condition		Duncan grouping	Maximum isoinertial lifting capability (kg)	
Mode	Container		Mean (SD)	Percentage
Symmetry	50 $\times$ 35 $\times$ 15 cm	A	54.4 (5.8)	100.0%
Symmetry	70 $\times$ 35 $\times$ 15 cm	B	49.8 (7.0)	91.5%
Leg rotation	50 $\times$ 35 $\times$ 15 cm	B	49.4 (6.8)	91.0%
Leg rotation	70 $\times$ 35 $\times$ 15 cm	C	46.7 (6.2)	85.8%
Symmetry	50 $\times$ 50 $\times$ 15 cm	C	46.3 (6.1)	85.1%
Trunk rotation	50 $\times$ 35 $\times$ 15 cm	D C	45.0 (6.6)	82.7%
Leg rotation	50 $\times$ 50 $\times$ 15 cm	D E	43.6 (6.1)	80.1%
Trunk rotation	70 $\times$ 35 $\times$ 15 cm	E	42.0 (6.6)	77.2%
Trunk rotation	50 $\times$ 50 $\times$ 15 cm	F	39.2 (6.5)	72.1%

Means with the different letter in Duncan grouping are significantly different ($p<0.05$).

significantly among each other ($p < 0.05$). Additionally, the order from the highest to lowest maximum isoinertial lifting capabilities for the three containers was $50 \times 35 \times 15$ cm, $70 \times 35 \times 15$ cm and $50 \times 50 \times 15$ cm container, regardless of lifting modes. Likewise, Duncan multiple range tests revealed the lifting capabilities associated with the three lifting containers also differed significantly among each other ($p < 0.05$).

Discussion

Human lifting capability differed significantly to each other among lifting modes. This study showed that asymmetric lifting significantly decreased human maximum isoinertial lifting capability as compared with symmetric lifting. Participants lifted 7.2% and 16.1% less weight when lifting asymmetrically with leg rotation and with trunk rotation, respectively, as compared to symmetric lifting. The decrease in maximum asymmetric lifting capability can be attributed to the fact that a greater directional change in the applied force, more muscular strain, and poorer posture and stability. In asymmetric lifting, the applied force is likely to include a lateral component to move the load from the origin to the destination, and a horizontal force to pull the load close to the body, as well as the obvious vertical force¹⁴). Additional body movement and greater displacement of the container in asymmetric lifting might also be responsible for the lower maximum isoinertial lifting capability.

This study demonstrated asymmetric lifting with leg rotation obtained significantly higher maximum isoinertial lifting capability as compared with asymmetric lifting with trunk rotation. Participants' initial posture for asymmetric lifting with leg rotation was similar to that for symmetric lifting. Apparently, asymmetric lifting with leg rotation provides a biomechanical advantage over asymmetric lifting with trunk rotation, because the trunk is required to twist less, providing more stability to the body during the lifting. The main shortcoming for asymmetric lifting with leg rotation is that more body movement is required during lifting, potentially limiting maximum isoinertial lifting capability. This additional body movement during lifting might account for the 7.2% decrement in lifting capability from symmetric lifting. Due to the fact that asymmetric lifting with leg rotation could obtain a higher lifting capability as compared with asymmetric lifting with trunk rotation, this study recommends that asymmetric lifting with leg rotation should be recommended from the viewpoint of biomechanics when it is unavoidable for a heavy asymmetric lifting.

Container width or length significantly affected human maximum isoinertial lifting capability. This study showed that the mean human maximum isoinertial lifting capa-

bility 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. The paired t tests for the differences of maximum isoinertial lifting capability between the two container widths (35 cm vs. 50 cm) and two container lengths (50 cm vs. 70 cm) were significant ($p < 0.05$). The experimental data further demonstrated that the order of the highest to the lowest maximum isoinertial lifting capability for the three container dimensions was $50 \times 35 \times 15$ cm, $70 \times 35 \times 15$ cm and $50 \times 50 \times 15$ cm, regardless of the lifting modes. The decreasing effect of container's width on lifting capability in this study is correlated with the concept of an increase in horizontal distance from the midpoint of the ankles of the lifters to the point of force application in NIOSH lifting equation¹⁷). Notably, increasing a container's length or width would not only decrease human maximum isoinertial lifting capability due to a longer moment arm for the exerted muscles but also impose a more hazardous condition to the musculoskeletal system since the muscles contracts at a longer muscle length. It is well known that skeletal muscles are more prone to injuries during eccentric contractions than isometric or concentric contractions^{18–21}) due to the muscle tension produce being distributed over a smaller number of active fibers, increasing the load for individual fibers and thus the risk of damage²²). This physiological phenomenon and the experimental data of lifting capability encourage a necessity for designing an optimal containers dimension for manual materials handling tasks.

Finally, the data of maximum isoinertial lifting capability for symmetrical lifting of our study was further compared with that of Legg and Pateman²³). The mean (SD) maximum isoinertial lifting capability were 54.4 (5.8) kg and 89.6 (12.8) kg for our study and Legg and Pateman²³), respectively. Since the participants in the study of Legg and Pateman²³) were British soldiers who were taller, heavier and fitter than our participants. The effects of participants' race, anthropometry, and occupation could be responsible for the big difference in maximum isoinertial lifting capability between the two studies.

Conclusions

This study reported the human maximum isoinertial lifting capability for nine different lifting conditions. This study showed that human maximum isoinertial lifting capability ranged significantly across the nine different lifting conditions. Additionally, lifting mode and container dimension significantly affected human maximum isoinertial lifting capability. The results of this study can enhance the understanding of the human maximum isoin-

ertial lifting capability; however, these reported lifting capability data cannot be used as the upper load limit for workplace practice since lifting a load at the maximum human capability is very hazardous to the musculoskeletal system and easily results in loss of human stability while lifting.

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