Velocity associated characteristics of force production in college weight lifters

H Kanehisa, T Fukunaga

Abstract

Objective—To determine velocity specific isokinetic forces and cross sectional areas of reciprocal muscle groups in Olympic weight lifters.

Methods—The cross sectional area of the flexor or extensor muscles of the elbow or knee joint was determined by a B-mode ultrasonic apparatus in 34 college weight lifters and 31 untrained male subjects matched for age. Maximum voluntary force produced in the flexion and extension of the elbow and knee joints was measured on an isokinetic dynamometer at 60, 180, and 300°/s.

Results—The average cross sectional area was 31–65% higher, and the force was 19–62% higher in weight lifters than in the untrained subjects. The ratio of force to cross sectional area was the same in both groups. The weight lifters showed a lower velocity associated decline in force than untrained subjects in the elbow and knee flexors but not in the extensors.

Conclusions—These results indicate that for muscle contractions with velocities between 60°/s and 300°/s the difference in isokinetic force between weight lifters and untrained subjects can be primarily attributed to the difference in the muscle cross sectional area. However, the lower velocity associated decline in force implies that weight lifters may have a higher force per cross sectional area than untrained subjects at velocities above 300°/s.

(Br J Sports Med 1999;33:113–116)

Keywords: force-velocity relation; muscle cross sectional area; isokinetic contraction; ultrasound

Regression analysis for mixed samples including resistance trained and untrained subjects has shown that the force generation capability of a muscle is highly correlated with its cross sectional area.^{1–6} However, the magnitude of the force per unit of cross sectional area for resistance trained subjects differs from report to report. Some researchers have indicated a lower force per cross sectional area in resistance trained people than in untrained subjects,^{1–5} and others have failed to find significant difference between the two groups.^{2–4, 6} Most of these studies examined a single muscle group. Moreover, athletes at a high power event, such as Olympic weight lifting, have not been used as a representative sample of strength trained subjects. Differences in force per cross sectional area between strength trained and untrained subjects may

depend on the type of strength training and may vary between different muscle groups.

The Olympic weight lifter's ultimate goal is to improve the maximum mass that he can lift in the "snatch" and the "clean and jerk" for one repetition. The participants in this event exercise with heavier loads and fewer repetitions for a given load than bodybuilders,⁷ with concentration on speed and explosion even if the mass being lifted is too great.⁸ On the other hand, bodybuilders train solely to develop superior muscularity, symmetry, and harmony between body parts with little concern for subsequent athletic performance.⁹ It is known that resistance training increases the force per cross sectional area owing to initial adaptations of neural factors to exercise¹⁰ and alters the force-velocity relation.¹¹ Explosive or power training and heavy resistance-few repetitions training, which are typical exercise regimens for weight lifters, can greatly improve neural activation during maximum voluntary contractions.^{12–14} Possibly, the force per cross sectional area may be higher in weight lifters than in untrained subjects, secondary to specific neural or velocity dependent efforts.

In this study the maximum isokinetic force and cross sectional area of flexor and extensor muscles of the elbow and knee joints were measured in Olympic weight lifters and untrained subjects. The purpose of this study was to compare isokinetic force per cross sectional area between Olympic weight lifters and untrained subjects across a range of contraction velocities.

Methods

SUBJECTS

Thirty four college weight lifters (mean (SE) age 19.8 (0.3) years, mean (SE) height 166.2 (1.2) cm, mean (SE) body mass 70.8 (2.0) kg) and 31 untrained men (20.2 (0.2) years, 171.1 (1.2) cm, 64.1 (1.9) kg) were studied. The untrained group had not taken part in any organised programme of regular physical exercise (≥ 30 min/day, ≥ 2 days/week) for at least one year before being tested. All the weight lifters had participated in Olympic weight lifting from high school age, and so their duration of training experience ranged from 3.1 to 8.5 years (mean 4.8 years). They had competed in Olympic weight lifting at regional or intercollegiate level in the preceding year, and were placed first, second, or third at their highest level of competition. All weight lifters maintained active training schedules at the time of the measurements. The force and cross sectional area measurements for the weight lifters were made more than 40 hours after comple-

Department of Life Sciences (Sports Sciences), University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo, 153-8902 Japan
H Kanehisa
T Fukunaga

Correspondence to:
Dr H Kanehisa.

Accepted for publication
21 December 1998

tion of a training session. Because data were collected during the last five to six weeks of training before the competition, it is likely that none of the subjects was dehydrated trying to make body mass for a match. This study was approved by the department of sports sciences at the University of Tokyo and complies with their requirements for human experimentation. The subjects were fully informed about the procedure to be used and the purpose of the study, and their written informed consent was obtained.

MEASUREMENT OF CROSS SECTIONAL AREA

Cross sectional photographs of the right upper arm and thigh were taken by a B-mode ultrasonic apparatus (SSD-120 Echo-Vision, Aloka, Japan). The apparatus and the experimental set up have been described previously.¹⁵ The measurement site in the upper arm was 60% of the distance between the acromion process and the lateral epicondyle of the humerus. The thigh site was 50% of the distance between the greater trochanter and the articular cleft between the chondyles of the femur and tibia. From the photograph of the ultrasound image the fat/muscle and muscle/bone interfaces were traced, and planimetric values were obtained. These values were then converted into the actual cross sectional areas by the calibrated formula: cross sectional area = planimetric value $\times 1/a^2$, where a is the magnifying power of ultrasonic photograph. The following muscles were investigated: elbow flexors, which included the biceps brachii and brachialis; elbow extensors, the triceps brachii; knee flexors, the biceps femoris, semitendinosus, semimembranosus, gracilis, adductor magnus, and sartorius; knee extensors, quadriceps femoris. The accuracy and test-retest reproducibility of measuring cross sectional areas by this technique were shown in an earlier study.¹⁵

MEASUREMENTS OF FORCE

An isokinetic dynamometer (Cybex II) was used to determine the force-velocity relation of flexion and extension of the elbow and knee joints, respectively. Before testing, the dynamometer was calibrated using a weight on the lever arm. Maximum voluntary peak torque produced in each of the movements was measured at 60, 180, and 300°/s with the same

experimental set up as reported earlier.¹⁵ To standardise the measurement and localise the action to the proper muscle group the subjects were seated in an adjustable chair with support for the back and hips. The length of the lever arm was adjusted to the length of each subject's limb. Elbow flexion and extension tasks were performed first.

During the tests the subject's right upper arm was supported horizontally on an adjustable padded table with a semi pronated lower arm, and the wrist was fixed with a strap at the end of an adjustable lever arm. Each upper arm and thigh was fixed with an adjustable lap belt to avoid any upward movement with elbow extension and knee flexion tasks, respectively. After a standardised warm up period and familiarisation with the measurement apparatus the subjects were encouraged to perform maximum voluntary muscle contractions isokinetically throughout a range of elbow joint angles from fully extended position (0°) to the 110° flexed position. The order of the test velocity was random for each subject. The subjects performed elbow flexion and extension alternately at every test velocity. A period of 10 s was permitted between flexion and extension tasks and one minute's rest allowed between each test velocity.

The same protocol was followed for knee extension and flexion tasks. The subject's right ankle was fixed to the end of the adjustable lever arm of the dynamometer. The knee flexion and extension tasks were performed from fully extended to the 100° flexed position. Three to five attempts were made at every test condition and the maximum peak torque produced was recorded; the peak torque was divided by the length of the lever arm of the dynamometer for conversion to newtons. The difference between the force output at 60°/s and that at 300°/s, expressed as a percentage of the force at 60°/s (percentage decline in force), was calculated to assess the velocity associated decline in force.

STATISTICS

Descriptive data were given as means (SE). The correlation coefficient (r) between cross sectional area and force was calculated by a least squares regression analysis. The force data were analysed by three way analysis of variance: 2 (group) $\times$ 3 (velocity) $\times$ 4 (muscle). Moreover, a two way analysis of variance: 2 (group) $\times$ 4 (muscle), was used to analyse the percentage decline in force. A Scheffé test was used to assess the differences between groups. For other descriptive data a one way analysis of variance was used to identify any significant difference between the weight lifters and untrained subjects. The probability level accepted for statistical significance was set at $p < 0.05$.

Results

Tables 1 and 2 give the descriptive data on cross sectional area and force measurements, respectively. The average cross sectional area was 31–65% higher, and force was 19–62% higher in weight lifters than in the untrained

Table 1 Comparison of anthropometric variables and muscle cross sectional areas for the weight lifters and untrained subjects

Variables	Weight lifters (W)		Untrained subjects (U)		W/U (%)
	Mean	SE	Mean	SE	
Height (cm)	166.2	1.2	171.1	1.2	97.1*
Body mass (kg)	70.8	2.0	64.1	1.9	110.4*
Limb length (cm)					
Upper arm	30.9	0.3	32.1	0.3	96.3*
Thigh	38.8	0.4	40.3	0.4	96.3*
Cross sectional area (cm ²)					
Elbow flexors	22.0	0.6	14.3	0.4	153.8*
Elbow extensors	30.9	1.0	18.7	0.5	165.2*
Knee flexors	80.9	2.1	61.6	1.6	131.3*
Knee extensor	108.1	2.8	76.3	2.3	141.7*

W/U = the ratio of the average value in the weight lifters to that in the untrained subjects expressed as a percentage.

* $p < 0.05$.

Table 2 Comparison of force score for weight lifters and untrained subjects

		Force (N)				
Movement patterns	Test velocity (°/s)	Weight lifters (W)		Untrained subjects (U)		W/U (%)
		Mean	SE	Mean	SE	
Elbow flexion	60	196.1	7.8	131.4	4.2	149.2*
	180	163.4	5.9	105.3	3.3	155.2*
	300	126.7	5.0	78.1	3.0	162.2*
Elbow extension	60	264.6	10.9	164.0	5.1	161.3*
	180	232.4	8.1	146.4	5.7	158.7*
	300	186.2	6.2	117.6	4.4	158.3*
Knee flexion	60	352.8	8.2	297.3	9.6	118.7*
	180	268.6	7.2	208.6	6.9	128.8*
	300	192.5	6.1	134.3	4.3	143.3*
Knee extension	60	597.5	22.2	481.5	16.0	124.1*
	180	434.6	12.7	345.4	12.1	125.8*
	300	301.0	8.5	226.2	8.4	133.1*

W/U = ratio of average value in the weight lifters to that in the untrained subjects expressed as a percentage.

* $p < 0.05$.

Table 3 Comparison of force per cross sectional area in weight lifters and untrained subjects

		Force per cross sectional area (N/cm ²)				
Movement patterns	Test velocity (°/s)	Weight lifters (W)		Untrained subjects (U)		W/U (%)
		Mean	SE	Mean	SE	
Elbow flexion	60	8.98	0.33	9.24	0.25	97.2
	180	7.49	0.25	7.45	0.24	100.5
	300	5.84	0.24	5.53	0.22	105.6
Elbow extension	60	8.69	0.34	8.91	0.32	97.5
	180	7.67	0.31	7.91	0.28	97.0
	300	6.17	0.25	6.34	0.21	97.3
Knee flexion	60	4.41	0.11	4.90	0.19	90.0
	180	3.35	0.07	3.42	0.11	98.0
	300	2.39	0.06	2.20	0.07	108.6
Knee extension	60	5.58	0.21	6.37	0.17	87.6
	180	4.08	0.14	4.55	0.11	89.7
	300	2.83	0.10	2.97	0.08	95.3

W/U = ratio of average value in the weight lifters to that in the untrained subjects expressed as a percentage.

subjects. Force at each velocity was significantly correlated with cross sectional area in every muscle group with correlation coefficients of 0.528 to 0.801 ($p < 0.05$).

Table 3 shows the mean (SE) force per cross sectional area for each group. The ratio of the average values of force per cross sectional area in the weight lifters to those in the untrained subjects tended to be higher with increasing test velocities. However, the difference in force per cross sectional area between the two groups was not statistically significant.

Table 4 compares the percentage decline in force in the weight lifters and untrained subjects. Although there was no significant two

Table 4 Comparison of the velocity associated decline in force between contractions at 60°/s and 300°/s in weight lifters and untrained subjects

Movement patterns	Decline in force (%)				Group difference
	Weight lifters		Untrained subjects		
	Mean	SE	Mean	SE	
Elbow flexion	34.3	2.1	40.0	1.9	p<0.05
Elbow extension	27.9	2.1	28.2	1.5	
Knee flexion	45.1	1.6	53.9	1.7	p<0.05
Knee extension	48.3	1.6	52.7	1.3	

way interaction (group $\times$ muscle, $F = 2.21$, $p > 0.05$) in the percentage decline in force, the effects of group ($F = 12.58$, $p < 0.05$) and muscle ($F = 79.07$, $p < 0.05$) were significant. The percentage decline in force in elbow and knee flexor muscles was significantly lower in weight lifters than in the untrained subjects.

Discussion

Contrary to the initial expectation, the force per cross sectional area in the weight lifters did not exceed that in the untrained subjects. This result suggests that the difference between the two groups in isokinetic forces with contraction velocities from 60°/s to 300°/s can be primarily attributed to the difference in muscle cross sectional area. However, the velocity associated decline in force in the elbow and knee extensors was lower in the weight lifters than in the untrained subjects. This implies that weight lifters might have been able to develop higher force per cross sectional area than the untrained subjects if the force measurements had been performed at velocities well above 300°/s. Similar findings have been reported in sprinters.^{16, 17} Johansson *et al*¹⁷ estimated that peak power would be over 451°/s in sprinters compared with 270°/s in marathon runners.

The lower velocity associated decline in force in the weight lifters may be explained by either neural or fibre type adaptations to resistance training. In the snatch lift and the clean phase of the clean and jerk lift, the bar must be lifted from the floor to arms' length overhead and the shoulders, respectively, by pulling actions. In these movements a higher mechanical power can be generated compared with those reported for short term maximum exercises in the literature.^{9, 18} After the completion of the pulling movements, a lifter shifts quickly to a deep squatting position to catch the barbell which has been pulled. In the jerk lift, the lifter rapidly extends to thrust the barbell upward after slight flexion of the knee and hip joints, and then splits the feet forward and backward, or again quickly flexes the knee and hip joints, to lower body and catch the barbell at arms' length overhead.¹⁹ The training regimens performed regularly by weight lifters mainly consist of actual competitive lifts using the above mentioned actions and assistance exercises which aim at improving the physical qualities requisite for the optimum execution of competitive lifts.¹⁹ Moreover, weight lifters are advised to concentrate on speed and explosion when they perform their own exercise regimens.⁹ The benefit of resistance training reflects the condition of exercise regimens as a result of adaptations in neuromuscular functions to the contraction mode, velocity or force development of exercising muscles.^{11, 20} Sale²¹ pointed out that resistance training might cause adaptive changes within the nervous system that allow a trainee more fully to activate prime movers in specific movements and to coordinate better the activation of all relevant muscles, thereby effecting a greater net force in the intended direction of movement. An emphasis on a high rate of force development during high intensity contraction is thought to

be the principal stimulus for the high velocity training response.²² The ability of weight lifters to develop greater forces during high velocity contractions may be due to specific neural adaptation to their own training style.

Some researchers have noted significant positive correlation between either the percentage distribution or the cross sectional area of fast twitch (type II) fibre in vastus lateralis and muscular output in isokinetic knee extensions at relatively high velocity contractions.²³⁻²⁵ The correlation coefficients between the percentage distribution of fast twitch fibres and isokinetic torque normalised to that at slow velocity contraction become higher with increasing test velocity.²⁴ From the previous reports on the muscle fibre composition of weight lifters,²⁶⁻²⁷ the participants in this event have a similar or high percentage distribution of slow twitch (type I) fibres in vastus lateralis or deltoid muscle as compared with untrained persons. However, because no fibre data are available for the elbow and knee flexors of weight lifters, we cannot rule out the possibility that the difference in the velocity associated decline in force between weight lifters and untrained subjects may be explained by a type II fibre population.

In summary, our results indicate that the difference in isokinetic forces with contraction velocities between 60°/s and 300°/s between weight lifters and untrained subjects can be attributed to the difference in muscle cross sectional area. However, the lower velocity associated decline of force suggests that weight lifters may have greater force per cross sectional area than untrained subjects at velocities above 300°/s.

Contributors

Hiroaki Kanehisa initiated and coordinated the study hypothesis, discussed core ideas, designed the study protocol, and participated in data collection, analysis, and writing of the paper. Tetsuo Fukunaga participated in the design of the study protocol, collected data, discussed core ideas and interpretation of the findings, and contributed to the paper.

- 1 Always SE, Stray-Gundersen J, Grumbt WH, *et al.* Muscle cross-sectional area and torque in resistance-trained subjects. *Eur J Appl Physiol* 1990;67:24-31.
- 2 Ikai M, Fukunaga T. Calculation of muscle strength per unit cross-sectional area of human muscle by means of ultrasonic measurement. *Internationale Zeitschrift für angewandte Physiologie Einschliesslich Arbeitsphysiologie* 1968;26:26-32.
- 3 Kanehisa H, Ikegawa S, Fukunaga T. Force-velocity relationships and fatigability of strength and endurance-trained subjects. *Int J Sports Med* 1997;18:106-12.

- 4 Maughan RJ, Watson JS, Weir J. Muscle strength and cross-sectional area in man: a comparison of strength-trained and untrained subjects. *Br J Sport Med* 1984;18:149-57.
- 5 Sale DG, MacDougall JD, Always SE, *et al.* Voluntary strength and muscle characteristics in untrained men and women and male bodybuilders. *J Appl Physiol* 1987;62:1786-93.
- 6 Schantz P, Randall-Fox E, Hutchison W, *et al.* Muscle fibre type distribution, muscle cross-sectional area and maximal voluntary strength in humans. *Acta Physiol Scand* 1983;117:219-26.
- 7 Tesch PA. Training for bodybuilding. In: Komi PV, ed. *Strength and power in sport*. Vol III. *Encyclopaedia of sports medicine*. Oxford:Blackwell Scientific, 1992:370-9.
- 8 Garhammer J. Power production by Olympic weightlifters. *Med Sci Sports Exerc* 1980;12:54-60.
- 9 Katch VL, Katch FI, Moffatt R, *et al.* Muscular development and lean body weight in body builders and weight lifters. *Med Sci Sports Exerc* 1980;12:340-4.
- 10 Ikai M, Fukunaga T. A study on training effect on strength per unit cross-sectional area of muscle by means of ultrasonic measurement. *Internationale Zeitschrift für angewandte Physiologie Einschliesslich Arbeitsphysiologie* 1970;28:173-80.
- 11 Sale DG, MacDougall D. Specificity in strength training: a review for the coach and athlete. *Canadian Journal of Applied Sport Science* 1981;6:87-92.
- 12 Häkkinen K, Komi PV, Alen M. Effects of explosive type strength training in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. *Acta Physiol Scand* 1985;125:587-600.
- 13 Schmidtbleicher D, Haralambie G. Changes in contractile properties of muscle after strength training in man. *Eur J Appl Physiol* 1979;46:221-8.
- 14 Schmidtbleicher D, Buehrle M. Neural adaptation and increase of cross-sectional area studying different strength training methods. In: Jonsson B, ed. *Biomechanics X-B*. Champaign: Human Kinetics, 1987:615-20.
- 15 Kanehisa H, Ikegawa S, Fukunaga T. Comparison of muscle cross-sectional area and strength between untrained and women and men. *Eur J Appl Physiol* 1994;68:148-54.
- 16 Harridge SDR, White MJ. A comparison of voluntary and electrically evoked isokinetic plantar flexor torque in males. *Eur J Appl Physiol* 1993;66:343-8.
- 17 Johansson C, Loontjens R, Sjöström M, *et al.* Sprinters and marathon runners. Does isokinetic knee extensor performance reflect muscle size and structure? *Acta Physiol Scand* 1987;130:663-9.
- 18 Garhammer J. A comparison of maximal power outputs between elite male and female weightlifters in competition. *Int J Biomech* 1991;7:3-11.
- 19 Garhammer J, Takano J. Training for weightlifting. In: Komi PV, ed. *Strength and power in sport*. Vol III. *Encyclopaedia of sports medicine*. Oxford: Blackwell Scientific, 1992:357-69.
- 20 Jones DA, Rutherford OM, Parker DF. Physiological changes in skeletal muscle as a result of strength training. *Q J Exp Physiol* 1989;74:233-56.
- 21 Sale DG. Neural adaptation to resistance training. *Med Sci Sports Exerc* 1988;20:S135-45.
- 22 Behm DG, Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol* 1993;74:359-68.
- 23 Thorstensson A, Grimby G, Karlsson J. Force-velocity relations and fiber composition in human knee extensor muscles. *J Appl Physiol* 1976;40:12-16.
- 24 Coyle ED, Costill DL, Lesmes GR. Leg extension power and muscle fiber composition. *Med Sci Sports Exerc* 1979;11:12-15.
- 25 Ryushi T, Fukunaga T. Influence of subtype of fast twitch fibers on isokinetic strength in untrained men. *Int J Sports Med* 1986;7:250-3.
- 26 Gollnick PD, Armstrong RB, Saubert IV CV, *et al.* Enzyme activity and fiber composition in skeletal muscle of untrained men. *J Appl Physiol* 1972;33:312-19.
- 27 Tesch PA, Thorsson A, Kaiser P. Muscle capillary supply and fiber type characteristics in weight and power lifters. *J Appl Physiol: Respirat Environ Exerc Physiol* 1984;56:35-8.