Industrial Health 2004, **42**, 369–372 **Short Communication**

Lifting Strengths in Different Exertion Heights Conditioned on Extended Legs

Tzu-Hsien LEE*

Department of Management and Information Technology, Southern Taiwan University of Technology, No. 1, Nan-Tai Street, Yung-Kang 710, Tainan, Taiwan, Republic of China

Received July 7, 2003 and accepted January 30, 2004

Abstract: This study recruited seven height-matched healthy males to examine their maximum isometric lifting strengths across 13 exertion heights, ranging from 25 cm to 133 cm in increment of 9 cm. The results showed a nonlinear (increasing-decreasing-increasing) strength-height relationship for all subjects. The subjects' lifting strength was strongest (mean 1253.2 N) at the exertion height of 61 cm and weakest (mean 454.1 N) at the exertion height of 115 cm. Due to a large variability of strength ratio for the weakest individual strength to the strongest individual strength across the 13 exertion heights, ranging from 59.6% to 83.7%, practitioners should be cautious when assessing workers' lifting capacity based on strength testing.

Key words: Isometric lifting strength, Strength-height relationship, Exertion height

Introduction

Most occupational activities are performed through human intervention. Insufficient strength can lead to overloading of the muscle-tendon-bone-joint system and possible consequent injuries[1]. These injuries range from minor strain or sprain to permanent partial disability. The direct and indirect costs of such injuries are a significant occupational health problem in USA[2], and the same problem also occurs in other countries. Hence, the reasons for job designers to control the severity and frequency of these injuries are both humane and economic.

The knowledge regarding human strength is of special interest to product designer and occupational health professional in designing equipments or selecting workers to perform a specific job. Previous studies have reported some maximum isometric strength data for lifting tasks[3–6]; however, they failed to establish the relationship between strength and exertion height due to only a limited levels of exertion height were investigated in experiments. Additionally, most previous studies did not eliminate the body size effect, especially stature, in examining the effect of exertion height on strength capability, which might confound the experimental data. A clear atlas of the relationship between human strength and exertion height would enhance human knowledge of lifting capability and job design; hence, the purpose of this study was to examine human maximum two-handed isometric lifting strengths exerted across a wide range of exertion height (ranging from 25 cm to 133 cm) conditioned on extended legs. The reason for restricting the legs in an extended manner served to eliminate confounding effects of lower-limb muscles on lifting strengths in different exertion heights.

Materials and Methods

Subjects

Seven height-matched healthy males, experienced in lifting tasks, participated in this study. Subjects gave their written consent to participation. Their mean (SD) stature, body weight, chest circumference and waist circumference were 166.2 (1.8) cm, 61.0 (3.8) kg, 85.5 (3.0) cm and 71.0 (1.1) cm, respectively.

Experimental design and apparatus

A randomized complete block design was used for

*To whom correspondence should be addressed.

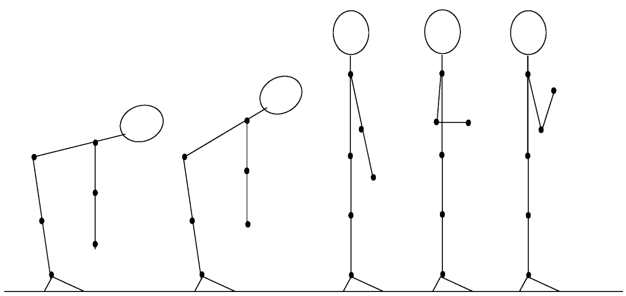

Fig. 1. Some typical lifting postures from low to high exertion heights.

analyzing subjects' maximum isometric lifting strengths in 13 different exertion heights, ranging from 25 cm to 133 cm in increment of 9 cm. These exertion heights were measured from the center of handle bar's diameter to the floor. A digital strength evaluation system (Lafayette instrument, model 32528) was used for measuring the subjects' isometric lifting strength. The load cell of the strength evaluation system was fixed on the ground and the strength signals were sampled at 60 Hz. A 60 cm long handle bar (diameter was 3.5 cm) was used for two-handed exertion. A steel chain was used to connect the handle bar with the load cell, and adjust the handle bar at different exertion heights.

Procedure

Subjects were allowed to perform practice exercises to familiarize themselves with the apparatus and lifting tasks in a few days prior to formal experiments. For formal experiments, subjects were instructed to perform the 13 lifting tasks in a random order. For each lifting task, subjects stood with extended legs and bare feet in a symmetric manner, and adjusted themselves to their own comfortable foot position to the handle bar. Then subjects exerted gradually their maximum isometric vertical lifting strengths as hard as they could on the handle bar without jerking. Precautions, such as maintaining a steady maximum exertion strength for about 4 s, at least two minutes rest between two tests, no direct strength data feedback to subjects and absent of spectators, to prevent isometric strength data contamination were adhered to in all tests[7–9]. Figure 1 demonstrates some subjects' typical lifting postures in this experiment, showing the postural changes from low to high exertion heights. Each subject attempted ten repetitions for all 13 lifting tasks. The measurements of subjects' peak isometric lifting strengths were collected and adjusted, by adding the total weight of the handle bar and steel chain to the measurements, for analysis.

Statistical analysis

The raw subjects' lifting strengths varied across the ten repetitions due to different test days or other uncontrollable factors. Hence, this study selected the five larger strengths from the ten repetitions for representing subjects' maximum lifting strengths. The total number of all analyzed strength measurements was 455 (7 subjects × 13 exertion heights × 5 repetitions). These strength measurements were subjected to analysis of variance (ANOVA), then the Tukey multiple comparison test was applied to determine which exertion heights yielded strengths that were different from others.

Results

The ANOVA results showed that subject ($F_{6,436}$=108.0, $p<0.0001$) and exertion height ($F_{12,436}$=354.2, $p<0.0001$) significantly affected lifting strength. The results of Tukey multiple comparison test on the mean lifting strengths associated with the 13 different exertion heights are summarized in Table 1. Subjects' lifting strength was strongest (1,253.2 N) at the exertion height of 61 cm and weakest (454.1 N) at the exertion height of 115 cm. The highest lifting strength was approximately 2.8 folds of the lowest lifting strength.

Figure 2 demonstrates the individual mean lifting strengths across the 13 exertion heights. Similar nonlinear (increasing-

Table 1. The means and standard deviations (SD) for isometric lifting strengths (N) at different exertion heights (n=7 subjects × 5 repetitions)

	Exertion height (cm)												
	25	34	43	52	61	70	79	88	97	106	115	124	133
Mean	1,022.8	1,037.0	1,061.7	1,131.2	1,253.2	1,243.8	990.6	821.1	617.6	493.4	454.1	536.9	678.3
SD	156.5	163.2	164.9	171.1	240.7	161.5	164.6	165.6	94.2	89.3	71.5	61.8	72.1
Tukey			b	b	a	a		d	e	f		f	e
group	c	c	c				c			g	g		

Means with the same letter in Tukey group are not statistically significant at the 5% level of significance.

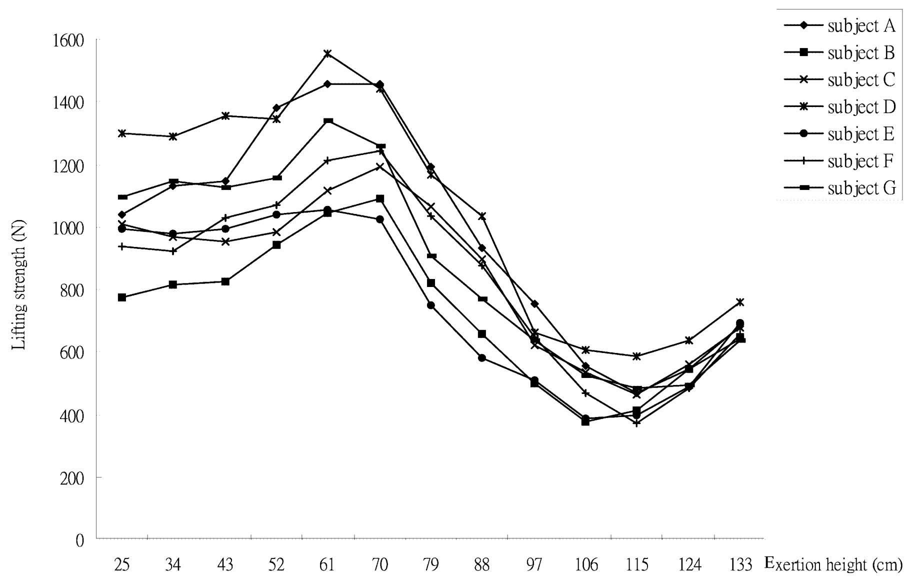

Fig. 2. The strength-height relationship for all individual subjects.

decreasing-increasing) strength-height relationships were observed among subjects. Additionally, the inter-subject strength differences decreased with exertion height.

Discussion

This study examined human lifting strengths across a wide range of exertion height and demonstrated a nonlinear (increasing-decreasing-increasing) strength-height relationship. This nonlinear strength-height relationship can be attributed to different contributions of trunk and upper extremities to lifting strength for different exertion heights. First, subjects' trunk changed from a fully flexed posture to an erected posture as the exertion height increased from 25 cm to about 70 cm. In this range of exertion height, the more the trunk flexed, the lesser trunk strength would be exerted due to lesser number of active cross-bridges in the sarcomeres of erector spinae[10]. As the exertion height further increased from 70 cm to about 115 cm, the lifting strength decreased because the role of subjects' trunk on lifting strength decayed. The final increasing strength-height relationship for the exertion heights above 115 cm was attributed to that subjects utilized their shoulder strength in lifting.

Although the nonlinear strength-height relationships were similar among subjects, considerable inter-subject strength differences existed even this study eliminated the effect of subjects' body size on examining lifting strength. This study further observed that the inter-subject strength differences decreased with exertion height. We attributed this phenomenon to higher strength variability in subjects' trunk strength responsible for lower exertion heights than that in arm strength responsible for higher exertion heights. The decreasing variability in subjects' strength from trunk muscles to arm muscles explains the decreasing inter-subject strength differences with exertion height. The strength ratio for the weakest individual strength to the strongest individual strength ranged from 59.6% to 83.7% among the 13 exertion heights. This large variability implies practitioners may commit an error in pre-employment strength testing if they only assess workers' strength within a limited and narrow height range.

References

1) Mital A, Kumar S (1998) Human muscle strength definitions, measurement, and usage: Part I—Guidelines for the practitioner. Int J Ind Ergonomics **22**, 101–21.
2) Mital A, Nicholson AS, Ayoub MM (1993) A guide to manual materials handling. Taylor and Francis, London, UK.
3) Yates JW, Kamon E, Rodgers SH, Champeney PC (1980) Static lifting strength and maximal isometric voluntary contractions of back, arm and shoulder muscles. Ergonomics **23**, 37–48.
4) Fothergill DM, Grieve DW, Pheasant ST (1991) Human strength capabilities during one-handed maximum voluntary exertions in the fore and aft plane. Ergonomics

34, 563–73.

5) Kumar S, Garand D (1992) Static and dynamic lifting strength at different reach distances in symmetrical and asymmetrical planes. Ergonomics **35**, 861–80.
6) Mamansari DU, Salokhe VM (1996) Static strength and physical work capacity of agricultural labourers in the central plain of Thailand. Appl Ergonomics **27**, 53–60.
7) Caldwell LS, Chaffin DB, Dukes-Dobos FN, Kroemer KHE, Laubach LL, Snook SH, Wasserman DE (1974) A proposed standard procedure for static muscle strength testing. Am Ind Hyg Assoc J **35**, 201.
8) Chaffin DB (1975) Ergonomics guide for the assessment of human static strength. Am Ind Hyg Assoc J **36**, 505–11.
9) Rube N, Secher NM (1981) Paradoxical influence of encouragement on muscle fatigue. Europ J Appl Physiol **46**, 1–7.
10) Winter DA (1979) Biomechanics of human movement. 1–102, Wiley, New York.