The Effects of Asymmetric Dynamic and Isometric Liftings on Strength/Force and Rating of Perceived Exertion

(非対称の動的・静的持ち上げがstrength/forceおよび自覚的作業強度感の程度に及ぼす影響)

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Abstract

A laboratory study was done to determine the postural and physical characteristics and subjective stress during dynamic lifting of a usual load (10 kg) in comparison with those during isometric lifting. The authors also aimed to clarify the effects of asymmetric lifting on these parameters. The subjects were thirteen male college students. They were asked to lift a box weighing 10 kg. They performed sixteen different lifting tasks from the floor to a height of 71 cm, involving a combination of three independent factors: two lifting modes (isometric lifting and dynamic lifting), four lifting angles in relation to the sagittal plane (Sagittal plane, Right 45, Right 90 and Left 90 planes) and two lifting postures (Squat and Stoop). For each lifting task, strengths or forces and ground reaction forces were measured. At the end of each task, the authors asked the subjects to rate their perceived exertion (RPE) during lifting at ten sites of the body.

Angle factor had a significant effect on isometric strengths and dynamic peak forces. Isometric strengths during the maximum three seconds were highest in lifting at Right 45 plane, followed by that at Sagittal plane, while those at Right 90 and Left 90 planes were the lowest. However, peak forces in dynamic lifting were the highest in the lifting at Sagittal plane, followed by that at R45 plane, while those at Right 90 and Left 90 planes were the lowest. Postural factor had a significant effect on height at peak force, which is higher in squat lifting than in Stoop lifting. RPEs for the left arm, the backs and the right whole body in isometric lifting were significantly higher than in dynamic lifting of 22 lbs. There were remarkably high RPEs for the ipsilateral thigh to the box in Right 90 and Left 90 planes during both isometric and dynamic liftings. Locations of the resultant force consisting of three component forces on the force plate were closer to the foot on the same side as the box in asymmetric lifting.

Thus, some similarities and differences were found between isometric lifting and dynamic liftings regarding the indexes of strength used in this experiment. The authors consider that the subjects used the foot nearer to the box as a fulcrum during asymmetric lifting. Dynamic measurement using the 10 kg weight is less stressful than the conventional isometric measurement. It was possible to obtain the height data at peak force and time-based changes in the force and the box location during lifting only through dynamic lifting measurement. The results provide new knowledge about the biomechanical features of dynamic lifting tasks.

Key words; asymmetric lifting, dynamic lifting, isometric lifting, strength, force, RPE

1. Introduction

Asymmetric lifting in the workplace often results in low back injury and various musculoskeletal problems (Andersson 1991, Hettinger 1985, Marras and Mirka 1992). It is regarded to be more dangerous than symmetric lifting because of the combined effects of flexion and accompanying axial rotation of the spine. Twisting is reported to increase internal pressure on the abdomen (Andersson 1985) and load upon annulus fibrosus layers leading to the possibility of disc rupture (Davis 1967, Farfan 1970). It also increases EMG activity in erector spinae and external oblique muscles (Kumar 1980). Furthermore, there is a study that ratings of perceived exertion (RPEs) at the lower back and the lower body in asymmetric lifting suggest higher stress than those in symmetric lifting (Garg and Banaag 1988).

As for symmetric lifting, maximum force during isometric muscle contraction has often been measured to evaluate the load on the musculoskeletal system (Mital (b) 1986, Mital et al. 1985). This measurement does not cost much and is well standardized and validated (Chaffin 1974). However, indexes obtained from such design do not reflect the actual lifting situations including muscle movement (Mital (a) 1986; Kumar et al. 1988). To overcome this problem, researchers have often measured isokinetic or isoinertial muscle strength in the fields of rehabilitation treatment, ergonomics and human engineering (Griffin et al. 1986, Osternig 1986, Cabri 1991).

Previous studies, however, have not yet fully analysed the time-based changes in lifting postures and physical parameters including force, acceleration and ground reaction force during dynamic lifting activities. The data base for workers' perceived exertion at various musculoskeletal regions is also still insufficient regarding dynamic lifting tasks.

The aim of this study is to determine the postural and physical characteristics and subjective stress during dynamic lifting of a usual load (10 kg) in comparison with those during isometric lifting. We also aimed to clarify the effects of asymmetric lifting on these parameters. For these purposes, we used new equipment for measuring both dynamic and isometric lifting strengths and a force plate as well.

2. Method

2.1. Subjects

Thirteen male students volunteered for this experiment. Their average age, body length and body weight were 23.3 years (SD 5.2), 170.5 cm (SD 7.0) and 64.0 kg (SD 10.6), respectively. Their average isometric maximum strength in vertical pulling-up was 138.7 kg (SD 19.0), as measured before the experiment by a back strength tester (Takeikiki Kogyo Co., Japan). The authors explained the purpose and content of the experiment to the subjects before measurements, and the subjects gave their informed consent in writing to participate in the experiment. A physician checked the subjects by interviewing them with respect to physical conditions and ensured they had no past histories of orthopaedic or cardiovascular problems.

2.2. Equipment and Experimental Design

The authors asked the subjects to stand on one force plate with their ankles placed 41 cm apart and parallel to the sagittal plane. They were then asked to lift a box straight up from the floor without raising their heels. Figure 1 shows the positions of the subjects' feet and of the boxes in the experiment. We attached the box to the main arm of a Lido Lift (Loredan Biomedical Inc., USA), specifically designed to assess lifting capacity. The box was 29 cm long, 24.5 cm wide and 23 cm high, with handles located 18 cm from the bottom on two opposite sides. Box weight was set at 10 kg (22 lbs).

The experiment consisted of three factors: mode of the movement of boxes (Mode), positions of the boxes in relation to the sagittal plane of the subject (Angle) and subject's postures at the beginning of the lifting (Posture). The Mode consisted of two levels, i.e., isometric lifting and dynamic lifting. The Angle consisted of four levels, i.e., Sagittal plane, 45^o right lateral plane (R 45 plane), 90^o right lateral plane (R 90 plane) and 90^o left lateral plane (L 90 plane). The Posture was comprised of two levels, i.e., back bent with knee stretching (Stoop) and back straight with knee squatting (Squat). Combination of the levels selected from three factors resulted in 16 measurements for each subject. We randomly assigned the order of the measurement.

Before the experiment, the subjects practiced and became accustomed to dealing with the equipment.

2.3. Measurements

The isometric strength test consisted of three five-second trails, with a 20-second rest between two adjacent trials. We asked each subject to apply a maximum effort when vertical lifting a fixed box. Mean strength was calculated for every moving time-window with a length of three seconds. Then, the maximum value for the three seconds was extracted as the representative value from each five second trial (maximum three seconds).

We measured dynamic (gravity inertial) forces while subjects lifted the box vertically from the floor to the height of 71 cm every five seconds. The subjects were asked to lift the box four times with all their might. Peak force, peak velocity, average upward acceleration and height at peak force were measured. The height set at 71 cm, the estimated average value of knuckle height from the floor for Japanese young male, was based upon published anthropological data for Japanese people (Laboratory of Physical Education Tokyo Metropolitan University 1989). In the experiment, the horizontal distance from the midpoint between the subject's ankles to the center of the box was set at 41 cm.

We measured ground reaction forces, i.e., anteroposterior, transverse and vertical component forces using one force plate (Kistler; Type 9 281B). Presuming that the midpoint between the ankles was a reference point, we monitored the locations of the resultant force consisting of three component forces on the force plate, anteroposterior, transverse and vertical component forces, and recorded them on an eight-channel digital data recorder (TEAC; PR-110T).

At the end of each measurement, we asked the subjects to give RPEs while lifting at ten sites of the body (left and right shoulders, arms, backs, thighs and whole bodies). We used the category scale of one to ten for RPE to assess large-muscle-group activity (Borg 1982).

2.4. Collection of Data and Statistical Analyses

We stored all the data from the Lido Lift in an IBM compatible personal computer for analyses. The analog signal from the force plate was first recorded on a data recorder and then sampled at a rate of 100 Hz and converted from analog signals to digital ones using a personal computer before storage into floppy disks. Afterward, statistical analyses were done using SAS software (SAS Institute Japan Co.) on the mainframe in the computation center of Nagoya University (Fujitsu: M-1800/20, VP2600).

The strength/force data were statistically analyzed using two-way analysis of variance (ANOVA). The data from the force plate were subjected to three-way analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA). When some factors were significant in ANOVA, multiple comparisons by Scheffe's test were applied. The data for RPEs were analyzed using either the Wilcoxon rank-sum test or the Kruskal-Wallis test.

3. Results

3.1. Isometric Strength

Table 1 shows mean and standard deviation of isometric strengths for the period selected as a maximum three seconds. The results of isometric strengths are also presented, regarding Squat and Stoop posture in Sagittal plane lifting as a reference (Figure 2). The highest mean value, 352.8 N, was observed when the subjects were in Squat posture at R 45 plane. Low values were observed at both R 90 and L 90 planes. Angle factor was significant in ANOVA (Table 2). Subsequent Scheffe's test revealed that isometric strength at R 45 plane was significantly different from those at R 90 and L 90 planes.

3.2. Dynamic Force and Related Variables

a. Peak Force

The mean peak force was the highest in Stoop posture at Sagittal plane, 361.6 N (Table 3, Figure 3). In ANOVA, Angle factor was significant (Table 2). Peak forces at Sagittal and R 45 planes were significantly higher than those at R 90 and L 90 planes (Table 2). The peak force occurred immediately after the box left the floor under each of the conditions (Figure 4).

b. Peak Velocity

Angle factor was significant in ANOVA (Table 2). Peak velocity at Sagittal and R 45 planes were significantly different from those at R 90 and L 90 planes (Table 2).

c. Average Upward Acceleration

The highest mean average upward acceleration, 1.35 G, was observed in Stoop posture at Sagittal plane (Table 3, Figure 3). Angle factor was significant in ANOVA (Table 2). Significant difference could be demonstrated in average upward acceleration between Sagittal and R 90 or L 90 planes and also between R 45 and L 90 planes in Scheffe's test (Table 2).

d. Height at Peak Force

Height at Peak Force occurred immediately after the box left the floor under each of the conditions (Figure 4). When the subjects were in Squat posture at Sagittal plane, the mean height at peak force was the highest, 17.9 cm (Table 3). Postural factor was significant in ANOVA (Table 2). Height at peak force in Squat lifting was significantly higher than that in Stoop lifting in Scheffe's test (Table 2).

3.3. Ground Reaction Force and Location of Resultant Force on Force Plate

The highest vertical component force in dynamic lifting was observed in Stoop posture at Sagittal plane. In isometric lifting, it was observed in Squat posture at R 45 plane. In dynamic lifting of the 10 kg box, the vertical component force occurred immediately after the box left the floor. Isometric lifting does not produce the instantaneous exertion as in dynamic lifting of the 10 kg box. The magnitude of total transverse and anteroposterior component forces was only about 8% of that of the vertical component forces.

Mode and Angle factors were significant in ANOVA regarding the vertical component force (Table 4). Subsequent Scheffe's test revealed that the vertical component force in dynamic lifting of the 10 kg box was significantly higher than in isometric lifting. There was also a significant difference between Sagittal plane and R 90 or L 90 planes.

As for transverse and anteroposterior component forces, Mode or Angle factors and some interaction effects were also significant in ANOVA.

Mode, Angle and Postural factors were significant in MANOVA regarding resultant force and location of resultant force made of three component forces on the force plate (Table 4). In dynamic lifting of the 10 kg box, locations of the resultant force on the force plate were closer to the midpoint between the ankles than those in isometric lifting (Figure 5). In both isometric and dynamic liftings of the 10 kg box at Sagittal plane, they were located a little in front of the midpoint between the ankles. They moved nearer to the right heel in liftings at R 45 plane and were around or behind the right or left heels when the liftings were done at R 90 and L 90 planes. In Squat lifting, they were closer to the midpoint between the ankles than those in Stoop lifting.

3.4. Rating of Perceived Exertion

RPEs tended to be higher in isometric lifting than in dynamic lifting of the 10 kg box (Table 5). In both isometric and dynamic liftings, RPE for the left thigh was the highest in lifting at L 90 plane and that for the right thigh was the highest at R 90 plane (Figure 6 and 7). RPEs for the right low back, the right thigh and the right whole body in isometric lifting were significantly higher than those in dynamic lifting of the 10 kg box as well as for the left arm and the left low back. RPEs for the left low back, the thighs and the left whole body significantly differed among four angle levels in isometric lifting. RPE for the left thigh significantly differed among four angle levels in dynamic lifting of the 10 kg box. Postural factor had no significant effect on RPE.

4. Discussion

4.1. Isometric Measurement in Asymmetric Lifting

Angle factor was significant in ANOVA regarding isometric strength. This was particularly remarkable for L 90 and R 90 plane liftings, where isometric strengths were 18.3% and 17.3% lower, respectively, in comparison with those for Sagittal plane. Some other studies have shown a concomitant decrease in strength as the angle of asymmetry increased (Garg and Badger 1986, Garg and Banaag 1988, Warwick et al. 1980). The results of our study are partially consistent with such findings. However, Garg and Badger (1986), Garg and Banaag (1988) and Warwick et al. (1980) reported the respective strength at 90^o asymmetric lifting was 31%, 42% and 38-50% lower than in symmetric lifting. Thus, rates of decrease in these studies were larger than in the present study. One cause of these differences may be based on the positioning of the feet and some experimental conditions not clearly defined in those studies. We asked the subjects to stand on the force plate with their ankles placed 41 cm apart and parallel to the sagittal plane in the present study. This permitted the subjects to use the foot nearer to the box as a fulcrum during asymmetric lifting. This might have made it easier for them to bring their strength into full play. The data regarding locations of the resultant force on the force plate supported this interpretation.

Regarding Angle factor, isometric strengths were the highest at R45 plane, followed by that at Sagittal plane, and those at R90 and L90 planes were the lowest. This was somewhat different from some reported studies in which the strength at Sagittal plane was the highest (Garg and Badger 1986, Garg and Banaag 1988, Warwick et al. 1980). The reason would be the distance from the anterior margin of the foot base to the center of the box. It is nearer in the 45 plane than in the 0^o and 90^o planes. According to some authors, since lifting strength is a function of body weight and probably related to its deployment relative to the foot base (Sanchez and Grieve 1992), isometric strength at 45 plane was thought to be highest. The same interpretation seems to support our study because the conditions for lifting and positioning of the feet in their study were nearly identical to those used in the present study.

In isometric lifting, RPEs for many body sites in asymmetric lifting were more stressful than those in symmetric lifting. In particular, RPE for the thigh located ipsilaterally to the box was very high. The results of RPEs and locations of the resultant force on the force plate will indicate that the leg closer to the box is subject to a relatively heavy internal load as compared with the other leg in asymmetric lifting.

4.2. Dynamic Measurement in Asymmetrical Lifting

Angle factors were significant in ANOVA regarding both peak force and average upward acceleration. They were highest in lifting at Sagittal plane, followed by that at R45 plane, and those at Right 90 and Left 90 planes were lowest. This was similar to the results of isometric strengths and maximum acceptable weights obtained by Garg et al. (1980) and Garg and Badger (1986).

Marras and Mirka (1990) reported that a significant amount of coactivation of muscles occurs in asymmetric lifting. In their study, the asymmetric position required the subject to turn clockwise to the right; therefore it appears that the left internal oblique muscle is the contralateral muscle that compensates for asymmetry on the left side of the body by increasing its activity and bearing more of the load. Therefore, in the present study, we presume that much coactivation of muscles occurred in asymmetric lifting, because much overall body instability occurred with an increase in the angle. However, RPEs for the low backs in the present study were not significantly different among angles. The reason for this may be related to the short lifting duration in the present study.

There was a different trend of force or strength between Sagittal plane and R 45 plane. In dynamic lifting of the 10 kg box, peak force at Sagittal plane was higher than at R 45 plane. However, this tendency was reversed in isometric lifting. The reason for this might be that, in isometric lifting at R 45 plane, the fulcrum point remained unchanged and strength could be maintained because the box did not actually move. On the contrary, in dynamic lifting of the 10 kg box at R 45 plane, the box movement enhances body instability, which in turn decreases the subjects' ability to provide greater lifting force. Thus, we suppose that dynamic measurement enables us to detect more actual lifting capability of the subjects than isometric measurement.

In dynamic lifting, Kumar (1984) reported higher RPEs for asymmetric lifting than for symmetric lifting. Moreover, Mital and Fard (1986) reported that asymmetric lifting tasks were physically more difficult than symmetric lifting. Garg and Banaag (1988) reported that RPEs for wrist, shoulder, lower back, lower body and whole body increased with an increase in the angle of asymmetric lifting, and the highest rating was observed in the lower back and the lower body. Similar results were found in the present study, but there was also an increased RPE for the ipsilateral thigh to the box, which was remarkably high in R 90 and L 90 plane liftings. Data on the ground reaction forces and locations of the resultant force on the force plate also supported these results, because we observed that a greater load was put on the foot ipsilateral to the box, which was remarkably high in the R 90 and L 90 plane liftings.

4.3. Postures during Dynamic Lifting

Height at peak force in Squat lifting was significantly higher than in Stoop lifting. In Squat lifting, it was observed that the subjects first began to straighten their knees and then lift the box using their legs and upper bodies. Therefore, the result of height at peak force in Squat lifting may not be as low as that in Stoop lifting. Waikar et al. (1991) and DeLooze et al. (1994) have reported that the lower the position at which the lifting task was performed, the higher the recorded L5/S1 maximum compression force and lumbar peak moment. Thus, Stoop lifting presumably caused a greater load on the low back than Squat lifting in the present study. Such data as height at peak force can be investigated only through dynamic lifting studies.

There have been some studies on the postural effect (stoop vs. squat) upon strengths in both isometric (Mital et al. 1985, 1986(b)) and dynamic lifting conditions (Mital et al. 1986, Gallagher and Bobick 1986). Many of them reported that body postures influence strengths. In the present study, however, Postural factor had no significant effect on some dependent variables including isometric strength, dynamic peak force, peak velocity or average upward acceleration. Kumar et al. (1992) has reported there was no postural effect upon strengths when the horizontal reach distance to the objects was three-quarters of the full reach distance between the shoulder joint and the hand grip center. Their result seems to support our finding, because the distance of 41 cm between the center of box and the subject in the present study was nearly equivalent to 70%

of the average full reach of the subjects, which was almost the same reach condition used in their experiment. However, it should be studied in the future whether the horizontal distance from the worker is influential to the postural effects upon lifting strength/force.

4.4. Advantages of Dynamic Method

In the workplace, nearly all work involves dynamic or semidynamic movement. A number of past studies have highlighted the limitations of isometric strength tests as pre-employment screening tools. They have demonstrated that measurement of maximum dynamic strengths is more suitable for assessing a person's lifting capacity than isometric test (Kamon et al. 1982, Kumar 1991, Kumar et al. 1988, Mital 1986). Mital and Das (1987) reported that because there is no effective limb movement, isometric testing can not be used to determine one's capacity to perform such dynamic tasks as manual material handling. Other reports have also recommended the use of dynamic strength tests in worker screening procedures (Aghazadeh and Ayoub 1986, Dales et al. 1986). Furthermore, NIOSH (1981) has announced that the optimal method for evaluation of lifting capacity should be safe, time and cost effective, accurate in assessing risk of future back injury, and biomechanically applicable to actual workplace demands. Some studies reported that force and moments predicted by static model are underestimated due to lack of the inertia of load and body segments in calculation (DeLooze et al. 1994, Leskinen 1985, McGill and Norman 1985, Tsuang et al. 1992). Judging from these reports, dynamic lifting measurement with inertial force is considered more reliable than isometric lifting measurement.

We found some advantages of using dynamic measurement over isometric measurement in the present study. Firstly, RPEs for the left arm, the backs and the right whole body in dynamic lifting of the 10 kg box were significantly lower than those in isometric lifting. We thought this due to the fact that the level of strength applied decreased soon after peaking and the whole duration in which great strength was demanded was very short. Thus, it would appear that, with the set the load of 10 kg, even were subjects to use maximum strength as in the isometric testing in order to lift the box, the dynamic lifting test would be presumably be less stressful. Secondly, in dynamic measurement, we obtained data on time-based changes in the force and the height of the box location during lifting as shown in Figure 4. This helps one estimate the load on the low back as indicated by DeLooze et al. (1994). This also makes it possible to judge the smoothness of lifting as in the study by Danz and Ayoub (1992). Therefore, this data will provide new knowledge about the biomechanical features of dynamic lifting tasks. Such data can be obtained only through dynamic lifting measurements. Thus, we think that dynamic measurement has advantages for assessing the time-based characteristic of lifting tasks with low stress for subjects.

4.5. Limitations of this study and Future Directions

In this study, the only dynamic lifting task assigned was the lifting of the 10 kg box. Future research needs to include the lifting of objects of various weights. In addition, among other more realistic experimental criteria, future studies must more accurately incorporate the width of the subject's stance and other conditions encountered in the actual workplace.

5. Conclusion

The lifting strength/force used in this experiment showed similarities and differences in isometric and dynamic measurements.

There was an increased RPE for the ipsilateral thigh to the box, which was remarkably high in the R 90 and L 90 plane during both isometric and dynamic liftings of the 10 kg box.

The data on height at peak force and time-based changes in the force and the height of the box location during lifting could be obtained only through dynamic lifting studies. The present finding provide new knowledge about the biomechanical features of the dynamic lifting tasks.

RPEs for many sites of body tended to be significantly lower in dynamic lifting of the 10 kg box than in conventional isometric lifting.

Thus, dynamic measurement of the 10 kg box has advantages for assessing the time-based character of lifting tasks with low stress for subjects.

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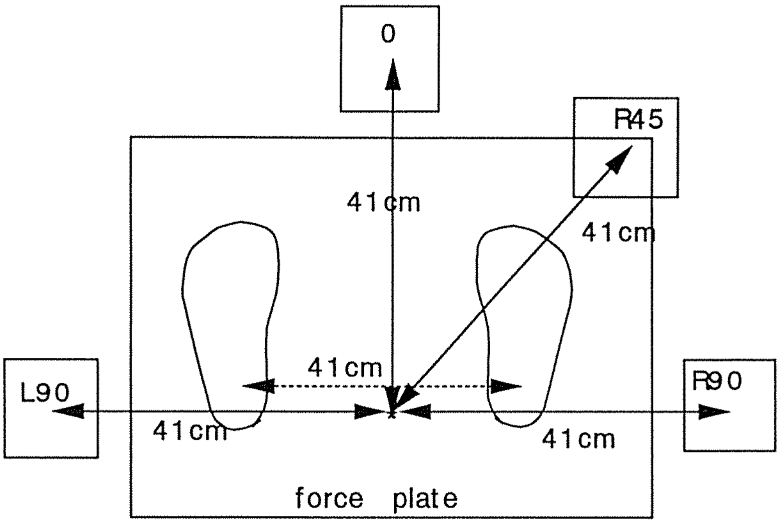

Figure 1. The position of the feet of the subjects and of the boxes in the experiment.
0=sagittal plane, R45=45° right lateral plane, R90= 90° right lateral plane, L90=90° left lateral plane

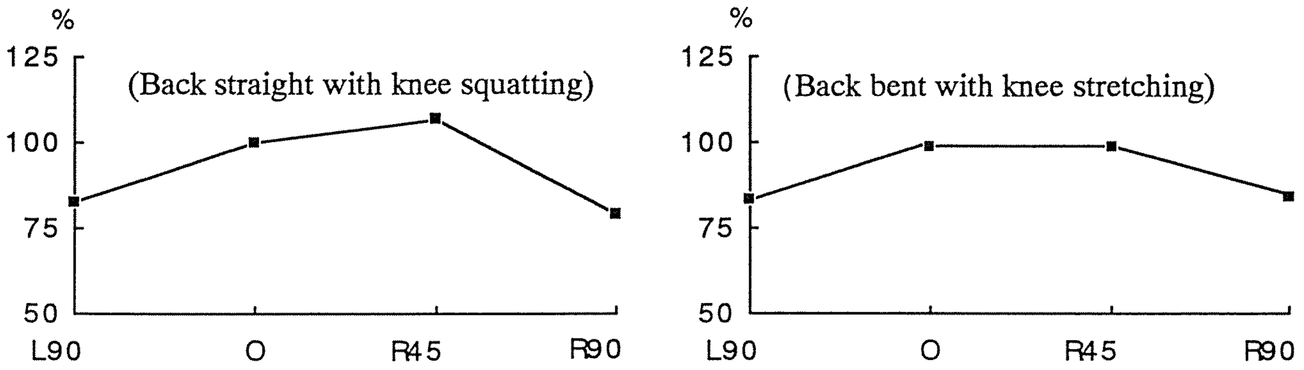

Figure 2. Relative changes in isometric strength expressed as a percentage of corresponding values in sagittal plane.
L90=90° left lateral plane, 0=sagittal plane, R45=45° right lateral plane, R90=90° right lateral plane

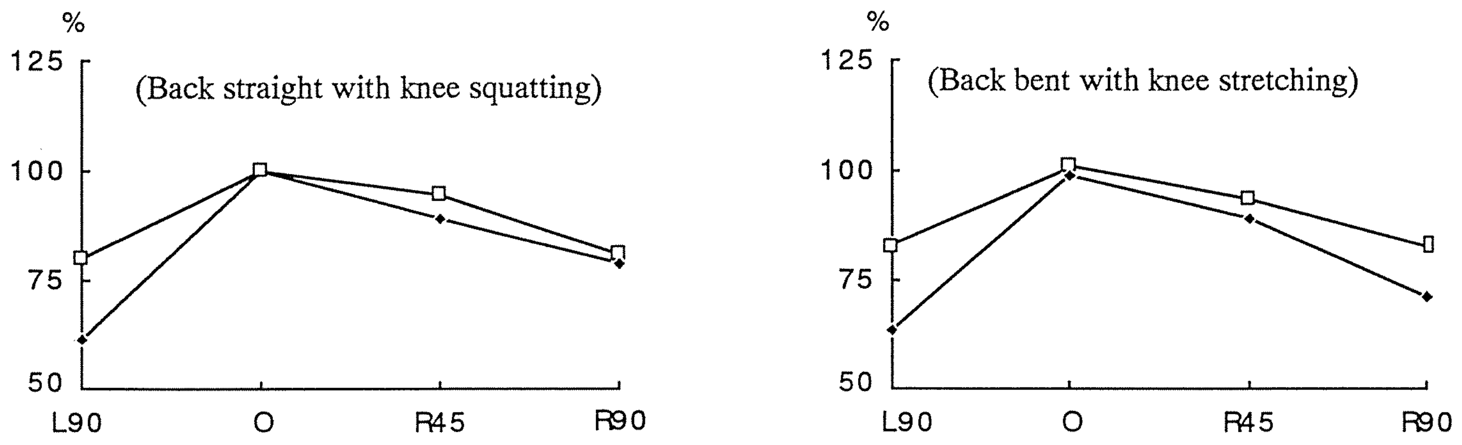

Figure 3. Relative changes in dynamic peak force and average upward acceleration expressed as a percentage of corresponding values in sagittal plane.

L90=90° left lateral plane, 0=sagittal plane, R45=45° right lateral plane, R90=90° right lateral plane □ =peak forc◆ =average upward acceleration,

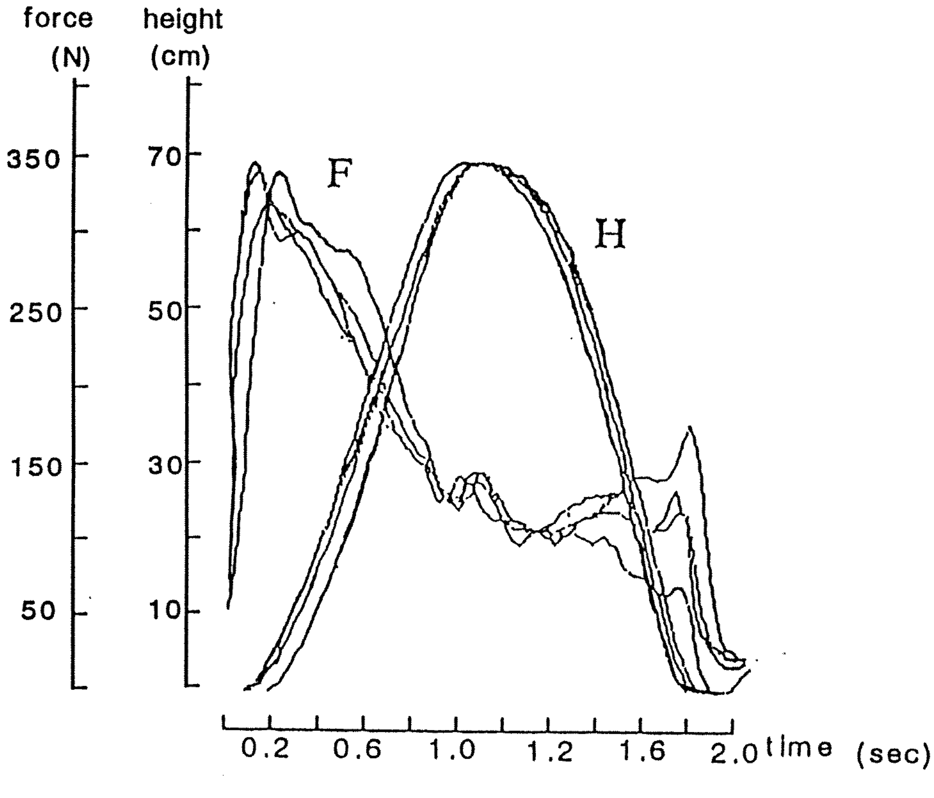

Figure 4. Time based changes in the force (F) and height (H) of the box during dynamic lifting. Using stoop posture in Sagittal plane, condition of a subject is presented.

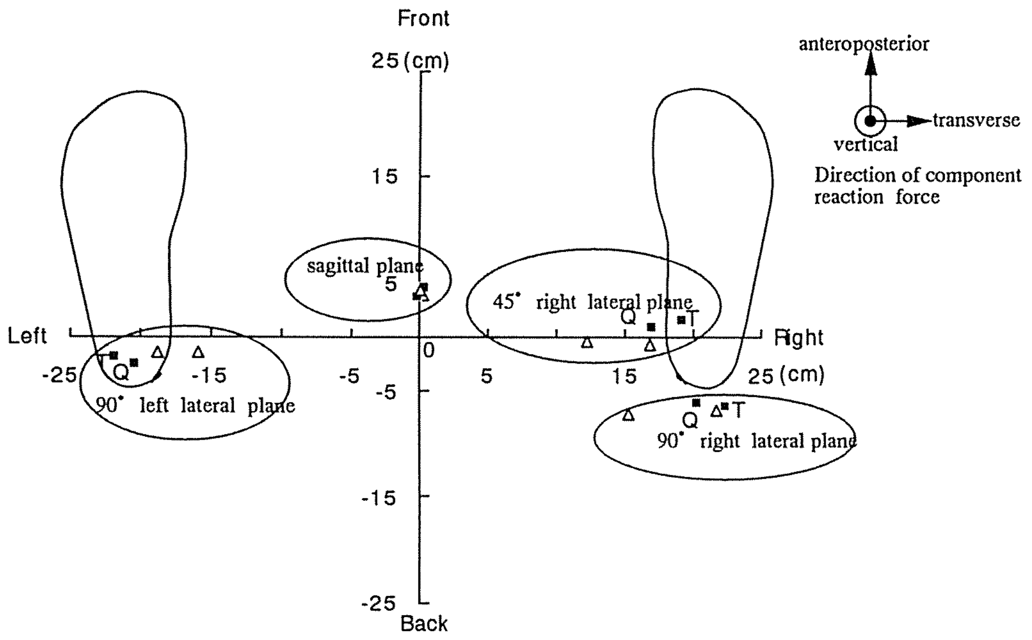

Figure 5. Locations of the resultant force consisting of three component reaction forces on the force plate: (anteroposterior, transverse and vertical forces) under experimental conditions.

■=Isometric lifting △=Dynamic lifting

T=Back bent with knee stretching Q=Back straight with knee squatting

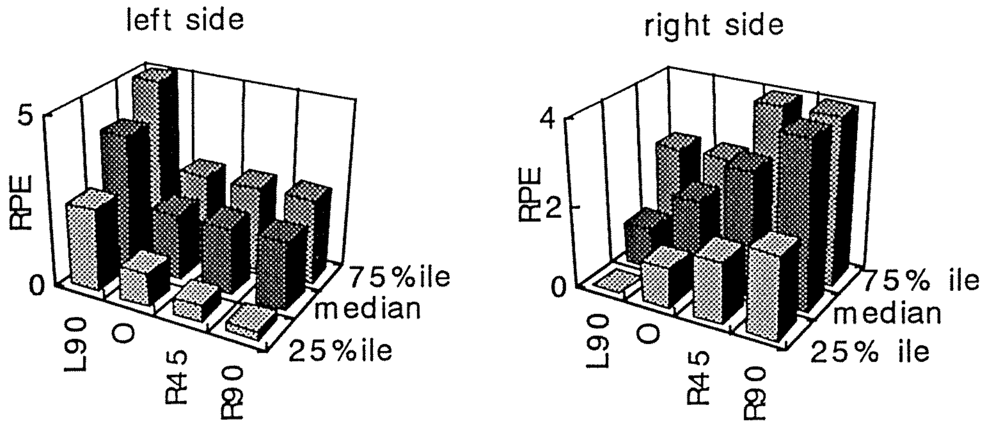

Figure 6. Rating of perceived exertion for the thighs in isometric lifting at Squat posture. 25% ile, median and 75% ile of subjects are presented.

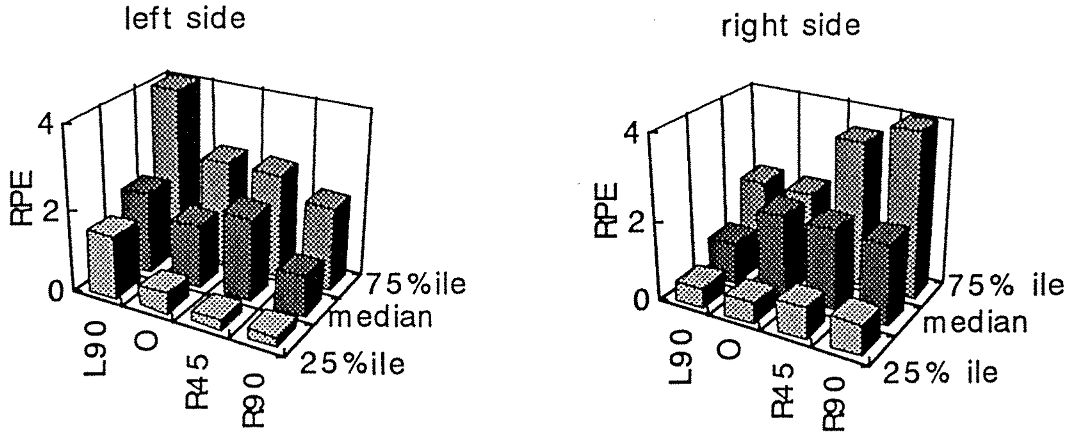

Figure 7. Rating of perceived exertion for the thighs in dynamic lifting at Stoop posture. 25% ile, median and 75% ile of subjects are presented.

Table 1. Mean and standard deviation (SD) of isometric strength for the maximum three seconds by angle and posture.

Angle	Posture	Strength[1] (N) Mean SD
Sagittal	Squat	329.3 ± 76.4
Sagittal	Stoop	330.3 ± 74.5
Right 45	Squat	352.8 ± 104.9
Right 45	Stoop	329.3 ± 70.6
Right 90	Squat	262.6 ± 51.0
Right 90	Stoop	277.3 ± 83.3
Left 90	Squat	272.4 ± 84.3
Left 90	Stoop	273.4 ± 77.4

1) Mean strength was calculated for every moving time-window with length of three seconds. Then, the maximum values for three seconds was extracted as the representative value from each five-second trial.

Table 2. Analysis of variance with isometric strength and dynamic force and related variables as the dependent variable

	Isometric Lifting	Dynamic Lifting			
Dependent variables / Factors	Strength	Peak Force	Peak Velocity	Average Upward Acceleration	Height at Peak Force
Angle(A)[1]	**	***	***	***	NS
Posture(P)[2]	NS	NS	NS	NS	*
A×P	NS	NS	NS	NS	NS
Scheff's Test	R45*>R90, L90	0*>R90, L90 R45*>R90, L90	0*>R90, L90 R45*>R90, L90	0*>R90, L90 R45*>L90	Q*>T

1) Comparison of Lifting Angles 2) Comparison of back straight with knee squatting and back bent with knee stretching Scheffe test completed when some factors were significant in ANOVA.

Statistical significance: * P<0.05, ** P<0.01, *** P<0.001, NS Not Significant, 0 = sagittal plane, R45 = 45° right lateral plane, R90 = 90° right lateral plane, L90 = 90° left lateral plane, Q = back straight with knee squatting, T = back bent with knee stretching

Table 3. Mean and standard deviation (SD) of dynamic force and related variables by angle and posture.

Angle	Posture	Peak Force (N)	Peak Velocity (m/sec)	Acceleraton1) (G)	Height 2) (cm)
		Mean SD	Mean SD	Mean SD	Mean SD
Sagittal	Squat	358.7±68.6	1.68±0.07	1.35±0.40	17.9±14.3
Sagittal	Stoop	361.6±50.0	1.68±0.04	1.33±0.44	5.9± 4.9
Right 45	Squat	339.1±48.0	1.68±0.04	1.20±0.36	9.0± 9.7
Right 45	Stoop	335.2±56.8	1.67±0.03	1.20±0.35	6.6± 9.3
Right 90	Squat	290.1±46.1	1.66±0.03	1.06±0.33	12.0±12.2
Right 90	Stoop	295.0±51.9	1.64±0.04	0.96±0.35	7.5± 9.1
Left 90	Squat	287.1±47.0	1.63±0.05	0.83±0.22	6.6± 6.2
Left 90	Stoop	296.0±62.7	1.63±0.05	0.86±0.32	5.9±10.4

1) Average upward acceleration 2) Height at peak force

Table 4. Ground reaction forces (anteroposterior, transverse and vertical forces), resultant force and location of the resultant force consisting of three component forces on the force plate analyzed by multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA).

	MANOVA		ANOVA		
Dependent variables / Factors	Resultant Force$^{1)}$	Location of Resultant Force	Tranverse Force	Anteroposterior Force	Vertical Force
Mode(M)$^{2)}$	***	*	NS	*** (D>I*)	* (D>I*)
Angle(A)$^{3)}$	***	***	*** (R45, R90, L90>0*)	*** (R45* >R90, L90)	** (0*>R90, L90)
Posture(P)$^{4)}$	NS	**	NS	NS	NS
M×A	NS	NS	***	***	NS
M×P	NS	NS	**	NS	NS
A×P	NS	NS	NS	NS	NS
M×A×P	NS	NS	NS	NS	NS

1) Resultant Force of three vector (anteroposterior force, transverse force and vertical force) 2) Comparison of Isometric lifting and Dynamic lifting in 22 lb 3) Comparison of Lifting Angles 4) Comparison of back straight with knee squatting and back bent with knee stretching, When some factors were significant in ANOVA, Scheffe's test results are shown in parentheses. Statistical significance: * $P<0.05$, ** $P<0.01$, *** $P<0.001$, NS Not significant, D = Dynamic lifting, I = Isometric lifting, 0 = sagittal plane, R45 = 45° right lateral plane, R90 = 90° right lateral plane, L90 = 90° left lateral plane

Table 5. Rating of perceived exertion analyzed by Wilcoxon rank sum test or Kruskal-Wallis test. Differences among levels are shown in parentheses.

	RPEs in left side of body				RPEs in right side of body			
	Factors				Factors			
	Mode1)	Posture2)	Angle3) (Isometric lift)	Angle3) (Dynamic lift)	Mode1)	Posture2)	Angle3) (Isometric lift)	Angle3) (Dynamic lift)
Shoulder	NS	NS	NS	NS	NS	NS	NS	NS
Arm	* (I>D)	NS	NS	NS	NS	NS	NS	NS
Back	* (I>D)	NS	* (R45, R90, >0, L90)	NS	* (I>D)	NS	NS	NS
Thigh	NS	NS	** (L90> 0, R45, R90)	* (L90> 0, R45, R90)	* (I>D)	NS	** (R90, R45 > 0, L90)	NS
Whole Body	NS	NS	** (L90> 0, R45, R90)	NS	** (I>D)	NS	NS	NS

1) Comparison of isometric lifting and dynamic lifting in 22 lb 2) Comparison of back straight with knee squatting and back bent with knee stretching 3) Comparison of lifting angles Statistical significance: * $P<0.05$, ** $P<0.01$, NS Not Significant, I = isometric lifting, D = Dynamic lifting, 0 = sagittal plane, R45 = 45° right lateral plane, R90 = 90° right lateral plane, L90 = 90° left lateral plane