Strength training for wheelchair users

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Sedentary adult males with spinal lesions, all habitual wheelchair users, were allocated to exercise (n = 11) and control (n = 4) groups. A Cybex II dynamometer was used to assess peak power, average power, total work and muscular endurance for elbow flexion/extension, shoulder flexion/extension and shoulder abduction/adduction at five angular velocities, on recruitment and after eight and 16 weeks of forearm ergometer training (three days/week). Small sub-groups of the exercised subjects were assigned to high or low intensity endurance effort (70 or 40 per cent of maximal oxygen intake) and long or short training sessions (40 or 20 minutes per session). Despite the aerobic nature of the activity, gains of average power were registered by the two muscle groups most involved in the ergometer task (shoulder extension and elbow flexion). In keeping with current theories of training, gains were largest with prolonged, high intensity activity at angular velocities approximating those adopted during training.

Keywords: Spinally paralysed, wheelchair users, strength training, paraplegia, spinally disabled

Upper body strength and endurance have obvious practical importance for habitual wheelchair users. Cross-sectional comparisons have demonstrated an advantage of isokinetic strength of shoulder flexors and elbow extensors to those individuals who are highly active[1], and others have also shown up to 50 per cent greater upper body strength in sports participants[2–4].

However, there have been few longitudinal studies of strength in the spinally disabled[5–9]. Gairdner[10] and Walsh and Seaward[9] have recommended that specific training exercises for the wheelchair disabled be based upon the usual principles of muscular training for the able-bodied. In general, muscle strength is increased by working at or near its maximal force-generating capacity, improvements of function being determined by the intensity of 'overload' rather than the type of activity performed[11, 12].

A very practical issue for the wheelchair user is the extent to which the strength of the arm muscles can be developed through the less intense contractions of endurance activities. While disabled populations have apparently shown some gains of strength with endurance conditioning programmes, existing experiments have suffered from a lack of standardization of the training stimulus. The purpose of the present investigation was thus to assess changes in muscle strength and endurance following sixteen weeks of training based upon the controlled cranking of a forearm ergometer.

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0306-3674/90/010025–06

Methods

Subjects and experimental plan

The subjects were fifteen asymptomatic males, ranging in age from 16 to 37 years. All were volunteers, with significant lower-limb disabilities, but free of cardio-respiratory or orthopaedic complications. Four exercise regimens were randomly assigned. However, because of the limited number of subjects who completed the study, much of the strength data (obtained by Cybex II dynamometer) has been compared more simply between exercised (n = 11) and control (n = 4) subjects over eight and 16 weeks of ergometer training.

Preliminary examination

The medical examination included a detailed clinical examination, measurement of resting blood pressure and 12-lead electrocardiogram. No volunteers were excluded as a result of this screening. Lower limb disability was classified using the International Stoke Mandeville Games Federation (IMSGF) grading scheme, based upon the level of the spinal cord lesion and on residual muscle function, the latter being classified on a 0 − 5 scale[13, 14].

Body mass was determined on a recumbent hospital scale, and subcutaneous fat was measured at four sites (biceps, triceps, subscapular and suprailiac) using Harpenden callipers (Quinton Instruments, Burlington, Ont.). Body length was determined in the supine position, with manual stretching of the limbs. Opportunity was taken to familiarize the subject with laboratory procedures on the day of this preliminary examination.

Strength measurements

The peak moment (M) peak power (PP), average power (AP) and total work (W) of shoulder and elbow joint flexion and extension and shoulder joint abduction and adduction were assessed on a Cybex II isokinetic dynamometer (Lumex Inc., New York) at five angular velocities (1.05, 2.09, 3.14, 4.19 and 5.24 rad.sec^{-1}) and a damping factor of 2. All measurements were made on the dominant limb while the subject was lying in the supine position. To prevent extraneous movements, strapping was applied at the level of the chest (juxta-nipple) and hips (iliac crest). The moment and power scores reported for each visit represent the highest of five trials for each joint movement.

Force-time curves were digitized using a HP9874A digitizer (Hewlett-Packard, Canada, Inc., Toronto) interfaced to a HP9835A microcomputer (Hewlett-Packard, Inc.) without application of a specific gravity correction. To assess differences of muscular endurance between groups, 'drop-off' indices were calculated for each joint movement, using the average of the highest three and the lowest three power scores during 50 repeated biphasic contractions at 3.14 rad.sec^{-1}.

Training plan

All training was carried out using a Monark ergometer (Monark Rehab Trainer 881, Quinton Instruments, Burlington, Ont.) operated at a cadence of 80 revs.min^{-1}. The exercised subjects (E) attended the laboratory thrice weekly for 16 weeks, and were randomly assigned to one of two intensities (high intensity, H, 70 per cent of the directly measured peak oxygen intake, or low intensity, L, 40 per cent of the directly measured peak oxygen intake) and one of two durations (L, 40 or S, 20 min per session). Control subjects (C) continued with their normal pattern of daily activities, but reported to the laboratory for strength assessment at eight and 16 weeks after the preliminary tests.

Statistical analyses

The physical characteristics of the exercised and control subjects were contrasted using a one-way ANOVA. Alterations of strength and endurance scores within and among groups were assessed using factorial analysis of differences from initial values at each of the five testing velocities. Factor main effects consisted of subject group (C, n = 4 vs E, n = 11; or C, n = 4 vs HL, n = 4, HS, n = 2, LL, n = 3 or LS, n = 2), time differences at eight and 16 weeks from entry-level scores, and group × time interactions.

Table 1. Physical characteristics of the subjects

Variable	*Exercise group*	*Control group*
Age (yr)	29.0 ± 2.5	28.5 ± 3.9
Body length (cm)	163.0 ± 3.1	170.3 ± 9.8
Body mass (kg)	67.5 ± 5.0	78.2 ± 9.7
Sum of 4 skinfolds (mm)	48.1 ± 7.5	49.6 ± 7.5
ISMGF classification	3 to 5	3 to 5
Years disabled	17.6 ± 3.6	9.0 ± 4.0

Values are means ± SD

The main and interaction effects were tested using a nested statistical model (subjects within group). *A posteriori* comparisons were performed using least square means (marginal means, adjusted as appropriate for unequal cell sample sizes) and the error mean square from the factorial analysis of variance[15]. Differences of physical characteristics and strength scores between C and E or among C, HL, HS, LL and LS over time were considered at the two per cent level.

Results

Physical characteristics

The control subjects were considerably taller (/7.3 cm) and heavier (/10.7 kg) than the exercised group, and had also been confined to a wheelchair for a shorter time (/8.7 yr) than their active counterparts (*Table* 1). These differences reflect the greater proportion of exercised subjects with spinal paralysis of atraumatic etiology (spina bifida or anterior poliomyelitis) compared with controls (5/11, 1/4).

Training responses

Group means suggested some training-induced gains of muscle function in the exercised group, especially at the higher velocities of contraction (*Figures 1–6*), but the factorial analysis of variance for peak and average power differences generally demonstrated

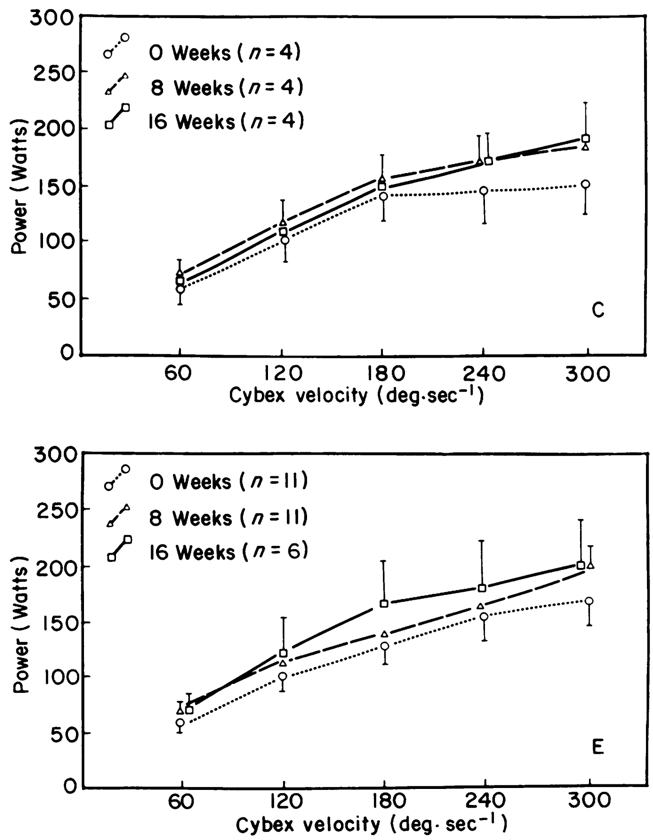

Figure 1. Average power of shoulder extension at selected velocities of isokinetic effort after 0, 8 and 16 weeks of training. Data for exercised (E) and control (C) subjects

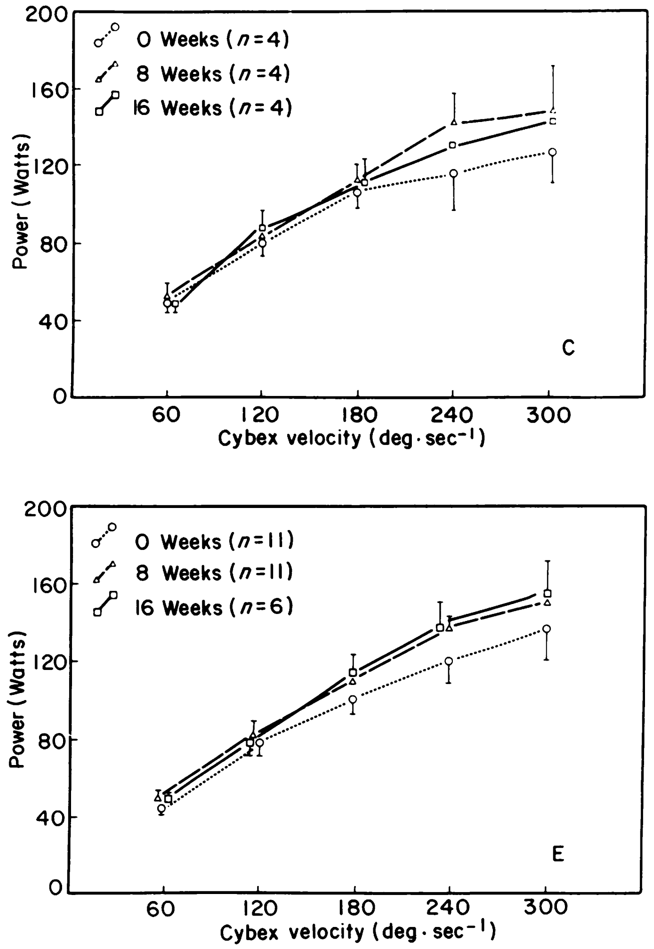

Figure 2. Average power of shoulder flexion at selected velocities of isokinetic effort after 0, 8, and 16 weeks of training. Data for exercised (E) and control (C) subjects

statistical significance only for the main effects of subjects nested within groups ($p < 0.05$). The between group (C vs E), training time (differences from initial values after eight or 16 weeks or training) and interaction of group with time effects were usually non-significant.

Exceptions to this rule were noted for the average power of shoulder extension (both C and E were increased by 6–8 W at 1.05 rad.sec^{-1} after eight weeks) and the average power or peak power of elbow extension (E improved by 13–31 W at 2.09, 4.19 and 5.24 rad.sec^{-1} following eight or 16 weeks of training). There were no differences of strength endurance 'drop-off' scores among groups over the experimental period. These results imply that in terms of the pooled data, neither muscular strength nor muscular endurance was consistently enhanced by sixteen weeks of aerobic forearm crank training.

When changes of peak power and average power were analysed by subject group, training time and group × time interaction, the subjects following the HL regimen augmented their average power at most limb velocities and for most joint movements. The largest strength gains were seen during shoulder flexion (*Figure 7*); average power increments over joint speeds of 1.05–5.24 rad.sec^{-1} ranged from 10–50 W at eight weeks (<0.02), and from 8–28 W at 16 weeks ($p < 0.02$). HL participants also demonstrated a significantly enhanced average power of elbow extension (*Figure 8*) after eight and 16 weeks (6–29 W above entry-level scores). In contrast, LL subjects tended to a decrease of both peak and average power, while C, HS and LS subjects showed inconsistent changes.

Discussion

The physical characteristics and medical status of the present sample were generally similar to overall data for Canadian paraplegic males[16], although subjects were somewhat shorter and more obese than previous samples. These differences reflect in part the higher proportion of atraumatic lesions in our sample, and in part the deliberate selection of inactive individuals for the training experiment.

It was unfortunate that, because of defections from the experiment, there were substantial differences of body size between exercised and control subjects. However, the two groups were substantially similar in initial muscular strength, and since the focus of the analysis was upon the differences that developed with time, the impact of discrepancies in body size is likely to have been minimal. The influence of etiology is more problematic. We are unaware of any reports

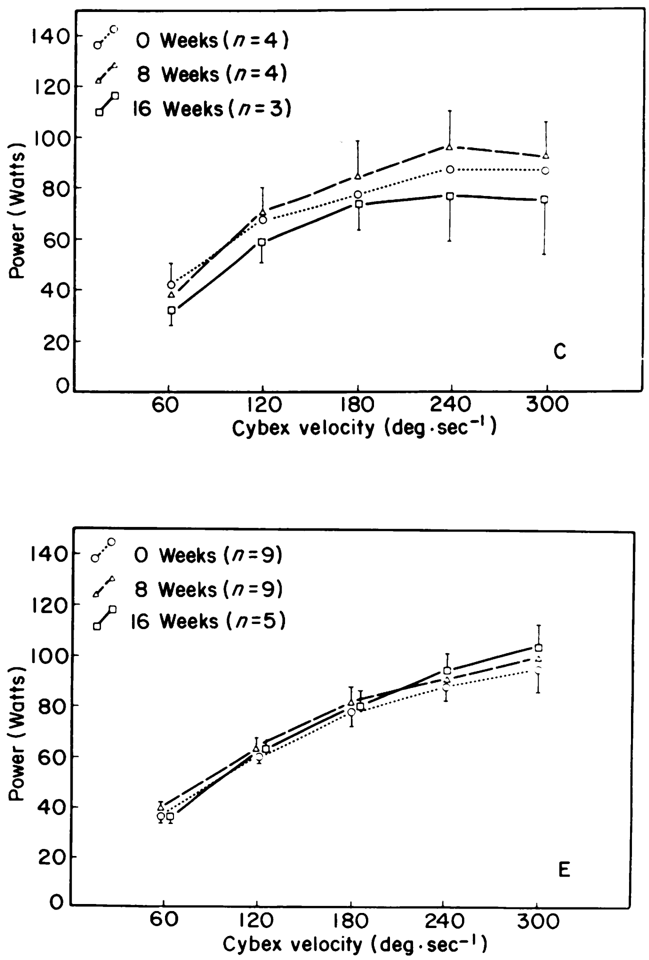

Figure 3. Average power of shoulder abduction at selected velocities of isokinetic effort after 0, 8, and 16 weeks of training. Data for exercised (E) and control (C) subjects

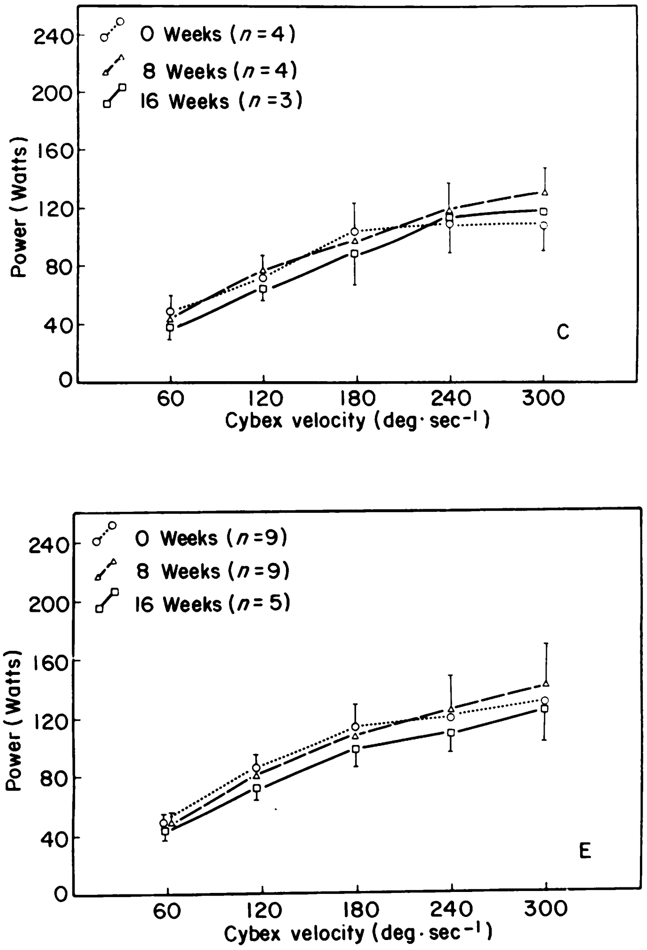

Figure 4. Average power of shoulder adduction at selected velocities of isokinetic effort after 0, 8, and 16 weeks of training. Data for exercised (E) and control (C) subjects

suggesting a relationship between the cause of disability and trainability, but because of residual function below the lesion, we suspect that the atraumatic subjects may have had a small training advantage.

Nilsson *et al.* previously observed a 19 per cent increase of dynamic strength in older paraplegics in response to a combination of forearm ergometry and conventional weight training[6]. They also noted 80 per cent gains of muscular endurance, defined as the number of 85 per cent maximum voluntary weight lifts that could be undertaken. Gersten and associates likewise reported gains of both isometric force and dynamic endurance in response to progressive resistance exercises[17].

Much more modest muscle forces were undoubtedly developed during the present bouts of forearm ergometry, particularly as we adopted a high cadence (80 revs.min^{-1}). Nevertheless, despite the small sample size and a substantial inter-individual variability of response, our results suggest that 16 weeks of such activity were sufficient to enhance both peak and average muscle power. Increases of muscle strength were most marked for shoulder flexion and elbow extension, which are the prime movers in forearm cranking and in wheelchair ambulation. Moreover, most of the observed gains were attributable to the HL subjects, with some contribution from HS participants at certain joint velocities.

In contrast to the earlier experiments with mixed training plans, we did not observe any augmentation of muscular endurance.

Our findings imply an enhanced power production by the pectoralis and triceps muscle groups. It remains unclear how far improved coordination contributed to the observed gains. Muscle biopsy studies of wheelchair users[18, 19] have sometimes demonstrated skeletal muscle fibre diameters two to three times anticipated normal values, with a high proportion of fast twitch fibres[20]. These gains have apparently developed through sports participation rather than participation in specific muscle building regimens. On the other hand, Nilsson *et al.* found no increment of limb dimensions following participation in their training programme[6].

It is interesting that training induced gains of muscle performance were more apparent in average than in peak power measurements. Our earlier observations suggested that average power was important to the biomechanics of wheelchair force production[21]. In similar fashion, forearm ergometry requires steady dynamic movements at 8.38 rad.sec^{-1}

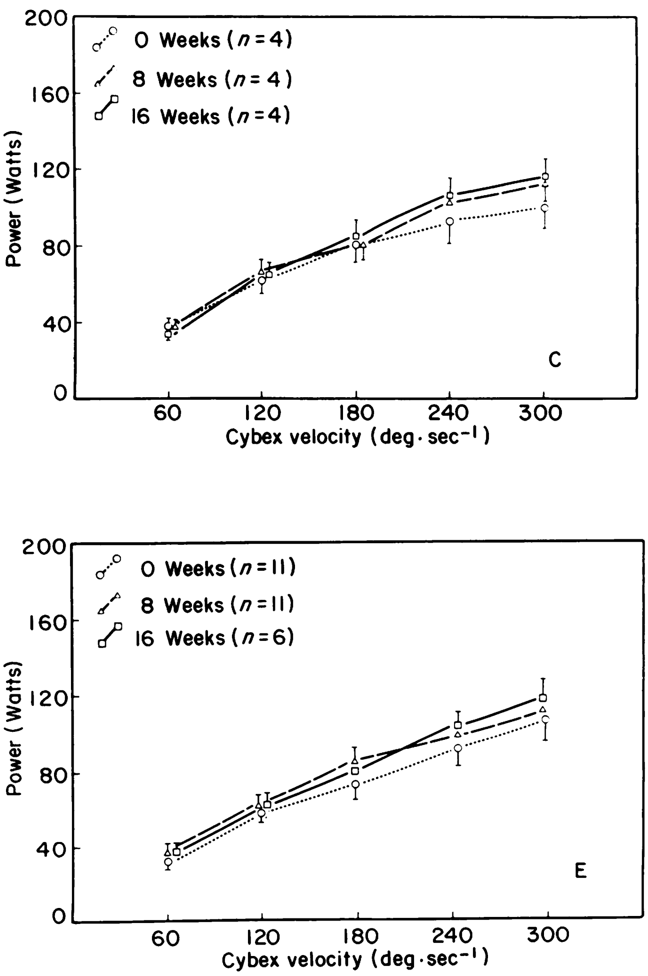

Figure 5. Average power of elbow extension at selected velocities of isokinetic effort after 0, 8, and 16 weeks of training. Data for exercised (E) and control (C) subjects

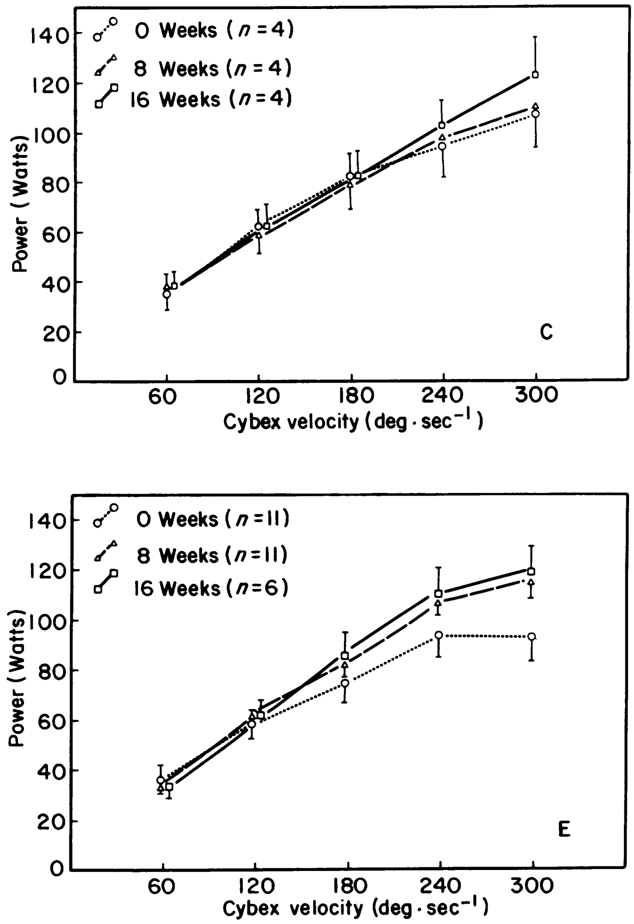

Figure 6. Average power of elbow flexion at selected velocities of isokinetic effort after 0, 8, and 16 weeks of training. Data for exercised (E) and control (C) subjects

rather than the explosive type of movements that might be expected to increase peak power.

Apparently, we are looking at one more example of the specificity of training. In support of this hypothesis, we may further note that the observed gains of average power were greatest at the two highest test velocities (4.19 and 5.24 rad.sec^{-1}), which more closely matched the demands of the ergometer task.

Conclusion

We conclude that disabled subjects, participating in a three day/week 16 week forearm crank training programme designed to improve cardio-respiratory fitness, demonstrate increments of average and peak power output in the main agonists for this type of exercise (the shoulder flexors and the elbow extensors). The largest gains are registered with a regimen demanding a high intensity of effort (70 per cent of maximal oxygen intake) and long training sessions of 40 minutes duration. In keeping with theories of training specificity, changes are most apparent at velocities close to those used during training. No gains of muscular endurance are induced by this type of programme.

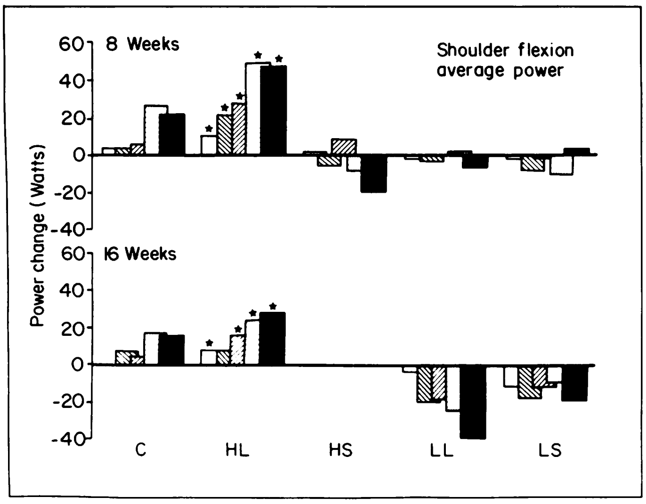

Figure 7. Changes in the average power of shoulder flexion among control and exercised groups (HL, HS, LL, LS) over 8 and 16 weeks of training at five selected velocities of isokinetic effort. Asterisks indicate $p < 0.02$

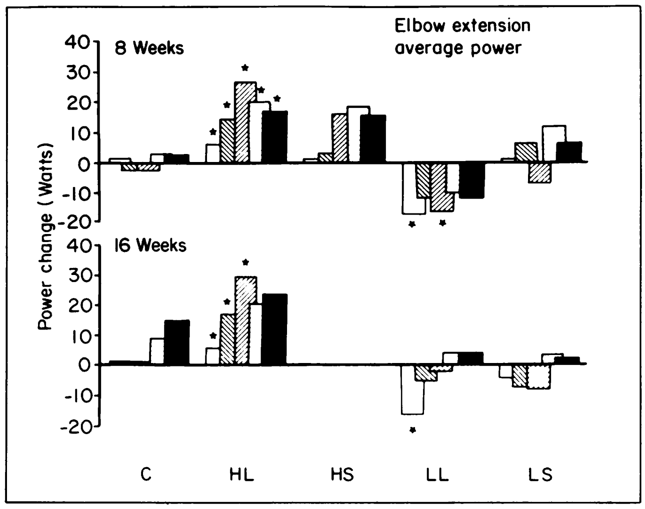

Figure 8. Changes in the average power of elbow extension among control and exercised groups (HL, HS, LL, LS) over 8 and 16 weeks of training at five selected velocities of isokinetic effort. Asterisks indicate $p < 0.02$

Acknowledgement

This research was supported in part by grants from the Province of Ontario (Provincial Health), and Health and Welfare Canada.

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