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Strength and Perceived Exertion in Isometric and Dynamic Lifting with Three Different Hand Locations

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Abstract: Strength and Perceived Exertion in Isometric and Dynamic Lifting with Three Different Hand Locations: Shoko ANDO, *et al.* Nagoya University School of Health Sciences—The dynamic and isometric strength and physical stress in symmetric and asymmetric lifting were measured with some common pairs of hand locations and a pair of clearly defined foot positions. In the experiment, eleven healthy male students were required to lift a small box attached to the arm of a dynamometer. The size of the box was 29 cm long, 24.5 cm wide and 23 cm high, and it weighed 10 kg. Both hands were located at three different positions on the box; the two handles near the upper edges of the box gripped with the hands (Handle type), the bottom on either side (Bottom type), and the left lower proximal corner and the right upper distal corner (Oblique type). The dynamic and isometric forces at the three hand locations were significantly different, and the least values were observed in the Oblique type irrespective of the lifting angle. Perceived exertions on the category scale (CR-10) for the left arm were very high in Oblique type lifting with any combination of height and symmetry during dynamic lifting. Therefore the burden of Oblique type lifting was thought to be greater than in the other two types of lifting, if workers are ordered to handle a box in otherwise identical conditions. In dynamic lifting Handle type lifting was thought to be the best among the three types.
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In workplaces many types of lifting are commonly observed, but only a few studies have dealt with workloads in terms of hand locations on boxes during lifting. Drury *et al.*[1)] analyzed more than 2,000 different box handling tasks, performed by workers in nine factories. They found that the most common hand position pairing was where one hand gripped the upper front corner of the box and the other the lower rear corner. They also found that hand positions located at right and left handles or bottom edges were very common in heavy box handling, but the strength which workers can produce in lifting and their workloads in terms of hand locations have not yet been fully studied. As sagittally symmetric lifting tasks have been reported to be the exception rather than the rule[1)], some researchers have studied asymmetric lifting tasks in comparison with symmetric ones[2–9)]. It was reported that the symmetry factor in lifting had a significant effect on strength[6)]. Effects of hand positions, however, were very little studied in combination with the symmetricity of the trunk postures of workers.

In strength testing, isometric tests have traditionally been the main method because of their reliability, expediency and inexpensiveness. The measurement of dynamic strength, however, has recently been considered to be the test of choice when lifting tasks are involved, because most material handling tasks are dynamic in nature[7)]. Workloads in dynamic handling are considered to be different from those in static handling[2–5)]. For example, a laboratory study[6)] found that perceived exertions for many body sites tended to be significantly lower in dynamic lifting of a 10 kg box than in conventional isometric lifting.

We therefore aimed to clarify dynamic and isometric strength and physical stress in symmetric and asymmetric lifting with some common pairs of hand locations and a pair of clearly defined foot positions.

Subjects and Methods

Subjects

Eleven healthy male students, aged 18 to 27 (average, 20.5), voluntarily participated in the study. Their demographic conditions are shown in Table 1. Their mean (SD) body height and weight were 170.2 (4.7) cm and 60.6 (7.3) kg, which were similar to the average body dimensions of male Japanese of the same age[6]. They had 1369 (194) N isometric maximum strength in vertical pull-up with a back strength tester (Takeikiki Kogyo Co., Japan) measured before the experiment. All of them were right-handed. They had no particular past history of orthopedic disorders including back pain. The subjects were informed as to the purpose, content, risks of the experiment, and their rights before measurements, and they gave informed consent in writing to participate in the experiment.

Table 1. Demographic data for subjects (n=11)

	Mean	SD	Range Min–Max
Age (yr)	20.5	2.8	18.0–27.0
Weight (kg)	60.6	7.3	50.0–70.0
Height (cm)	170.2	4.7	163.8–178.0
Vertical pull-up Strength (N)	1369	194	1127–1695

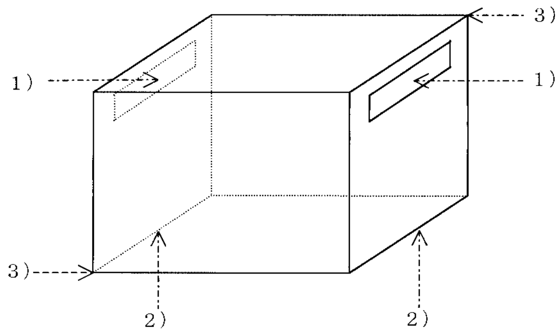

Fig. 1. Hand locations on the box in the experiment. 1) Handle type: gripping bilateral handles near the upper edges of the box. 2) Bottom type: holding bottom edges on either side. 3) Oblique type: holding the left lower proximal corner and the right upper distal corner.

Experimental procedures

The subjects were required to lift straight up a small box which was attached to the arm of a dynamometer (Lido Lift, Loredan Biomedical Co., USA). It was reported that the test-retest reliability of dynamic force in the dynamometer was high[10], which could be applied for evaluating the lifting capacity of workers. Data from the Lido Lift were stored in a personal computer for analysis. Statistical analysis was later done with SAS software (SAS Institute Japan Co.) on the mainframe in the Computation Center of Nagoya University (Fujitsu: M-1800/20,VP2600).

In the experiment, the isometric and dynamic (gravity isoinertial) lifting strength was measured. The isometric strength test consisted of three 5-sec trials, with a 20-sec rest inserted between two consecutive trials. The maximum value for 3 consecutive seconds was extracted as a representative value from each 5-sec trial. Dynamic strength was measured while the subjects lifted the box vertically four times every 5 sec with all their might.

The box was 29 cm long, 24.5 cm wide, and 23 cm high, with handles on two opposite sides located 18 cm up from the bottom. The hands were located at three different positions on the box (Fig. l): the two handles of the box gripped with the hands (Handle type), the bottom on either side of the box (Bottom type), and the left lower proximal corner and the right upper distal corner (Oblique type). The vertical height of the box was set at 0 cm (Low level) or 71 cm (High level) from the floor to the box base. The height set at 71 cm was applied, because the estimated average knuckle height was around 71 cm from the floor for young Japanese males[6]. For dynamic lifting, the final height of the box was 71 cm or 142 cm in order to keep the vertical traveling distance the same at 71 cm. The box weight was put at 10 kg.

Two angles for lifting were studied in the mid-sagittal plane (Symmetric) and 90° right lateral plane (Asymmetric) (Fig. 2). The subjects were asked to place their feet so as to make an angle of 50° at the intersection of two lines protracted from the long axes of the feet. Gross body posture in lifting was standing or free-style at the High level and squatting or semi-squatting at the Low level. The order of measurement was randomly assigned. Before the experiment the subjects practiced and became accustomed to the lifting and measuring equipment.

Strength and perceived exertion

Some physical parameters were measured in isometric and dynamic lifting of the box. In isometric lifting, peak force was measured by a dynamometer. In dynamic lifting, peak force, average upward acceleration and height at peak force were also measured. Peak force in isometric lifting was calculated as the average isometric force over the largest consecutive 3 sec period. The average acceleration in dynamic lifting of the box was calculated by using the mathematical expression shown in the following: Acceleration (in Gs)=(force applied −

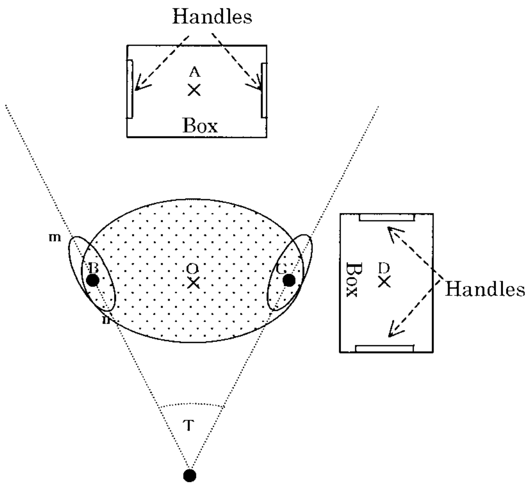

Fig. 2. Top view of the feet and the box in the experiment. A: Center of box in symmetric lifting. D: Center of box in asymmetric lifting. B: Equilibratory center of left foot. C: Equilibratory center of right foot. O: Midpoint between of B and C. T: Angles at point where two lines protracted from long axis of feet join. OA=OD=BC=40.6 cm, OB=OC=CD=20.3 cm, T=50 degrees, Bn/mn=0.45.

box weight)/box weight. In order to accelerate box lifting, the subject must exert a force on the box that exceeds the box weight. Acceleration is considered to be critical in understanding lifting, because it will allow us to estimate the biomechanical forces more accurately than the box weight alone. The height at peak force during dynamic lifting was calculated by subtracting the height at lift origin from that at peak force. Such data as height at peak force can be investigated only through dynamic lifting studies.

Immediately after each experiment, the subjects were asked to rate the degree of perceived exertion in Large-Muscle-Group activity on the category ratio scale (CR-10)[11] for the arms, shoulders, back, and thighs (Table 2).

Statistical analysis

The hand location, height, and symmetry factors were statistically analyzed by three-way analysis of variance (ANOVA). When the hand location factor was significant in ANOVA, multiple comparisons by the Bonferroni method were applied. The data for CR-10 of perceived exertions were analyzed by either the Kruskal-Wallis test or the Wilcoxon rank sum test.

Results

Isometric lifting strength

The hand location factor was significant in ANOVA, and the subsequent Bonferroni method revealed that the isometric peak force in Oblique type lifting was significantly less than in the Bottom and Handle type liftings (Table 3, Fig. 3). In the Bottom and Handle type liftings, similar isometric peak forces were observed. Isometric peak force in asymmetric lifting was significantly greater than in symmetric lifting.

Table 2. Category Ratio Scale (CR-10) for Perceived Exertion in Large-Muscle Group Activity (Borg G., 1990)

*	Maximal
10	Very, very strong (almost max)
9	
8	
7	Very strong
6	
5	Strong (heavy)
4	Somewhat strong
3	Moderate
2	Weak (light)
1	Very weak
0.5	Very, very weak (just noticeable)
0	Nothing at all

Dynamic lifting strength

The dynamic peak force in the three hand locations was significantly different in ANOVA, being least in the Oblique type in the Bonferroni method (Table 3, Fig. 4). In the Bottom type, the dynamic peak force was not as great as in the Handle type, which was inconsistent with the result for the isometric peak force. The order of average peak force with regard to hand locations for isometric and dynamic lifting was different. The dynamic force in low-level lifting was significantly greater than in high-level lifting (Table 3, Fig. 4). The symmetry factor had no significant effect on dynamic peak force, which was different from isometric peak force. The standard deviation of peak force in dynamic lifting tended to be smaller than in isometric lifting (Figs. 3, 4).

Hand location had a significant effect on average acceleration in ANOVA, being significantly less in the Oblique type than in other types irrespective of symmetry (Table 3, Fig. 5).

Height at peak force in dynamic lifting

In ANOVA, the two factors of hand location and height were significant. Subsequently a significant difference was found in height at peak force between Handle type lifting and Oblique type lifting in the Bonferroni method (Table 3, Fig. 6). In lifting from the Low level, the longest distance was found in Oblique type lifting until reaching the peak force, whereas Handle type lifting required the shortest distance (Fig. 6). The height at peak force in lifting at the High level was significantly higher than in

Table 3. Effects of hand locations, height, and symmetry on dependent variables, tested by Three-Way ANOVA and post hoc Bonferroni method

Factor	Dependent variables			
	Isometric force[1)]	Dynamic force[2)]	Average acceleration[3)]	Height at peak force[4)]
Hand Location [a)]	***	***	**	*
Bonferroni method	H>O*** B>O***	H>B*** B>O**	H>O** B>O*	O>H*
Height [b)]	NS	L>H*	NS	H>L**
Symmetry [c)]	A>S***	NS	NS	NS

Statistical significance: *p<0.05, **<0.01, ***<0.001, NS=Not significant.
1) Average isometric force over the highest consecutive three-second period of force output
2) Peak force in dynamic lifting of the box weighting 10 kg during lifting action
3) Average acceleration in dynamic lifting of the box weighing 10 kg during lifting action
4) Height at peak force during dynamic lifting calculated by subtracting height at origin of lift from that at peak force
a) Comparison of hand locations at handle (H), bottom (B), and oblique (O)
Bonferroni method was completed when hand location factor was significant in ANOVA.
b) Comparison of lifting at high level (H) and low level (L)
c) Comparison of symmetric lifting (S) and asymmetric lifting (A)
The results of interaction between factors are omitted because none of them was significant.

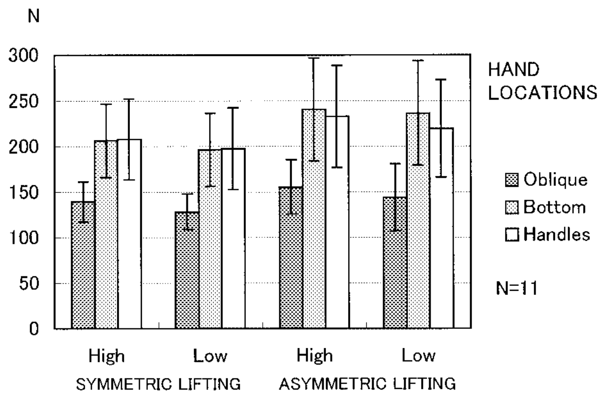

Fig. 3. The average isometric force over the highest consecutive 3 second period of force output. Values are means, and error bars indicate SD.

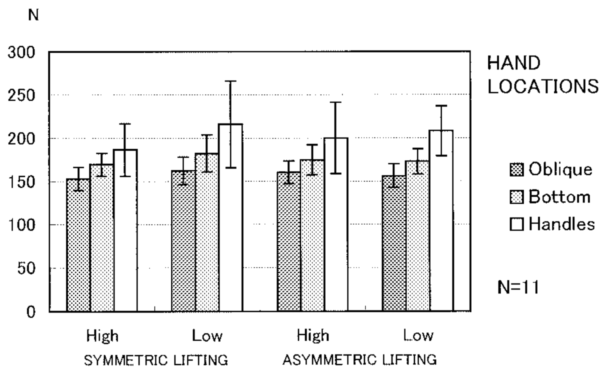

Fig. 4. Peak force in dynamic lifting of a box weighing 10 kg during lifting. Values are means, and error bars indicate SD.

lifting at the Low level.

Perceived exertion (CR-10)

Perceived exertions (CR-10) for the right arm during isometric lifting in the Oblique and Handle type liftings in the factorial combination of High level and asymmetry (Fig. 7-1) were significantly different. Perceived exertions for the left arm tended to be higher in Oblique type lifting than in other types, irrespective of any combination of height and symmetry factors (Fig. 7-1).

In dynamic lifting, perceived exertions for the left arm were significantly higher in Oblique type lifting than in other types (Fig. 7-2).

No significant effect of hand location was found in the shoulders, back, or thighs.

Discussion

In Oblique type hand location, strength measured with the dynamometer was significantly less, whereas perceived exertions of the subjects for the left arm were significantly higher than those in other types of hand location, suggesting that the burden of Oblique type lifting was greater than those in the other two types of lifting, if

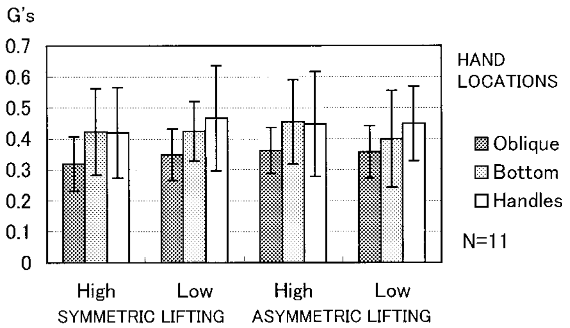

Fig. 5. The average acceleration in dynamic lifting of a box weighing 10 kg during lifting. Values are means, and error bars indicate SD. Acceleration (in G's)=(force applied-box weight)/box weight.

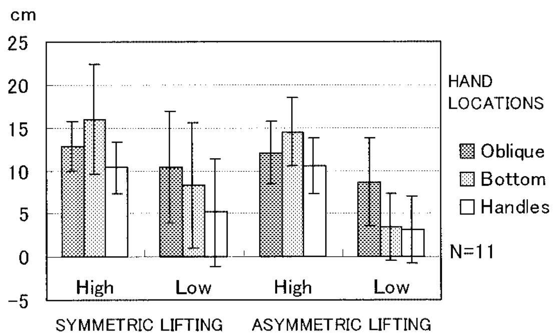

Fig. 6. The vertical travel distance for peak force during dynamic lifting, calculated by subtracting the height at origin of lift from that at peak force. Values are means and error bars indicate SD.

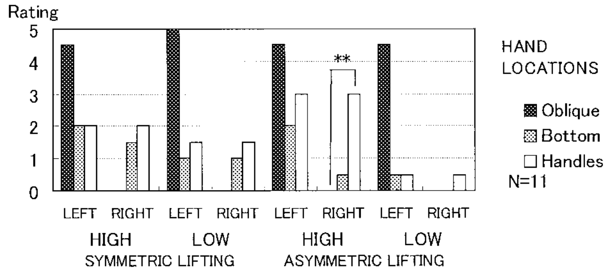

Fig. 7-1. Rating of perceived exertions (CR-10) for the arms in isometric lifting activities. Median values are presented.

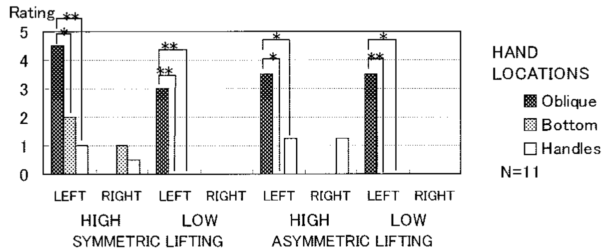

Fig. 7-2. Rating of perceived exertions (CR-10) for the arms in dynamic lifting activities. Median values are presented.

workers were ordered to handle a box in otherwise identical conditions. As Oblique type lifting was reported to be most common in workplaces[1], the results of the present study also suggest the importance of optimizing hand locations in manual material lifting in workplaces. Some laboratory studies[12–14], however, implied that Oblique type hand location could help workers by giving horizontal and vertical stability in lifting. These studies were based on their experiment results showing that oblique lifting could minimize the physiological and perceived stresses. In their studies, however, examinees held handles, in contrast to our study in which there were placed no handles on the box in oblique lifting. The boxes in their studies were far bigger than in ours. Hand locations for oblique lifting were not completely identical in theirs and ours, so that there still remains the possibility that optimal hand locations would be diverse in relation to the ergonomic factors in lifting.

In this study, dynamic peak force and the average acceleration were greatest in Handle type lifting among three hand locations applied for lifting. Handle type lifting could therefore be useful for particularly heavy, compact boxes. Drury *et al.*[15] reported that the Handle type was best for finger comfort in lifting 13 kg boxes. Handle position on the upper part of each lateral face has also been found to give smaller elbow and wrist angles than other handle positions[16]. Davis *et al.*[17] reported that handles reduced the spinal loads measured by an EMG-assisted biomechanical model, so that Handle type lifting was considered to minimize biomechanical stress and be better suited to lift heavier boxes. The results of this study together with those of previous studies will confirm the usefulness of Handle type lifting. Therefore, Handle type lifting was considered to use the best positions among the three types in dynamic lifting.

Strength was greater in asymmetric than in symmetric lifting in the present experiment, in disagreement with many other studies[3–5, 8, 9] concerning asymmetric lifting strength. In another study, foot positions were considered to affect the lifting capacity of workers and workloads on their feet[18]. We believe that subjects can exert a stronger force in asymmetric than in symmetric lifting, if the horizontal distance between one foot and the box is very short and subjects can easily use a foot as a fulcrum for a biomechanical lever[6, 19]. There might therefore be some difference between this study and others concerning the horizontal distances between the feet and the box, but many studies[3–5, 9] on isometric and dynamic lifting did not indicate foot positions in their experimental methods.

The dynamic peak force in lifting at the Low level was significantly greater than at the High level. As for the height factor, Ayoub *et al.*[20] indicated that the reduction in lifting capability may be as much 30% as the vertical height of lift increases from 76 to 165 cm. In the present experiment, the final height of the box was 142 cm when lifting at the High level, so the lifting capability of subjects at the High level may be reduced.

In the present study it was considered that dynamic lifting was validated as a measuring method of strength because it tended to give a smaller S.D. in peak force than in isometric force in the experiment. The order of average peak force with regard to hand locations in isometric and dynamic lifting differed. As dynamic measurement is performed with the dynamic lifting movement of examinees, it will reflect the difficulty in producing strength in a real lifting process. On the other hand, isometric measurement will only detect the strength at an inceptive lifting posture and also force the examinees to artificially sustain the posture during measurement. Therefore, the difference between dynamic and isometric measurements in the order of average peak force with regard to hand locations may reflect the discrepancy between real and artificial lifting, but this needs further investigations in order to find a plausible reason.

The height at peak force, that is, the height of the box when the peak force has just been produced, was significantly different for the three hand locations. The height at peak force was higher in types without handles than with them, which means that the distance until reaching the peak force in no Handle type lifting was greater than in Handle type lifting, so that it was supposed that Handle type lifting might facilitate quick production of maximal force by allowing the subjects to grip the handles firmly.

Since the subjects of the present experiment were Japanese male students, it was not clear that the results obtained would apply to females or workers in actual workplaces. Future research needs to include as subjects females or workers. In the experiment, the foot position used was with an angle of 50° at the intersection of two lines. This position, however, was different from that in some other studies, in which the foot lines of subjects were arranged parallel to the mid-saggital plane. This difference in foot position may limit the external validity of our study if it influenced the lifting force. This issue should also be studied in future.

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