Mathematical Modeling on the Isokinetic Muscle Characteristics of Elite Athletes among Different Sports

Chin Ming Kai
Hong Kong Sports Institute

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Isokinetic profile of dorsiflexors and plantar flexor of ankle: a comparative study of elite athlete against untrained.

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ISOKINETIC PROFILE OF DORSIFLEXORS AND PLANTAR FLEXORS OF THE ANKLE - A COMPARATIVE STUDY OF ELITE ATHLETES AGAINST UNTRAINED SUBJECTS

Chi-Hung SO MPhil[1], T.O. Siu Dr Sc[2], K.M. Chan MBBS FRCS(E) FRCS(G) M.Ch(ORTH) FRCS Ed(ORTH)[3], M.K. Chin PhD[1], C.T. Li MPhil[3]

1 Sports Science Department, Hong Kong Sports Institute

2 Statistical Consultation Services, City Polytechnic of Hong Kong

3 Department of Orthopaedics & Traumatology, Chinese University of Hong Kong

This has been a comparative study on the isokinetic characteristics of the ankle (plantar flexion and dorsi-flexion) in the young male. Six cyclists, seven gymnasts, 10 soccer players and 25 normal young men were tested on the Cybex II+ dynamometer. Measurements were made on peak torque, TAE (torque acceleration energy), total work, and average power. For plantar flexion, the cyclists had slightly higher (5%) average measurements compared to the rest. However, due to the small sample, statistical significance was not attained. The situation was reversed for dorsi-flexion. Moreover, the average dorsi-flexion per unit of plantar flexion was significantly higher in the gymnasts than it was in the cyclists both for torque and work measures. This suggests that at a specific level of plantar flexion, the gymnasts had stronger dorsi-flexion in comparison to the cyclists. It may imply that in sports involving jumping and running, increased attention must be directed to strengthening the antagonist muscle groups (dorsiflexors) in order to achieve greater agonist to antagonist muscle balance and thus preventing injuries. The normal subjects had substantially lower endurance capability in both flexors as measured by the endurance ratio. This result reinforces the expectation that training or engagement in specialized sports produces identifiable specialization in particular muscles.

Key words: ankle plantar flexion, ankle dorsi-flexion, isokinetics, muscle endurance, torque ratio

Address for correspondence : Mr. Chi-Hung So, MPhil., Sports Science Department, Hong Kong Sports Institute, Shatin, N.T., Hong Kong

INTRODUCTION

The past decade has experienced increased interests in the foot and ankle of the competitive athletes. Much interest has focused on muscle injury management and rehabilitation[1-5]. Etiologic investigations would further the prevention of these injuries and at the same time suggest parameters upon which athletes could be selected and trained.

In view of this we would like to provide baseline isokinetic measurements of plantar-flexion and dorsi-flexion movements of the ankle. By controlling speed, isokinetic exercise[6] allows maximum resistance through the entire range of motion by constantly accommodating to variation in output muscle strength . The control of velocity and resistance also allows objective evaluation of the ankle muscular characteristics .

METHOD :

Subjects

Elite athletes of Hong Kong from cycling (n=6), gymnastics (n=7), and soccer (n=10) were tested. They were the national team members in these sports for Hong Kong. Normal young men (n=25) were also tested as controls.

None of the subjects had ankle pain or injury at the time of the study.

Procedure and Materials

All data were collected from subjects in a single session. After informed consent, weight and height were measured.

The Cybex II+ isokinetic dynamometer with dual channel recorder and Cybex data reduction computer (CDRC), Upper Body Exercise Table (UBXT), plantar/dorsiflexion footplate were used in this study (Cybex, Division of Lumex, Inc., Ronkonkoma, NX11779). A damp setting of two was used throughout the testing. The dynamometer was calibrated at the beginning of each testing session.

Leg dominance was identified with the side of writing. All subjects were required to begin testing with a prescribed warm-up program. The Cybex set up and positioning for plantar flexion/dorsiflexion testing were in accordance with the Cybex isolated joint testing manual and with the knee in fully extended position (0 deg). All adjustments were made by the same investigator. Subjects were allowed to practise three submaximal and two maximal trials before each test. The axis of movement and Velcro straps were adjusted prior to testing.

Testing was done at speeds of 60 deg/sec and 180 deg/sec. Testing at 60 deg/sec included 5 consecutive repetitions of exercise, while 25 consecutive repetitions were performed at 180 deg/sec. A period of 30 sec rest was allowed between warm up and testing, and one minute was allowed between testing speeds of 60 deg/sec and 180 deg/sec.

In all cases, the lower speed and non-dominant side was tested first. The isokinetic measures tested and utilized for the statistical analysis included peak torque at 60 deg/sec and 180 deg/sec, torque acceleration energy (TAE), average power (AP), total work (TW), and endurance ratio (ER-work done in the last five in comparison with the work done in the first five repetitions) at 180 deg/sec. In order to measure the difference of the flexors of ankle, torque ratio and work ratio (dorsiflexor/plantar flexor) were calculated. Peak torque, TAE and TW were reported in newton-meter (Nm) and AP in watts.

Student's paired-t statistics were used to test all the isokinetic measurements for differences between dominant and non-dominant side. One way Anova with Scheffe post hoc comparison was used for comparison between each sporting specialty and the normal group.

For normal subjects, analysis of co-variance was used to test for the age effects on the isokinetic test results.

The level of significance was set at two-tailed 5% for all statistical comparisons.

RESULT

The height , weight and age of subjects were summarized in Table 1. Weight did not differ significantly among the groups. Mean and standard error of isokinetic measurements for the two speeds are given in Tables 2,3,4 and 5. Mean age was significantly different among the groups. However analysis of co-variance suggested that age factor had no effect on the isokinetic test results .

There were significant bilateral differences neither among `overall' (data of all subjects together) nor the controls. Significant bilateral differences could only be found in torque measures for the three sport groups. At low speed, cyclists had significantly higher peak torque for the dominant side dorsiflexors (Table 3) while soccer players had significantly higher peak torque for the non-dominant side dorsiflexors (Table 2). At high speed torque test, gymnasts had higher measurements for non-dominant side plantar flexors (Table 4).

Anova tests indicated that gymnasts were significantly higher in peak torque ratio and work ratio compared to cyclists for the non-dominant side at both speeds (Table 6&7, Fig 1,2 &3). For the non-dominant side dorsiflexors, compared to cyclists, soccer players and gymnasts had higher results in peak torque at the low speed (Table 6), TAE, AP and ER at high speed (Table 7). Statistical significance was attained only for the difference in peak torque at the low speed and only for the soccer team compared to others. The controls were significantly lower than the gymnasts and soccer players in endurance ratio for both dorsiflexors and plantar flexors (Table 7).

Other measures were not significantly different among different groups, but there was a pattern of orders. For the ankle plantar flexion peak torque, TAE, TW, and AP measures, the cyclists tended to have the highest measurements while the gymnasts the lowest. These relationship were reversed in dorsi-flexion movement.

DISCUSSION

In isokinetic evaluation of pitchers at low and high speeds, Tippet[7] found significant bilateral difference in the strength of dorsi-flexors, which he suggested to be resulting from pitching mechanism. As significant bilateral difference could only be found in the three sports groups but not in the normal adults group in the current study, such sports specific bilateral difference might reflect specific requirements of a particular sport, e.g. gymnasts were significantly higher in plantar flexion on the non-dominant side as they use the non-dominant side to start jumping.

It is well established that isokinetic muscular characteristics of each sporting event would reflect the specific characteristics and requirement of that particular sporting event[8-13]. Consequently, it is reasonably to hypothesize that specific muscular characteristics could be developed in ankle plantar flexors and dorsiflexors. This is supported by Fugal-Meyer[14], who found that isokinetic ankle plantar flexion peak torque in young athletes whose specialization demanded plantar flexion strength to be significantly higher than sedentary and untrained subjects. Fugal-Meyer[15] also noted that isokinetic plantar flexion torque to be independent of age within ages 20-49 years, although it declines as a function of age after 49. On the other hand, Falkel[16] had stated that weight was a significant determinant of plantar flexion strength. In the present study the weight of the four groups had no significant difference and except for gymnasts who tended to be younger, age among all other subjects were between 20-48. The literature provides no guidance as to whether age below 20 would be an important factor for plantar flexion performance. In addition, analysis of co-variance suggests that age had no effect on the isokinetic performance among the controls. Age has thus probably not confounded our results. In this project, the only measure for which normal young men were significantly lower than the elite athletes was endurance ratio. This suggests that intensive training in the three sports tested improves ankle muscle endurance significantly.

The lack of statistical significance for the observed differences among groups might be due to the smallness of the sample. As the pattern of orders was identical for both dominant and non-dominant ankles, and consistent for different parameters in the same muscle group, this trend could serve as an indicator of certain muscular characteristics of athletes in these sports, either inherent or as a result of training.

The plantar flexors of cyclists had the highest in peak torque, TAE, TW, and AP. Stronger plantar flexors would facilitate stepping forward of the foot pedal. In comparison with the cyclists, the gymnasts and soccer players had better development of dorsiflexors in proportion to plantar flexors in peak torque, TAE, TW, and AP measures. It has been stated that the antagonistic muscles during a given motion (e.g. hamstrings during knee extension) play a major role in preserving joint stability[17-18]. Morris[19] noted that the hamstring/quadriceps ratio may be specific to the demands put on the athlete by the sports in which he/she engages. As the soccer athletes and gymnasts scored similar to the controls but significantly higher than the cyclists in dorsiflexion to plantar flexion peak torque ratio, a specific range of dorsiflexion to plantar flexion ratio (peak torque ratio (60 deg/sec) : 30 - 40%) is important for running and jumping. The higher peak torque ratio and work ratio might improve the stability of the ankle in jumping, landing and running. It has been stated that strength imbalance exceeding 20 lbs between dorsi- and plantar flexors appears characteristic of people with shin splints[20]. Therefore, well and balanced development of the plantar flexors and dorsiflexors is important for the athletes in sports involving mostly running and jumping, while cyclists might not find such need. Nowadays, the prescribed foot and ankle exercises are prevalently limit to various type of "heel raise". These plantar flexion exercises stress the often overdeveloped posterior muscles of the calf (plantar flexors), increasing muscular imbalance. The ideal conditioning program would prescribe exercises that produce a balance of muscular strength[21].

As stated above, particular sporting event induces the athletes to develop specific musculr characteristics, but such muscular characteristics may expose them to a higher risk of getting injured. Therefore, it is important for them to maintain a specified range of agonist and antagonist muscle strength ratio for their protection. More studies must be done to identify the optimal range of agonist and antagonist muscle strength ratio specific to each sport, for injury prevention and sport performance enhancement.

CONCLUSION

Normative isokinetic values from the movement of ankle planar flexion and dorsiflexion are presented. Analysis of isokinetic muscular performance of athletes in different sports and untrained subjects has led us to suggest that :

i) Bilateral difference: specific sports requirement may develop specific bilateral difference.

ii) Muscular endurance: intensive training can improve an athlete's ankle muscular endurance.

iii) Plantar flexion and dorsiflexion peak torque ratio and work ratio: sports that involve more in jumping and running (e.g. gymnastics and soccer) require better agonist and antagonist muscle balance (higher plantar flexion to dorsiflexion torque ratio and work ratio) to stabilize the ankle. Sportsmen in such sports should be prescribed exercises that would achieve muscle balance , to counter antagonistic imbalance prone to developed from training in these sports.

Acknowledgments

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References

1 Baldüini, FC, Vegso JJ, Torg JS, Torg E. Management and rehabilitation of ligamnetous injuries to the ankle. *Spts Med* 1987; **4**: 364-480.

2 Cetti R. Conservative treatment of injury to the fibular ligaments of the ankle. *Brit J Spts Med* 1982; **16**: 47-52.

3 Cetti R, Christenssen SE, Corfitzen MT. Ruptured fibular ankle ligaments : plaster or pliton brace? *Brit J Spts Med* 1984; **18**: 104-9.

4 Copper D, Fair J. Ankle rehabilitation using the ankle disk. *Phys Spts Med* 1978; **June**: 141.

5 Cote DJ, Prentice WE, Hooker DN, Shields EW. Comparison of three treatment procedures for minimizing ankle sprain swelling. *Phys Ther* 1988; **68**: 1072-6.

6 Cybex, Division of Lumex, Inc, Isolated Joint Testing and Exercise : A Handbook for Using Cybex II and UBXT, Bay Shore, NY: 1980.

7 Tippett SR. Lower extremity strength and active range of motion in college baseball pitchers : A comparison between stance leg and kick leg. *J Orth Spts Phy Ther* 1986; **8**: 10-4.

8 Cisar CJ, Johnson GO, Fry AC, Housh TJ, Hughes AJ, Ryan AJ, Thorland WG. Preseason body composition, build, as predictors of high school wrestling success. *J Appl Spt Sci Resear* 1987; **1**: 66-70.

9 Gerard ES, Caizzo VJ, Rubin BD, Prietto CA, Davidson DM. Skeletal muscle profile among elite long, middle, and short distance swimmers. *Am J Spts Med* 1986; **14**: 77-82.

10 Inwold CH, Rider RA, Haymes EM, Green KD. Isokinetic torque differences between college female varsity basketball and track athletes. *J Spts Med* 1983; **23**: 67-73.

11 Johansson C, Lorentzon R, Fugl-Meyer AR. Isokinetic muscular performance of the quadriceps in elite ice hockey players. *Am J Spts Med* 1989; **17**: 30-4.

12 Li G, Chen X, Chiang W. Isokinetic assessment of the quadriceps and hamstring of the elite Chinese athlete. *Annual Scientific Report.* The National Research Institue of Sports Science of China, 1986.

13 Thorland WG, Johnson GO, Cisar CJ, Housh TJ, Tharp GD. Strength and anaerobic responses of elite young female sprint and distance runners. *Med Sci Spts Exerc* 1987; **19**: 56-61.

14 Fugl-Meyer AR. Maximum isokinetic ankle plantar and dorsal flexion torques in trained subjects. *Eur J Appl Physiol* 1981; **47**: 393-404.

15 Fugl-Meyer AR, Gustafsson L, Burstedt Y. Isokinetic and static plantor flexion characteristics. *Eur J Appl Physiol* 1980; **45**: 221-34.

16 Falkel J. Plantar flexor strength testing using the Cybex isokinetic dynamometer. *Phy Ther* 1978; **58**: 847-50.

17 Hagood S, Solomonow M, Baratta R, Zhou BH, D'Ambrosia R. The effect of joint velocity on the contribution of the antagonist musculature to knee stiffness and laxity. *Am J Spts Med* 1990; **18**: 182-7.

18 Poulmedis D. Isokinetic maximal torque power of Greek elite soccer players. *J Orth Spts Phy Ther* 1985; **6**: 293-5.

19 Morris A, Lussier L, Bell G, Dooley J. Hamstring/Quadripceps strength ratios in collegiate middle-distance and distance runners. *Phy Spts Med* 1983; **11**(10): 71-7.

20 Gleim GW, Nicholas JA, Webb JN. Isokinetic evaluation following leg injuries. *Phy Spts Med* 1978; **6**:74-82.

21 Blievernicht J. Training the foot and ankle for optimum performance and prevention of injuries. *NSCA J* 1986; **8**: 32-4.

22 Lentell GL, Katzman LL, Walters MR. The relationship between muscle function and ankle stability. *J Orth Sports Phy Ther* 1990; **11**: 605-11.

23 Malone TR, Hardaker WT. Rehabilitation of foot and ankle injuries in ballet dancers. *JOSPT* 1990; **11**: 355-61.

24 Oberg B, Bergman T, Tropp H. Testing of isokinetic muscle strength in the ankle. *Med Sci Spts Exerc* 1987; **19**: 318-22.

25 SPSS PC + V 3.0 : SPSS Inc, Chicago, Illinois, 1989.

26 Weldon G, Snouse SL, Shultz S. Normative strength values for knee, shoulder, elbow and ankle for females ages 9-73 as determined by isokinetic testing. *Ath Training* 1988; **23**: 325-31.

Table 1. Physical characteristics of subjects

SPORT	AGE (yrs)	Ht (cm)	Wt (kg)
CYCLING (n=6)	23 (2.8)	172.0 (3.5)	63.0 (4.6)
GYMNASTICS (n=7)	18 (2.5)	167.4 (3.7)	59.6 (7.7)
SOCCER (n=10)	21 (5.3)	172.4 (4.1)	62.6 (4.8)
NORMAL (n=25)	21 (2.4)	168.7 (4.7)	60.0 (7.9)

Values are mean (s.e.)

Table 2. Non-dominant side ankle plantar flexion and dorsiflexion result, measured at low speed test (60 deg/sec) with Cybex

		SPORT				
		OVERALL (n=48)	CYCLING (n=6)	GYMNASTICS (n=7)	SOCCER (n=10)	NORMAL (n=25)
Peak Torque (Nm)	Plan	96.4 (20.4)	109.7 (19.6)	83.6 (19.9)	104.9 (19.4)	93.0 (18.8)
	Dors	30.4 (5.5)	24.8 (4.2)	29.9 (4.3)	34.4 (5.7)	30.2 (4.8)
Peak Torque (BWR %)	Plan	159.0 (27.8)	173.3 (19.9)	141.7 (36.0)	168.1 (26.0)	156.5 (25.7)
	Dors	51.0 (8.7)	40.0 (6.2)	51.1 (3.0)	56.1 (9.3)	51.6 (8.0)
Peak Torque Ratio (Dors/Plan %)		33.0 (8.0)	23.3 (3.8)	37.7 (8.7)	34.0 (7.5)	33.8 (7.1)

Values are mean (s.e.)

Table 3. Dominant side ankle plantar flexion and dorsiflexion result, measured at low speed test (60 deg/sec) with Cybex

		SPORT				
		OVERALL (n=48)	CYCLING (n=6)	GYMNASTICS (n=7)	SOCCER (n=10)	NORMAL (n=25)
Peak Torque (Nm)	Plan	94.3 (20.2)	112.3 (23.2)	84.3 (14.6)	100.0 (18.9)	89.9 (18.6)
	Dors	30.4 (5.6)	28.7 (6.6)	29.6 (4.0)	31.3 (6.3)	30.6 (5.7)
Peak Torque (BWR %)	Plan	155.4 (27.5)	178.2 (30.5)	142.6 (22.1)	159.8 (23.1)	151.3 (27.8)
	Dors	51.1 (10.1)	46.0 (9.6)	50.9 (6.4)	51.1 (12.3)	52.6 (10.2)
Peak Torque Ratio (Dors/Plan %)		33.9 (9.3)	25.8 (4.2)	36.6 (8.8)	32.4 (8.7)	36.0 (9.7)

Values are mean (s.e.)

Table 4. Non-dominant side ankle plantar flexion and dorsiflexion result, measured at high speed test (180 deg/sec) with Cybex

		SPORT				
		OVERALL (n=48)	CYCLING (n=6)	GYMNASTICS (n=7)	SOCCER (n=10)	NORMAL (n=25)
Peak Torque (Nm)	Plan	42.1	46.7	39.7	42.9	41.2
		(9.8)	(10.3)	(7.0)	(11.0)	(10.1)
	Dors	15.7	13.3	17.0	17.3	15.1
		(3.5)	(3.5)	(2.2)	(3.9)	(3.3)
Peak Torque (BWR %)	Plan	69.6	73.7	68.1	69.2	69.1
		(13.3)	(12.7)	(13.3)	(16.0)	(12.9)
	Dors	26.8	21.8	30.1	28.5	26.4
		(5.9)	(4.8)	(5.0)	(6.1)	(5.7)
Peak Torque Ratio (Dors/Plan %)		39.1	29.3	44.3	42.6	38.5
		(7.9)	(3.6)	(2.6)	(9.9)	(6.5)
TAE (Joules)	Plan	9.5	10.2	9.9	9.7	9.0
		(1.9)	(2.3)	(1.4)	(1.6)	(2.1)
	Dors	4.1	3.8	5.1	4.6	3.7
		(1.1)	(1.2)	(0.6)	(1.1)	(1.0)
Total Work (Joules)	Plan	438.8	493.3	411.6	481.2	413.4
		(157.2)	(153.5)	(163.6)	(174.8)	(151.0)
	Dors	174.8	131.2	222.9	208.1	156.2
		(71.4)	(59.2)	(49.3)	(69.9)	(69.7)
Endurance Ratio (%)	Plan	41.8	43.8	47.0	53.0	37.0
		(13.9)	(13.1)	(7.8)	(9.3)	(11.8)
	Dors	40.0	33.3	55.4	47.9	33.3
		(15.9)	(18.3)	(9.3)	(14.5)	(12.8)
Average Power (Watts)	Plan	53.7	62.0	52.1	60.6	48.7
		(18.2)	(18.6)	(16.3)	(18.5)	(17.9)
	Dors	21.1	16.0	28.1	26.4	17.9
		(8.8)	(7.0)	(4.2)	(9.4)	(7.7)
Work Ratio (Dors/Plan %)		41.9	26.2	57.3	47.3	38.8
		(15.0)	(7.0)	(9.9)	(16.5)	(12.2)

Values are mean (s.e.)

Table 5. Dominant side ankle plantar flexion and dorsiflexion result, measured at high speed test (180 deg/sec) with Cybex

		SPORT				
		OVERALL (n=48)	CYCLING (n=6)	GYMNASTICS (n=7)	SOCCER (n=10)	NORMAL (n=25)
Peak Torque (Nm)	Plan	41.8	49.7	36.7	43.9	40.3
		(10.9)	(12.3)	(7.8)	(13.5)	(9.4)
	Dors	15.9	15.0	16.6	15.7	16.0
		(4.6)	(5.0)	(2.7)	(6.3)	(4.4)
Peak Torque (BWR %)	Plan	69.3	79.0	63.3	70.2	68.2
		(15.6)	(18.0)	(13.6)	(18.8)	(13.8)
	Dors	27.2	24.5	29.0	26.0	27.9
		(7.4)	(7.6)	(2.6)	(9.7)	(7.4)
Peak Torque Ratio (Dors/Plan %)		39.9	30.3	47.7	36.3	41.6
		(11.0)	(6.7)	(10.5)	(10.3)	(10.6)
TAE (Joules)	Plan	9.6	11.0	9.2	9.8	9.2
		(2.1)	(2.3)	(1.5)	(2.3)	(2.1)
	Dors	4.3	4.2	4.6	4.5	4.1
		(1.2)	(1.3)	(0.6)	(1.7)	(1.1)
Total Work (Joules)	Plan	446.1	536.2	414.7	520.5	397.7
		(164.4)	(158.9)	(107.9)	(204.5)	(147.0)
	Dors	179.4	161.3	209.7	197.4	166.5
		(83.1)	(83.5)	(39.3)	(103.8)	(83.8)
Endurance Ratio (%)	Plan	45.4	42.7	54.6	53.1	39.6
		(12.1)	(12.2)	(8.3)	(11.3)	(10.1)
	Dors	39.8	34.7	55.4	43.8	34.5
		(16.8)	(21.5)	(7.5)	(19.6)	(13.3)
Average Power (Watts)	Plan	55.1	67.2	53.6	64.8	48.0
		(18.9)	(19.3)	(12.9)	(23.3)	(15.3)
	Dors	21.9	19.8	26.6	24.6	19.8
		(10.1)	(10.5)	(4.4)	(12.9)	(9.6)
Work Ratio (Dors/Plan %)		41.0	28.3	52.4	37.3	42.5
		(16.2)	(10.5)	(11.6)	(17.1)	(15.7)

Values are mean (s.e.)

Table 6. Ankle flexors low speed test results comparison among different sports

		NON-DOMINANT SIDE	DOMINANT SIDE
Peak Torque (Nm)	Plan	N.S.	N.S.
	Dors	*:SOC>CYC	N.S.
Peak Torque (BWR %)	Plan	N.S.	N.S.
	Dors	*:SOC,NORM>CYC	N.S.
Peak Torque Ratio (Dors/Plan %)		*:GYM,NORM>CYC	N.S.

N.S. : no significant difference ($p>0.05$)
* : significant difference ($p<0.05$)
\> : significance higher than

NORM : Normal subjects
CYC : Cycling
SOC : Soccer
GYM : Gymnastics

Table 7. Ankle flexors high speed test results comparison among different sports

		NON-DOMINANT SIDE	DOMINANT SIDE
Peak Torque (Nm)	Plan	N.S.	N.S.
	Dors	N.S.	N.S.
Peak Torque (BWR %)	Plan	N.S.	N.S.
	Dors	N.S.	N.S.
Peak Torque Ratio (Dors/Plan %)		*:GYM,SOC,NORM>CYC	*:GYM>CYC
TAE (Joules)	Plan	N.S.	N.S.
	Dors	*:GYM>NORM	N.S.
Total Work (Joules)	Plan	N.S.	N.S.
	Dors	N.S.	N.S.
Endurance Ratio (%)	Plan	*:SOC>NORM	*:GYM,SOC>NORM
	Dors	*:GYM>CYC,NORM	*:GYM>NORM
Average Power (Watts)	Plan	N.S.	N.S.
	Dors	*:GYM,SOC>NORM	N.S.
Work Ratio (Dors/Plan %)		*:GYM,SOC>CYC GYM>NORM	N.S.

N.S. : no significant difference ($p>0.05$)
* : significant difference ($p<0.05$)
\> : significance higher than

NORM : Normal subjects
CYC : Cycling
SOC : Soccer
GYM : Gymnastics

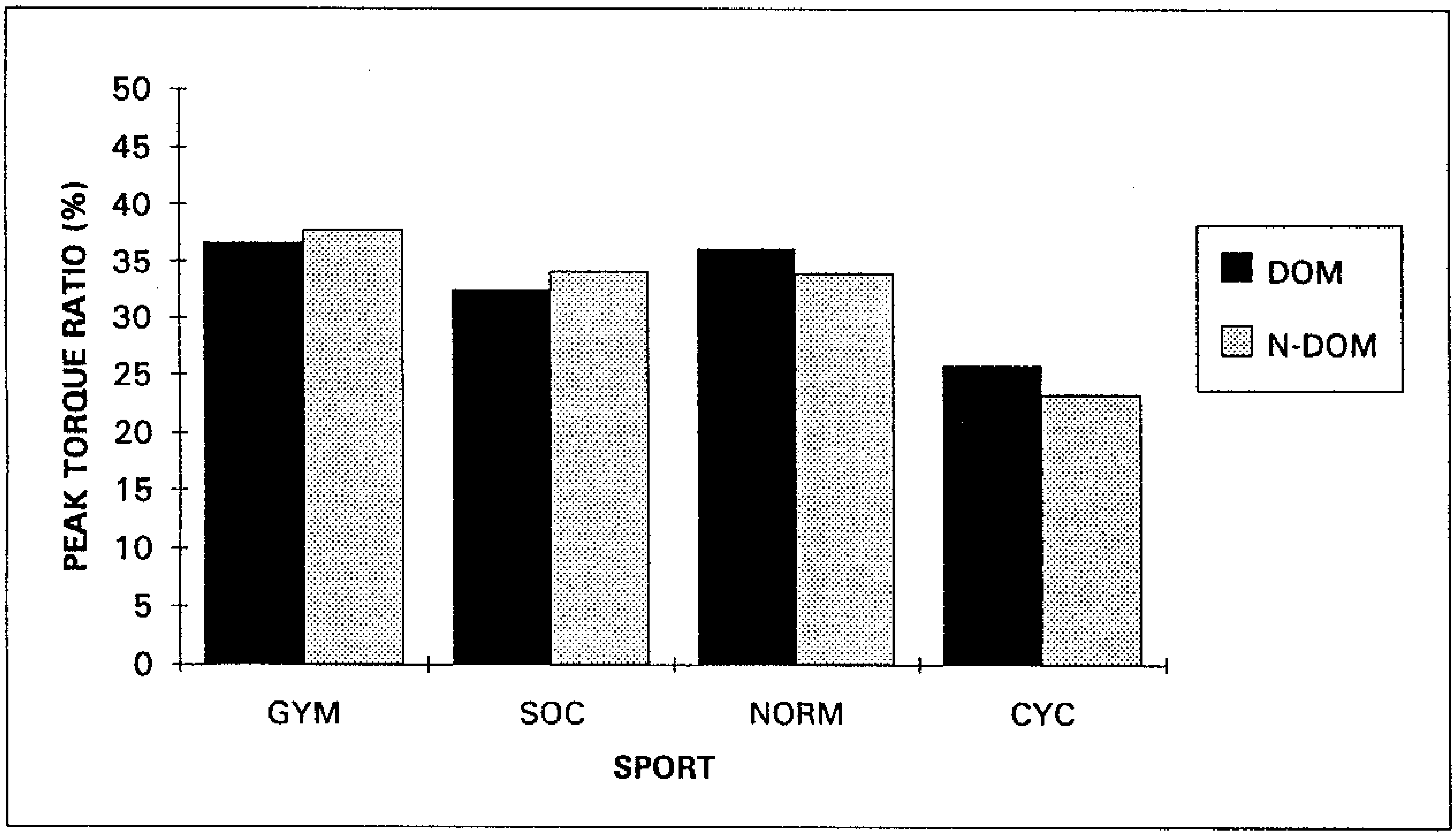

Fig 1. Ankle dorsiflexion/plantar flexion peak torque ratio (at 60 deg/sec)

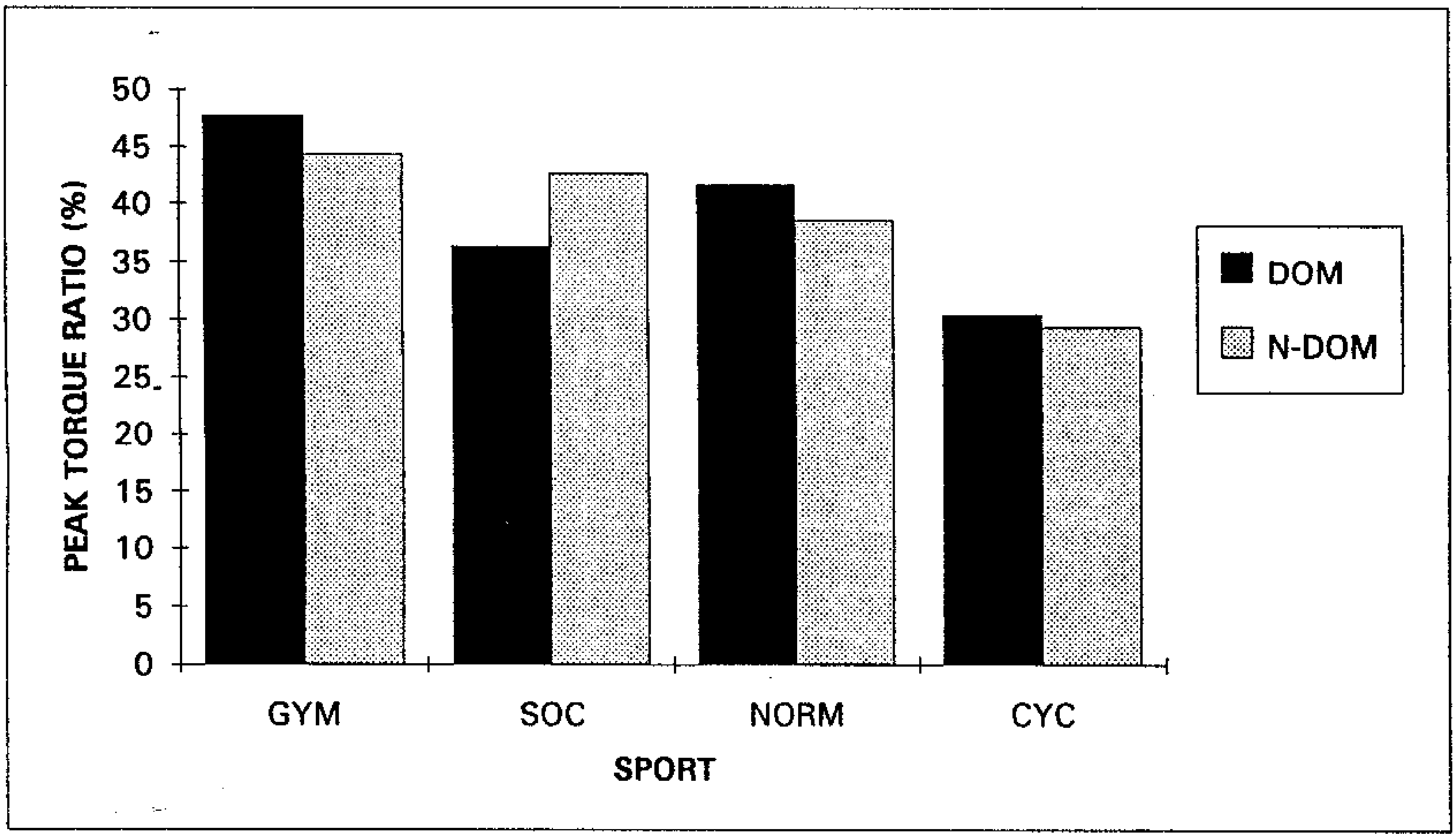

Fig 2. Ankle dorsiflexion/plantar flexion peak torque ratio (at 180 deg/sec)

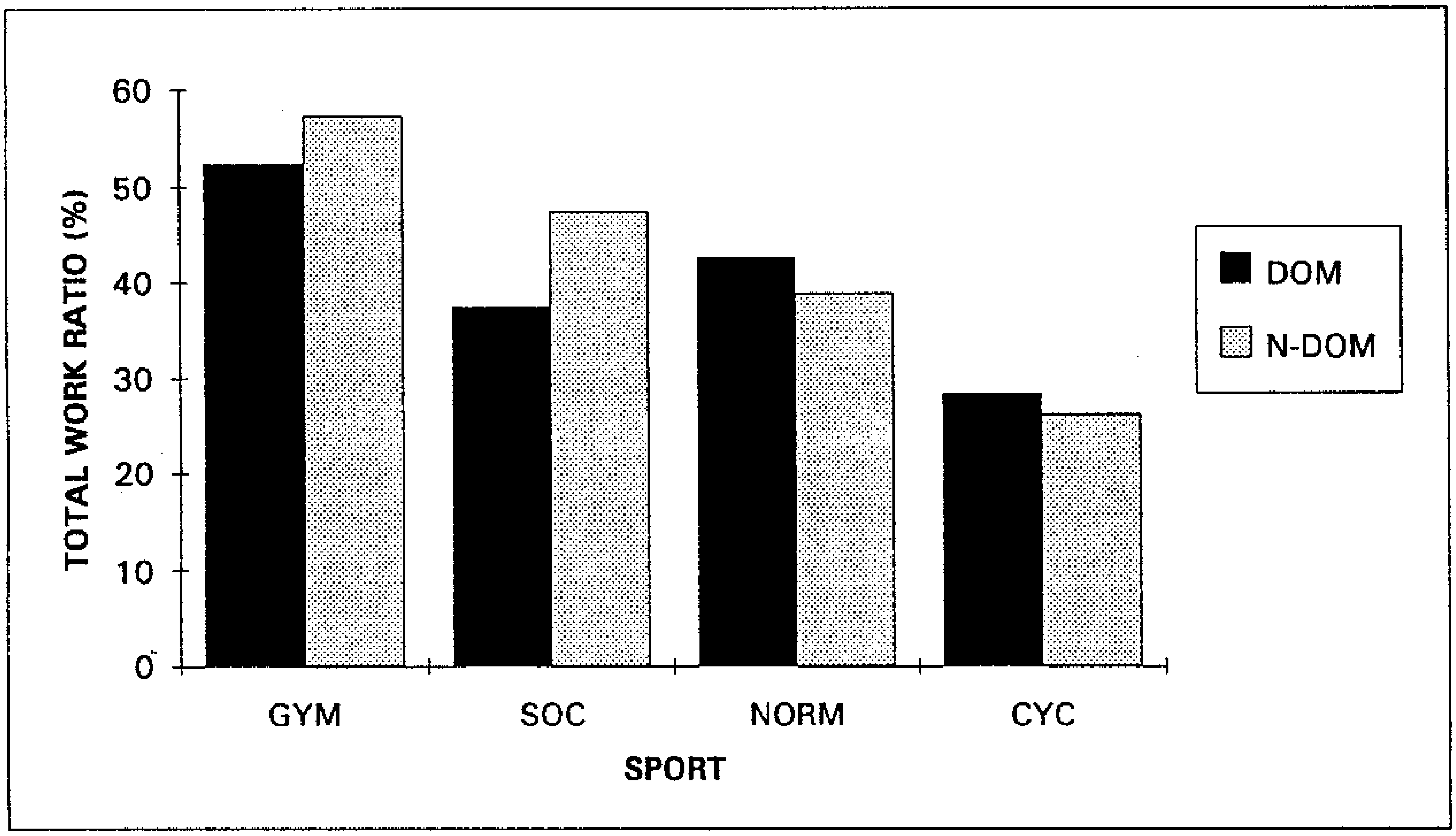

Fig 3. Ankle dorsiflexion/plantar flexion total work ratio (at 180 deg/sec)

Isokinetic profile of dorsiflexors and plantar flexors of the ankle – a comparative study of élite *versus* untrained subjects

Chi-Hung So MPhil, T. O. Siu Dr Sc*, K. M. Chan M.Ch (Orth) FRCS†, M. K. Chin PhD, CT Li MPhil†

Sports Science Department, Hong Kong Sports Institute, *Statistical Consultation Services, City Polytechnic of Hong Kong, and †Department of Orthopaedics and Traumatology, Chinese University of Hong Kong, Hong Kong

A comparative study was made of the isokinetic characteristics of the ankle (plantar-flexion and dorsiflexion) in young men. Six cyclists, seven gymnasts, 10 soccer players and 25 non-athletic young men were tested on the Cybex II+ dynamometer. Peak torque, torque acceleration energy (TAE), total work and average power were measured. Cyclists had slightly higher (5%) mean plantar flexion than the others, but this was not significant. The situation was reversed for dorsiflexion. Moreover, the average dorsiflexion per unit of plantar flexion was significantly higher in the gymnasts than it was in the cyclists for both torque and work. This suggests that at a specific level of plantar flexion, the gymnasts had stronger dorsiflexion compared with the cyclists and that in sports involving jumping and running, increased attention should be given to strengthening the antagonist muscle groups (dorsiflexors) in order to achieve greater agonist-to-antagonist muscle balance thus preventing injury. The non-athletic subjects had substantially lower endurance capability in both flexors as measured by the endurance ratio. This implies that identifiable specialization in particular muscles results from training or participating in specialized sports.

Keywords: Ankle plantar flexion, ankle dorsiflexion, isokinetics, muscle endurance, torque ratio

There has been increasing interest in the foot and ankle of the competitive athlete during the 1980s and early 1990s. Much interest has focused on muscle injury management and rehabilitation[1–5]. This study does not look at the aetiology of injuries. Aetiological investigations would further the prevention of athletics injuries and at the same time suggest parameters upon which athletes could be selected and trained.

In view of this we would like to provide baseline isokinetic measurements of plantar-flexion and dorsiflexion movements of the ankle. By controlling speed, isokinetic exercise[6] allows maximum resistance through the entire range of motion by constantly accommodating to variation in output muscle strength. The control of velocity and resistance also allows objective evaluation of the ankle muscular characteristics.

Subjects and method

Élite athletes of Hong Kong from cycling ($n = 6$), gymnastics ($n = 7$), and soccer ($n = 10$) were tested. They were the national team members in these sports for Hong Kong. Nonathletic young men ($n = 25$) were also tested as controls.

None of the subjects had ankle pain or injury at the time of the study.

Procedure and materials

All data were collected from subjects in a single session. After informed consent, weight and height were measured.

The Cybex II+ isokinetic dynamometer with dual channel recorder and Cybex data reduction computer (CDRC), Upper Body Exercise Table (UBXT), and plantar/dorsiflexion footplate were used in this study (Cybex, Division of Lumex, Ronkonkoma, New York, USA). A damp setting of two was used throughout the testing. The dynamometer was calibrated at the beginning of each testing session.

Leg dominance was identified with the side of writing. All subjects were required to begin testing with a prescribed warm-up programme. The Cybex set-up and positioning for plantar-flexion/dorsiflexion testing were in accordance with the Cybex isolated joint testing manual and with the knee in a fully extended position (0°). All adjustments were made by the same investigator. Subjects were allowed to practise three submaximal and two maximal trials before each teest. The axis of movement and velcro straps were adjusted before testing.

Testing was carried out at speeds of $60° s^{-1}$ and $180° s^{-1}$. Testing at $60° s^{-1}$ included five consecutive

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Address for correspondence: Mr Chi-Hung So, MPhil, Sports Science Department, Hong Kong Sports Institute, Shatin, New Territories, Hong Kong

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repetitions of exercise, while 25 consecutive repetitions were performed at 180° s^{-1}. A rest period of 30 s was allowed between warm up and testing, and 1 min was allowed between testing speeds of 60° s^{-1} and 180° s^{-1}.

In all cases, the lower speed and non-dominant side were tested first. The isokinetic measures tested and utilized for the statistical analysis included peak torque at 60° s^{-1} and 180° s^{-1}, torque acceleration energy (TAE), average power (AP), total work (TW), and endurance ratio (ER–work done in the last five repetitions in comparison with that done in the first five) at 180° s^{-1}. In order to measure the difference of the ankle flexors, torque ratio and work ratio (dorsiflexor/plantar-flexor) were calculated. Peak torque, TAE and TW are given in Newton-metres (Nm) and AP in watts.

Students' paired *t* statistics were used to test all the isokinetic measurements for differences between the dominant and non-dominant side. One-way analysis of variance with the Scheffe *post hoc* comparison was used to compare each sporting speciality with the nonathletic group.

Table 1. Physical characteristics of subjects

Sport	*Age (years)*	*Height (cm)*	*Weight (kg)*
Cycling (*n* = 6)	23(2.8)	172.0(3.5)	63.0(4.6)
Gymnastics (*n* = 7)	18(2.5)	167.4(3.7)	59.6(7.7)
Soccer (*n* = 10)	21(5.3)	172.4(4.1)	62.6(4.8)
Nonathletic (*n* = 25)	21(2.4)	168.7(4.7)	60.0(7.9)

Values are mean (s.e.)

For nonathletic subjects, analysis of covariance was used to test for the effects of age on the isokinetic test results.

The 5% level of significance was chosen for all the two-tailed statistical comparisons.

Results

The heights, weights and ages of subjects are summarized in *Table 1*. Weight did not differ significantly among the groups. Mean and standard error of isokinetic measurements for the two speeds are given in *Tables 2, 3, 4* and *5*. Mean age was significantly different among the groups. However analysis of covariance suggested that the age factor had no effect on the isokinetic test results.

There were no significant bilateral differences – neither among 'overall' (data of all subjects together) nor the controls. Significant bilateral differences could only be found in torque measures for the three sport groups. At low speed, cyclists had significantly higher peak torque for the dominant side dorsiflexors (*Table 3*) while soccer players had significantly higher peak torque for the non-dominant side dorsiflexors (*Table 2*). For the torque test at high speed, gymnasts had higher measurements for nondominant side plantar-flexors (*Table 4*).

Table 2. Nondominant side ankle plantar-flexion and dorsiflexion result, measured at low speed (60° s^{-1}) with Cybex dynamometer

	Sport				
	Overall (n = *48)*	*Cycling* (n = *6)*	*Gymnastics* (n = *7)*	*Soccer* (n = *10)*	*Nonathletic* (*n* = 25)
Peak torque (Nm)					
Plan	96.4(20.4)	109.7(19.6)	83.6(19.9)	104.9(19.4)	93.0(18.8)
Dors	30.4(5.5)	24.8(4.2)	29.9(4.3)	34.4(5.7)	30.2(4.8)
Peak torque (BWR%)					
Plan	159.0(27.8)	173.3(19.9)	141.7(36.0)	168.1(26.0)	156.5(25.7)
Dors	51.0(8.7)	40.0(6.2)	51.1(3.0)	56.1(9.3)	51.6(8.0)
Peak torque ratio (Dors/Plan%)	33.0(8.0)	23.3(3.8)	37.7(8.7)	34.0(7.5)	33.8(7.1)

Values are mean(s.e.). Plan, plantar-flexion; Dors, dorsiflexion; BWR, body weight ratio

Table 3. Dominant side ankle plantar-flexion and dorsiflexion result, measured at low speed (60° s^{-1}) with Cybex dynamometer

	Sport				
	Overall (n = *48)*	*Cycling* (n = *6)*	*Gymnastics* (n = *7)*	*Soccer* (n = *10)*	*Nonathletic* (*n* = 25)
Peak torque (Nm)					
Plan	94.3(20.2)	112.3(23.2)	84.3(14.6)	100.0(18.9)	89.9(18.6)
Dors	30.4(5.6)	28.7(6.6)	29.6(4.0)	31.3(6.3)	30.6(5.7)
Peak torque (BWR%)					
Plan	155.4(27.5)	178.2(30.5)	142.6(22.1)	159.8(23.1)	151.3(27.8)
Dors	51.1(10.1)	46.0(9.6)	50.9(6.4)	51.1(12.3)	52.6(10.2)
Peak torque ratio (Dors:Plan%)	33.9(9.3)	25.8(4.2)	36.6(8.8)	32.4(8.7)	36.0(9.7)

Values are mean(s.e.). Plan, plantar-flexion; Dors, dorsiflexion; BWR, body weight ratio

Analysis of variance indicated that gymnasts had significantly higher peak torque ratio and work ratio compared with cyclists for the nondominant side at both speeds (*Tables* 6 and 7, *Figures* 1, 2 and 3). For the nondominant side dorsiflexors, compared with cyclists, soccer players and gymnasts had higher results for peak torque at the low speed (*Table* 6), TAE, AP and ER at high speed (*Table* 7). Only the difference in peak torque at the low speed and the soccer team compared with others were statistically significant. The endurance ratio of the controls was significantly lower than that of gymnasts and soccer players for both dorsiflexors and plantar-flexors (*Table* 7).

Other measures were not significantly different among different groups, but there was a pattern of orders. For the ankle plantar-flexion peak torque, TAE, TW and AP measures, the cyclists tended to have the highest measurements with the gymnasts lowest. This relationship was reversed in dorsiflexion movement.

Table 4. Nondominant side ankle plantar-flexion and dorsiflexion result, measured at high speed (180° s^{-1}) with Cybex dynamometer

	Sport				
	Overall (n = *48*)	*Cycling* (n = *6*)	*Gymnastics* (n = *7*)	*Soccer* (n = *10*)	*Nonathletic* (*n* = 25)
Peak torque (Nm)					
Plan	42.1(9.8)	46.7(10.3)	39.7(7.0)	42.9(11.0)	41.2(10.1)
Dors	15.7(3.5)	13.3(3.5)	17.0(2.2)	17.3(3.9)	15.1(3.3)
Peak torque (BWR%)					
Plan	69.6(13.3)	73.7(12.7)	68.1(13.3)	69.2(16.0)	69.1(12.9)
Dors	26.8(5.9)	21.8(4.8)	30.1(5.0)	28.5(6.1)	26.4(5.7)
Peak torque ratio (Dors:Plan%)	39.1(7.9)	29.3(3.6)	44.3(2.6)	42.6(9.9)	38.5(6.5)
TAE (Joules)					
Plan	9.5(1.9)	10.2(2.3)	9.9(1.4)	9.7(1.6)	9.0(2.1)
Dors	4.1(1.1)	3.8(1.2)	5.1(0.6)	4.6(1.1)	3.7(1.0)
Total work (Joules)					
Plan	438.8(157.2)	493.3(153.5)	411.6(163.6)	481.2(174.8)	413.4(151.0)
Dors	174.8(71.4)	131.2(59.2)	222.9(49.3)	208.1(69.9)	156.2(69.7)
Endurance ratio (%)					
Plan	41.8(13.9)	43.8(13.1)	47.0(7.8)	53.0(9.3)	37.0(11.8)
Dors	40.0(15.9)	33.3(18.8)	55.4(9.3)	47.9(14.5)	33.3(12.8)
Average power (watts)					
Plan	53.7(18.2)	62.0(18.6)	52.1(16.3)	60.6(18.5)	48.7(17.9)
Dors	21.1(8.8)	16.0(7.0)	28.1(4.2)	26.4(9.4)	17.9(7.7)
Works ratio (Dors:Plan%)	41.9(15.0)	26.2(7.0)	57.3(9.9)	47.3(16.5)	38.8(12.2)

Values are mean(s.e.). Plan, plantar-flexion; Dors, dorsiflexion; TAE, torque acceleration energy; BWR, body weight ratio

Table 5. Dominant side ankle plantar-flexion and dorsiflexion result, measured at high speed (180° s^{-1}) with Cybex dynamometer

	Sport				
	Overall (n = *48*)	*Cycling* (n = *6*)	*Gymnastics* (n = *7*)	*Soccer* (n = *10*)	*Nonathletic* (*n* = 25)
Peak torque (Nm)					
Plan	41.8(10.9)	49.7(12.3)	36.7(7.8)	43.9(13.5)	40.3(9.4)
Dors	15.9(4.6)	15.0(5.0)	16.6(2.7)	15.7(6.3)	16.0(4.4)
Peak torque (BWR%)					
Plan	69.3(15.6)	79.0(18.0)	63.3(13.6)	70.2(18.8)	68.2(13.8)
Dors	27.2(7.4)	24.5(7.6)	29.0(2.6)	26.0(9.7)	27.9(7.4)
Peak torque ratio (Dors:Plan%)	39.9(11.0)	30.3(6.7)	47.7(10.5)	36.3(10.3)	41.6(10.6)
TAE (Joules)					
Plan	9.6(2.1)	11.0(2.3)	9.2(1.5)	9.8(2.3)	9.2(2.1)
Dors	4.3(1.2)	4.2(1.3)	4.6(0.6)	4.5(1.7)	4.1(1.1)
Total work (Joules)					
Plan	446.1(164.4)	536.2(158.9)	414.7(107.9)	520.5(204.5)	397.7(147.0)
Dors	179.4(83.1)	161.3(83.5)	209.7(39.3)	197.4(103.8)	166.5(83.8)
Endurance ratio (%)					
Plan	45.4(12.1)	42.7(12.2)	54.6(8.3)	53.1(11.3)	39.6(10.1)
Dors	39.8(16.8)	34.7(21.5)	55.4(7.5)	43.8(19.6)	34.5(13.3)
Average power (watts)					
Plan	55.1(18.9)	67.2(19.3)	53.6(12.9)	64.8(23.3)	48.0(15.3)
Dors	21.9(10.1)	19.8(10.5)	26.6(4.4)	24.6(12.9)	19.8(9.6)
Works ratio (Dors:Plan%)	41.0(16.2)	28.3(10.5)	52.4(11.6)	37.3(17.1)	42.5(15.7)

Values are mean(s.e.). Plan, plantar-flexion; Dors, dorsiflexion; TAE, torque acceleration energy; BWR, body weight ratio

Table 6. Comparison of ankle flexors low speed test results among different sports

	Nondominant side	*Dominant side*
Peak torque (Nm)		
Plan	n.s.	n.s.
Dors	*SOC > CYC	n.s.
Peak torque (BWR%)		
Plan	n.s.	n.s.
Dors	*SOC, NON > CYC	n.s.
Peak torque ratio (Dors: Plan %)	*GYM, NON > CYC	n.s

Plan, plantar-flexion; Dors, dorsiflexion; BWR, ? ? ? ; n.s., no significant difference ($P > 0.05$); *significant difference ($P < 0.05$); >, significance higher than analysis of variance; NON, nonathletic; CYC, cycling; SOC, soccer; GYM, gymnastics

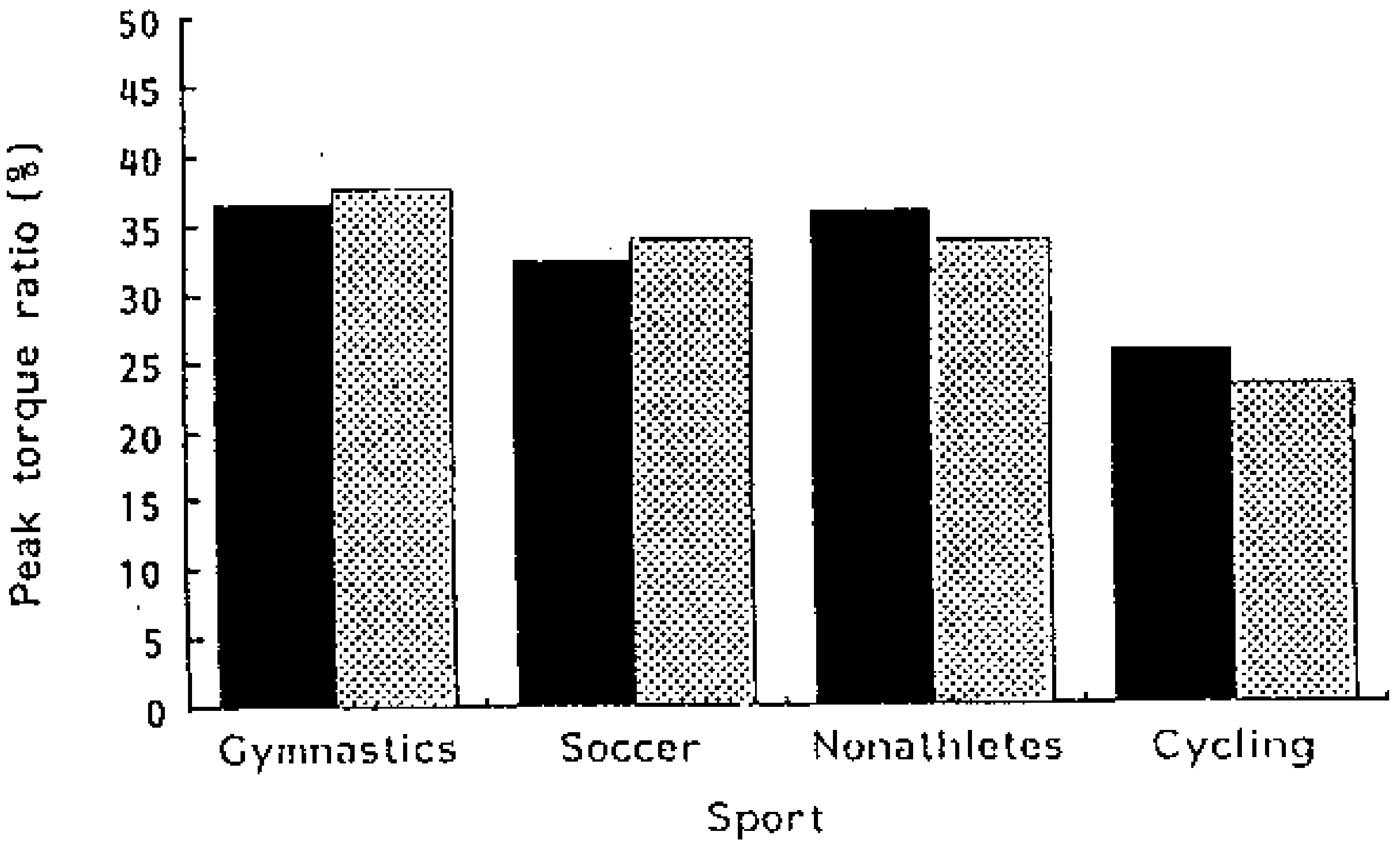

Figure 1. Ankle dorsiflexion: plantar-flexion peak torque ratio at 60°s^{-1}; ■, dominant side; ▨, nondominant side

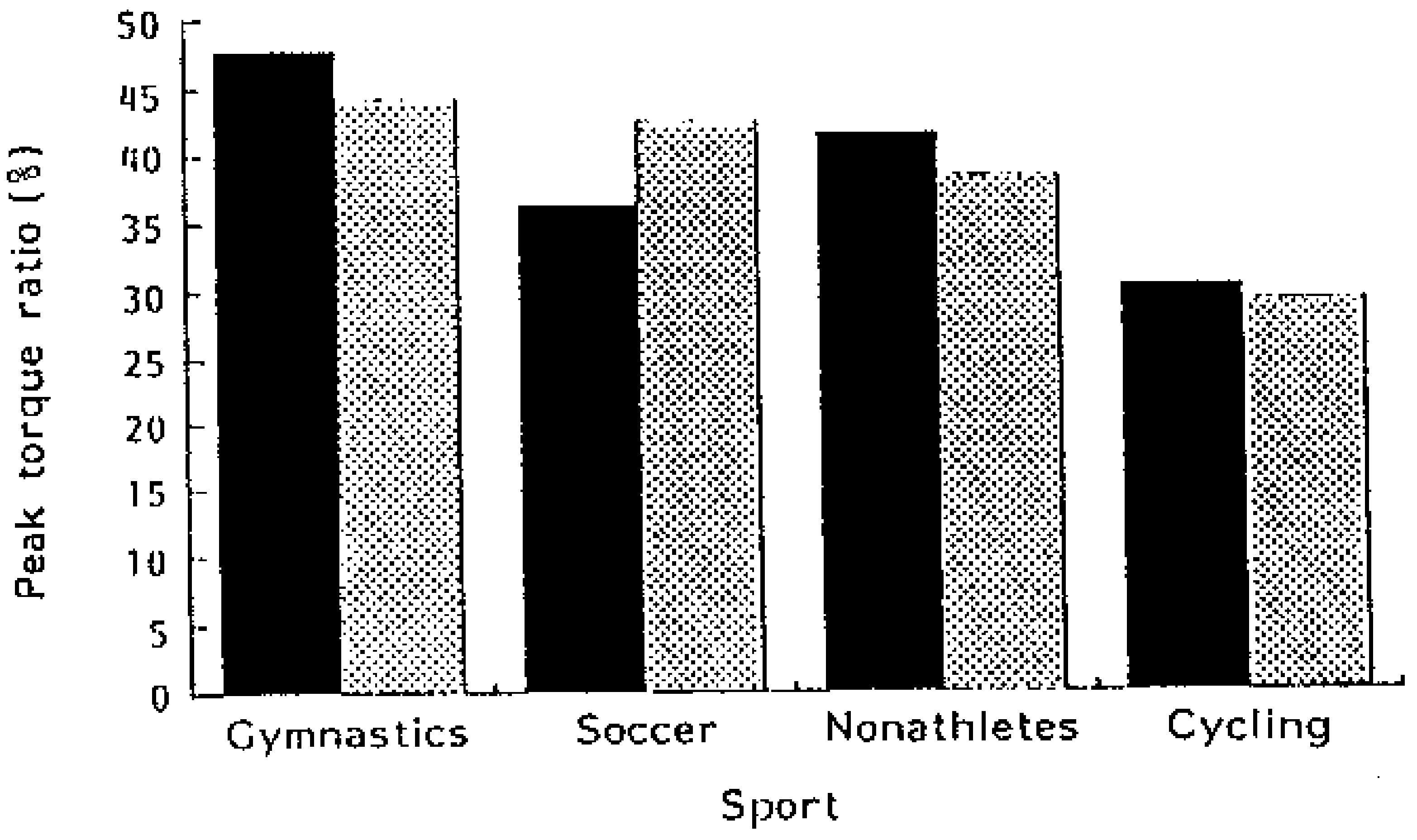

Figure 2. Ankle dorsiflexion: plantar-flexion peak torque ratio at 180°s^{-1}; ■, dominant side; ▨, nondominant side

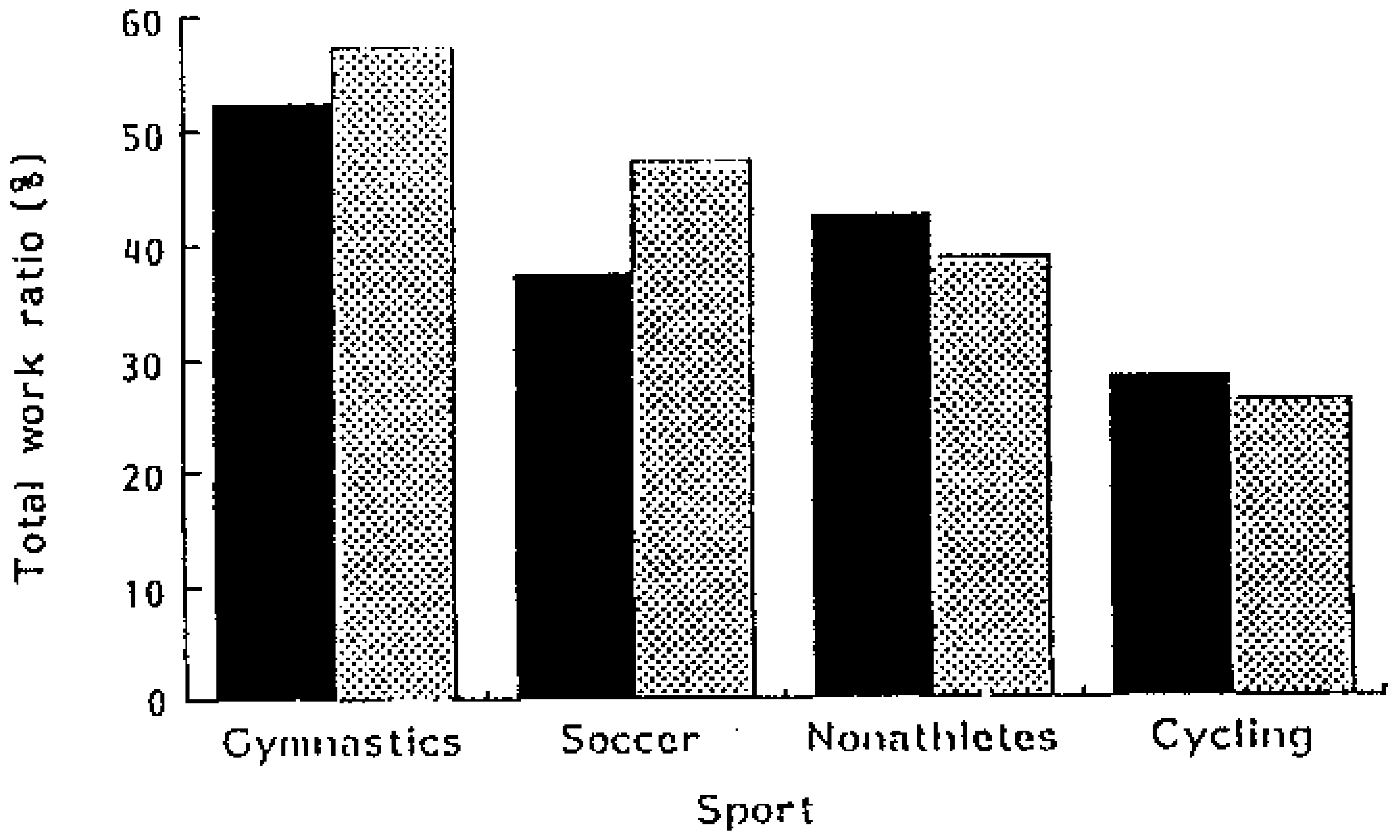

Figure 3. Ankle dorsiflexion: plantar-flexion total work ratio at 180°s^{-1}; ■, dominant side; ▨, nondominant side

Table 7. Comparison of ankle flexors high speed test results among different sports

	Nondominant side	*Dominant side*
Peak torque (Nm)		
Plan	n.s.	n.s.
Dors	n.s.	n.s.
Peak torque (BWR %)		
Plan	n.s.	n.s.
Dors	n.s.	n.s.
Peak torque ratio (Dors: Plan %)	*GYM,SOC,NON > CYC	*GYM > CYC
TAE (Joules)		
Plan	n.s.	n.s.
Dors	*GYM > NON	n.s.
Total work (Joules)		
Plan	n.s.	n.s.
Dors	n.s.	n.s.
Endurance ratio (%)		
Plan	*SOC > NON	*GYM,SOC > NON
Dors	*GYM > CYC,NON	*GYM > NON
Average power (watts)		
Plan	n.s.	n.s.
Dors	*GYM,SOC > NON	n.s
Work ratio (Dors: Plan %)	*GYM,SOC > CYC GYM > NON	n.s.

Plan, plantar-flexion; Dors, dorsiflexion; BWR, body weight ratio; TAE, torque acceleration energy; n.s., no significant difference ($P > 0.05$); *significant difference ($P < 0.05$); >, significance higher than analysis of variance; NON, nonathletic; CYC, cycling; SOC, soccer; GYM, gymnastics

Discussion

In isokinetic evaluation of pitchers at low and high speeds, Tippet[7] found a significant bilateral difference in the strength of dorsiflexors, which he suggested was as a result of the pitching mechanism. As significant bilateral differences could only be found among the three sports groups but not in the nonathletic adults group in the current study, such sports specific bilateral differences might reflect specific requirements of a particular sport, e.g. gymnasts had significantly higher plantar flexion on the nondominant side and they use the nondominant side to initiate jumping.

It is well established that isokinetic muscular characteristics of each sporting event would reflect the specific characteristics and requirements of that particular sporting event[8–13]. Consequently, it is reasonable to hypothesize that specific muscular characteristics could be developed in ankle plantar-flexors and dorsiflexors. This is supported by Fugal-Meyer[14], who found that isokinetic ankle plantar-flexion peak torque in young athletes, whose specialization demanded plantar-flexion strength, was significantly higher than in sedentary and untrained subjects. Fugal-Meyer[15] also noted that isokinetic plantar flexion torque was independent of age within ages 20–49 years, although it declines as a function of age after 49 years. On the other hand, Falkel[16] stated that weight was a significant determinant of plantar-flexion strength. In the present study the weights of the four groups were not significantly different and except for gymnasts who tended to be younger, the age range for all other subjects was 20–48 years. The literature provides no guidance as to whether an age of less than 20 years would be an important factor for plantar-flexion performance. In addition, analysis of covariance suggests that age had no effect on the isokinetic performance among the controls. Age has thus probably not confounded our results. In this project, the only measure for which nonathletic young men were significantly lower than the élite athletes was endurance ratio. This suggests that intensive training in the three sports tested improves ankle muscle endurance significantly.

The small sample size may account for the lack of statistical significance of the observed differences among groups. As the pattern of orders was identical for both dominant and nondominant ankles, and consistent for different parameters in the same muscle group, this trend could serve as an indicator of certain muscular characteristics of athletes in these sports, either inherent or arising through training.

The plantar flexors of cyclists had the highest peak torque, TAE, TW and AP. Stronger plantar flexors would facilitate stepping forward of the foot pedal. In comparison with the cyclists, the gymnasts and soccer players had better development of dorsiflexors in proportion to plantar flexors in peak torque, TAE, TW and AP measures. It has been stated that the antagonistic muscles during a given motion (e.g. hamstrings during knee extension) play a major role in preserving joint stability[17, 18]. Morris[19] noted that the hamstring: quadriceps ratio may be specific to the demands put on the athlete by the sports in which he/she engages. As the soccer athletes and gymnasts scored similarly to the controls but significantly higher than the cyclists in dorsiflexion:plantar-flexion peak torque ratio, a specific range of dorsiflexion:plantar-flexion ratio (peak torque ratio ($60° s^{-1}$) of 30–40%) is important for running and jumping. The higher peak torque ratio and work ratio might improve the stability of the ankle in jumping, landing and running. It has been stated that strength imbalance exceeding 20 lbs between dorsiflexors and plantar-flexors appears characteristic of people with shin splints[20]. Therefore, balanced development of the plantar-flexors and dorsiflexors is important for the athletes in sports involving mostly running and jumping, while cyclists might not find such need. Nowadays, the prescribed foot and ankle exercises are prevalently limited to various types of 'heel raise'. These plantar-flexion exercises stress the often overdeveloped posterior muscles of the calf (plantar-flexors), increasing muscular imbalance. The ideal conditioning programme would prescribe exercises that produce a balance of muscular strength[21].

As stated above, particular sports induce athletes to develop specific muscular characteristics, but such muscular characteristics may expose them to a higher risk of injury. Therefore, it is important for them to maintain a specified range of agonist and antagonist muscle strength ratio for their protection. More studies must be done to identify the optimal range of agonist and antagonist muscle strength ratios specific to each sport, for injury prevention and to enhance sport performance.

In conclusion, normative isokinetic values from the movement of ankle plantar-flexion and dorsiflexion are presented. Analysis of isokinetic muscular performance of athletes in different sports and untrained subjects has led us to suggest that for:

1. bilateral difference: specific sport's requirement may develop specific bilateral difference;
2. muscular endurance: intensive training can improve an athlete's ankle muscular endurance;
3. plantar-flexion and dorsiflexion peak torque ratio and work ratio: sports that involve more jumping and running (e.g. gymnastics and soccer) require better agonist and antagonist muscle balance (higher plantar flexion to dorsiflexion torque ratio and work ratio) to stabilize the ankle. Sportsmen in such sports should be prescribed exercises that would achieve muscle balance, to counter any antagonistic imbalance that they may be prone to develop as a result of training in these sports.

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References

1 Balduini FC, Vegso JJ, Torg JS, Torg E. Management and rehabilitation of ligamentous injuries to the ankle. *Sports Med* 1987; 4: 364–480.

2 Cetti R. Conservative treatment of injury to the fibular ligaments of the ankle. *Br J Sports Med* 1982; 16: 47–52.

3 Cetti R, Christenssen SE, Corfitzen MT. Ruptured fibular ankle ligaments: plaster or pliton brace? *Br J Sports Med* 1984; **18**: 104–9.

4 Copper D, Fair J. Ankle rehabilitation using the ankle disk. *Phys Sportsmed* 1978; June: 141.

5 Cote DJ, Prentice WE, Hooker DN, Shields EW. Comparison of three treatment procedures for minimizing ankle sprain swelling. *Phys Ther* 1988; **68**: 1072–6.

6 Cybex, Division of Lumex, *Isolated Joint Testing and Exercise: A Handbook for Using Cybex II and UBXT*, Bay Shore, New York, USA: Cybex, 1980.

7 Tippett SR. Lower extremity strength and active range of motion in college baseball pitchers: a comparison between stance leg and kick leg. *Journal of Orthopaedic and Sports Physical Therapy* 1986; **8**: 10–4.

8 Cisar CJ, Johnson GO, Fry AC, Housh TJ, Hughes AJ, Ryan AJ, Thorland WG. Preseason body composition, build, as predictors of high school wrestling success. *Journal of Applied Sport Science Research* 1987; **1**: 66–70.

9 Gerard ES, Caizzo VJ, Rubin BD, Prietto CA, Davidson DM. Skeletal muscle profile among elite long, middle, and short distance swimmers. *Am J Sports Med* 1986; **14**: 77–82.

10 Imwold CH, Rider RA, Haymes EM, Green KD. Isokinetic torque differences between college female varsity basketball and track athletes. *J Sports Med Phys Fitness* 1983; **23**: 67–73.

11 Johansson C, Lorentzon R, Fugl-Meyer AR. Isokinetic muscular performance of the quadriceps in elite ice hockey players. *Am J Sports Med* 1989; **17**: 30–4.

12 Li G, Chen X, Chiang W. Isokinetic assessment of the quadriceps and hamstring of the elite Chinese athlete. *Annual Scientific Report*. Beijing, China: The National Research Institute of Sports Science of China, 1986.

13 Thorland WG, Johnson GO, Cisar CJ, Housh TJ, Tharp GD. Strength and anaerobic responses of elite young female sprint and distance runners. *Med Sci Sports Exerc* 1987; **19**: 56–61.

14 Fugl-Meyer AR. Maximum isokinetic ankle plantar and dorsal flexion torques in trained subjects. *Eur J Appl Physiol* 1981; **47**: 393–404.

15 Fugl-Meyer AR, Gustafsson L, Burstedt Y. Isokinetic and static plantor flexion characteristics. *Eur J Appl Physiol* 1980; **45**: 221–34.

16 Falkel J. Plantar flexor strength testing using the Cybex isokinetic dynamometer. *Phys Ther* 1978; **58**: 847–50.

17 Hagood S, Solomonow M, Baratta R, Zhou BH, D'Ambrosia R. The effect of joint velocity on the contribution of the antagonist musculature to knee stiffness and laxity. *Am J Sports Med* 1990; **18**: 182–7.

18 Poulmedis D. Isokinetic maximal torque power of Greek elite soccer players. *Journal of Orthopaedic and Sports Physical Therapy* 1985; **6**: 293–5.

19 Morris A, Lussier L, Bell G, Dooley J. Hamstring/Quadriceps strength ratios in collegiate middle-distance and distance runners. *Phys Sportsmed* 1983; **11**: 71–7.

20 Gleim GW, Nicholas JA, Webb JN. Isokinetic evaluation following leg injuries. *Phys Sportsmed* 1978; **6**: 74–82.

21 Blievernicht J. Training the foot and ankle for optimum performance and prevention of injuries. *National Strength and Conditioning Association Journal* 1986; **8**: 32–4.

22 Lentell GL, Katzman LL, Walters MR. The relationship between muscle function and ankle stability. *Journal of Orthopaedic and Sports Physical Therapy* 1990; **11**: 605–11.

23 Malone TR, Hardaker WT. Rehabilitation of foot and ankle injuries in ballet dancers. *Journal of Orthopaedic and Sports Physical Therapy* 1990; **11**: 355–61.

24 Oberg B, Bergman T, Tropp H. Testing of isokinetic muscle strength in the ankle. *Med Sci Sports Exerc* 1987; **19**: 318–22.

25 SPSS PC + V 3.0. *Statistical Package for the Social Sciences*. Chicago, Illinois, USA: SPSS, 1989.

26 Weldon G, Snouse SL, Shultz S. Normative strength values for knee, shoulder, elbow and ankle for females ages 9–73 as determined by isokinetic testing. *Athletic Training* 1988; **23**: 325–31.

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Mathematical modeling on the isokinetic muscle characteristics of elite athletes among different sports

Chin Ming-kai 1993

- **Bilateral isokinetic parameters variables of the shoulder: a prediction model for young men**

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BILATERAL ISOKINETIC PARAMETERS OF THE SHOULDER - A PREDICTION FOR COMPARATIVE STUDY

Raymond C.H. So MPhil[1], T.O. Siu Dr Sc[2], Ming-Kai Chin PhD[1], K.M. Chan MBBS FRCS(E) FRCS(G) M.Ch(ORTH) FRCS Ed(ORTH)[3]

1. Sports Science Department, Hong Kong Sports Institute
2. Statistical Consultation Services, City Polytechnic of Hong Kong
3. Department of Orthopaedics & Traumatology, The Chinese University of Hong Kong

Clinicians frequently assumed the strength of the uninjured shoulder were equal to the preinjury strength of the injured shoulder muscles. The purpose of this study was to delineate the differences in bilateral isokinetic peak torque (PT) at 60 deg/sec and 240 deg/sec, and torque acceleration energy (TAE), average power (AP) and total work (TW) at 240 deg/sec during shoulder extension and flexion movements and to develop a method to determine the expected maximal isokinetic parameters of the dominant shoulder based upon isokinetic measurement from the non-dominant shoulder. Shoulder isokinetic measurements were obtained from 30 normal young male adults and national male athletes from the sports of badminton (n=11) and swimming (n=5). Results indicated that there were a significant ($p<0.05$) correlation between the bilateral measurements in both tested movements in normal young adult group only. Moreover, the tested measures in the two movement tests revealed significant ($p<0.05$) bilateral differences in normal young adult group while part of the tested measures showed such bilateral differences in elite athletic groups. These show that it is inappropriate to use the uninjured extremity to predict the pre-injured strength of the injured side directly. In this investigation, equations were developed (linear regression method) to predict normative isokinetic parameters values for the dominant shoulder based on measurements from the non-dominant shoulder for normal young male adults only.

INTRODUCTION

Clinicians traditional predict pre-injury strength of an injured extremity directly using performance measures of the corresponding un-injured extremity as a baseline. That is, the prescription of therapeutic exercises for rehabilitation of injuries is directly based on bilateral correspondence. However the scientific assumption of this practice needs further clarification. For example, considered the shoulders. Perrin et al[13] found that for shoulder extension (tested at 60 and 180 deg/sec), peak torque values were greater for the right than left side ($p<0.05$) for non-athletes. Supposedly, this demonstrates that neuromotor dominance leads to a difference in peak torque between the right and left sides of the body for upper extremity measures. On the other hand, the same investigator has not been able to find significant bilateral difference in the peak torque of the shoulder flexor. In fact, even the TAE ,TW and AP measures of shoulder extensor and flexor revealed no significant bilateral difference.

Further confusion in the literature abounds. Otis[11] demonstrated that shoulder flexion torque bilateral differences exist during isometric contractions at 0 deg and 90 deg, with the dominant shoulder producing greater torque than the non-dominant side. On the other hand, Connelly Maddux[4] found no significant difference in the isokinetic peak torque produced by an individual's dominant and non-dominant shoulder musculature, although the TAE measure did suggest bilateral differences. Ivey et al[9] reported no significant difference between dominant and non-dominant peak isokinetic torque at 60 and 180 deg/sec. Hinton et al[7] stated that the pitching shoulder internal rotators produced significantly higher isokinetic peak torque values, peak torque to body weight ratio measured at 60 and 180 deg/sec, and total work values measured at 240 deg/sec. Brown et al[2] found that significant greater isokinetic torque produced by the dominant arm in comparison with the non-dominant arm for both pitchers and position players at all testing speeds (180, 240 and 300 deg/sec) in the movement of shoulder internal and external rotation.

The objectives of this study were to i) examine the differences in bilateral isokinetic muscular characteristics during shoulder extension and flexion, and ii) to suggest a simple statistical model for determining the expected maximal isokinetic measures of the dominant (often the injured side) shoulder from non-dominant shoulder measures for both normal young adults and elite athletes from the sports of badminton and swimming.

The muscular isokinetic characteristics investigated included :

I) peak torque (PT), a measure of muscle strength, the single highest torque output of the joint produced by muscular contraction as the limb moves through the range of motion. (unit : Nm)

II) total work (TW), is derived by multiplying torque times distance of the total area under the torque curves over a preselected number of repetitions. It is a measure of muscle absolute endurance. Total work analysis measures muscle function in every repetition at all points in the range of motion, while peak torque analysis only reports muscle function at one point. (unit : watts)

III) average power (AP), the total work of the given contractions divided by the time taken to complete the motion. (unit : watts)

IV) peak torque acceleration energy (TAE), a measure of the peak power (explosive power) of the muscle involved, the greatest amount of work done in the first one-eighth of a second of a single torque production in the test repetitions. It is an indication of the rate at which motor unit fiber recruitment take place. (unit : joules)

MATERIALS AND METHODS

The normal subjects were 30 normal, healthy males convenience school sample. Elite athletes of Hong Kong from the sports of badminton (n= 11) and swimming (n= 5). They all were the national team members of these sports of Hong Kong. Dominant side was identified as a side used for handwriting and hold the racket. None of the subjects had shoulder pain or injury at the time of study. Subjects gave their written consent to participate.

Bilateral isokinetic measures were measured with a Cybex II+ isokinetic dynamometer (Cybex, Ronkokoma, NY) equipped with an upper body exercise and testing table (UBXT). The Cybex II+ dual channel recorder and dynamometer were interfaced with the Cybex Data Reduction Computer (CDRC) for analysis of tests results. Each subject underwent isokinetic testing for the right and left shoulder extensor and flexor muscle groups. Subjects were stabilized with straps during testing, and the joint's axis of rotation was aligned with the input shaft of the dynamometer. To provide gravity correction during shoulder testing, the gravitational movement of the Cybex arm, shank and the arm were determined by the CDRC. A damp setting of three was used throughout the testing. The dynamometer was calibrated at the beginning of each testing session. Shoulder extension and flexion tests were assessed with subjects in the supine position.

After setting the apparatus for the appropriate joint, according to the Cybex isolated joint testing manual, the subject underwent a warm-up session at 60 deg/sec. Warm up consisted of three submaximal and two maximal contractions, followed by a 30 sec rest period prior testing. Testing at 60 deg/sec included 5 maximal repetitions, and testing at 240 deg/sec included 25 maximal repetitions. One minute rest was allowed between tests at 60 deg/sec and 240 deg/sec, and a 10 minute rest period was allowed prior testing for the contralateral side testing. In all cases, the low speed and non-dominant side was tested first.

PT measures were obtained at both testing speeds. TAE, AP and TW measures were obtained during the 25 repetitions work test at the high speed of contractions. All isokinetic measures were obtained during one test session in a laboratory control environment.

Student's paired-t statistics were used to test all the isokinetic measures for bilateral differences with a level of significance set at two-tailed $P<0.05$. Correlation was used to determine the linear relationship between dominant and non-dominant results for the same measure with a level of significance set at one-tailed $P<0.05$. Moreover, correlation was also used to determine the linear relationship between all measures produced in each movement tests. Prediction models were developed by using stepwise multiple regression method for the group which showed significant bilateral differences in all tested measures in both test movements (i.e. shoulder extension and shoulder flexion) and together with significant bilateral correlation. SPSS was used to perform all the required calculations.

RESULTS

The height, weight and age of subjects were summarized in Table 1. Tables 2, 3, 4, 5, 6 and 7 list the means, standard errors, paired t-test result and correlation coefficients of the isokinetic measures for the dominant and non-dominant sides of normal adults, badminton players and swimmers respectively. In comparison of the three tested groups, normal young adult group scored the lowest isokinetic results. Only for the normal young adult group, dominant and non-dominant sides isokinetic results were statistically significant different for all measures of shoulder extension and flexion, and statistically significant correlation were found for all measures in the two movement tests also. But such picture was not found in badminton team and swimming team. Only in the shoulder flexion movement of swimming team had all the tested parameters with significant bilateral difference and together with significant bilateral correlation. Therefore, mathematical models for determining the expected maximal isokinetic measures of the dominant shoulder from non-dominant shoulder measures were developing only for the normal young adult group.

Tables 8 and 9 list the correlation coefficient among various measures for the isokinetic movements of the dominant shoulder. Tables 10 and 11 list the corresponding coefficients for the non-dominant shoulder. High correlation generally were everywhere. Therefore, two measures from non-dominant shoulder with the least correlation coefficient were chosen to do the multiple regression test to build up the model for predicting the performance of the dominant shoulder in each of movement test. Consequently, TAE and TW measures were chosen for the shoulder extension movement test and peak torque at 60 deg/sec and AP measures were chosen for the shoulder flexion test.

Tables 12 and 13 list the R square (stepwise multiple regression) values for each of the measures of the two dominant shoulder movement tests. The measure with the highest R square value was selected as the representative model for particular movement test.

Two different models (Table 14) were developed by using stepwise multiple regression to calculate the dominant shoulder average power measure in the shoulder extension test and total work measure in the shoulder flexion test. Non-dominant side total work measure was the sole factor in the model of predicting the dominant side peak torque measure in shoulder extension test. In addition to average power measure, peak torque at 60 deg/sec were the factors involving in the model for shoulder flexion test.

The R SQUARE (coefficient of determination calculated from linear regression method) indicate how well the equation fits the population. The average R square value for the two models was 0.863 which indicated that the equations are good to fit the population.

For example, of a 20 years old man who just starting a rehabilitation program of a deficit of the dominant shoulder. He can firstly do a Cybex muscular test on both shoulders with the movement of shoulder extension and flexion according to the standard protocol. The testing results of the uninvolved shoulder (non-dominant side) can be used to calculate the prediction average power of the involve shoulder (dominant side) in shoulder extension movement test by using the listed models (Table 14). If the total work measure on shoulder extension movement was 1100 joules for the non-dominant side and 40 watts for the dominant side average power measure, the calculation can as follows :

Predicted average power of the dominant shoulder in extension movement :

0.067*(1100) +15.27 = 88.97

Through the calculation, the clinicians can get the prediction value for all the two movement tests. The involve side result can compare with the prediction value. If the dominant shoulder result fell too off from the prediction value, it is reasonable to conclude that the affected side exhibiting muscular weakness.

DISCUSSION

The findings of this study to a certain extent confirmed the conclusion made by Perrin[13], he questioned the efficacy of assuming of bilateral equivalence for peak torque, torque acceleration energy, average power and total work measures in the prescription of therapeutic exercise for all muscle groups in all athletic and non-athletic populations. All the tested measures in the two movement tests revealed significant bilateral differences in normal adult group while part of the tested measures showed such bilateral differences in elite athletic groups. These seem that it is inappropriate to use the uninjured shoulder to predict the pre-injured strength of the injured side directly.

The differences in the tested results and bilateral relationship within the three tested groups might be due to the training effect and muscles involvement in specific sporting movement[2,3,10]. For example, the upper body musculature utilized in badminton is predominantly one-sided, therefore their dominant side, especially the shoulder extensors, had a significantly higher strength, endurance capabilities and explosive power. On the other hand, the stress on swimmers' both sides shoulder extensors might be about the same, and therefore result with no significant bilateral differences for all measures in the movement.

The models developed in this investigation for the normal young adults can be used to predict the pre-injury muscular characteristics of the injured shoulder. Moreover, through the calculation and comparison, the deficit muscle groups (shoulder extensor or flexor) can be identified. For example, if the dominant shoulder extensor average power measure fell too off from the prediction value, strength rehabilitation program for the involve shoulder extensor must be involved in the rehabilitation program.

These equations will provide the clinicians with subjective information about the situation of the involve shoulder muscle. In addition, the Cybex testing is a good method to evaluate the progress of the rehabilitation program. Clearly, an improvement to the predicted mean or greater for the involved shoulder would reflect a desirable outcome. Rehabilitation should continue until maximal recovery is achieved and the prediction value should be used to provide a reference for assessing the status of the affected shoulder at any given time.

Normative values of PT, TAE, AP, and TW from the testing of shoulder extension and flexion for the three groups were presented. The shoulder extension peak torque for both dominant and non-dominant sides of the normal young adult group were comparatively lower than the results reported by Perrin[13] (dominant side : 86 Nm and non-dominant side : 82 Nm).

The inconsistent on the theme of upper extremity bilateral difference and muscle strength might be due to the difference in population being tested. The models presented in this study may not applicable to other races males, older males, elite athletes and females. More study should be done on these population in order to determine the bilateral relationship for different specific population.

CONCLUSION

Normative isokinetic values for normal young Chinese adults, elite swimmers and badminton players from the movement of shoulder extension and flexion were presented. In the movement of shoulder extension and flexion, all the dominant side results were significantly higher than the non-dominant side only occur in the normal young adult group. Therefore, models were developed to predict normative isokinetic parameters values for the dominant shoulder based on the measurements from the non-dominant shoulder only for the normal young adults also.

Table 1. Mean (standard error) height , weight and age of subjects .

SPORT	AGE (yrs)	Ht (cm)	Wt (kg)
BADMINTON (n = 11)	21.0 (3.3)	173.7 (5.2)	63.6 (6.8)
SWIMMING (n = 5)	18.8 (3.9)	177.4 (5.8)	72.0 (9.7)
NORMAL (n = 30)	21.0 (2.3)	167.9 (4.4)	59.1 (7.3)

Table 2. Mean and standard error for isokinetic measures for 30 subjects, paired t-test value and correlation coefficients, both with significant levels for the bilateral analysis.

SHOULDER EXTENSION

Testing speed (deg/sec)	Measures	Dominant		Non-Dominant					
		X	SE	X	SE	t-value	p	Corr. Coef.	p
60	Peak Torque (Nm)	66.7	12.9	60.1	13.9	-4.73	S	0.838	S
240	Peak Torque (Nm)	44.5	10.2	37.5	10.9	-6.17	S	0.827	S
240	TAE (Joules)	18.22	4.07	15.68	4.08	-4.58	S	0.723	S
240	TW (Joules)	1265.9	391.2	1037.3	351.2	-5.59	S	0.823	S
240	AP (Watts)	84.3	27.8	70.1	25.4	-5.58	S	0.867	S

NS : no statistically significance ($p>0.05$)
S : statistically significance ($p<0.05$)

Table 3. Mean and standard error for isokinetic measures for 30 subjects, paired t-test value and correlation coefficients, both with significant levels for the bilateral analysis.

SHOULDER FLEXION

Testing speed (deg/sec)	Measures	Dominant		Non-Dominant		t-value	p	Corr. Coef.	p
		X	SE	X	SE				
60	Peak Torque (Nm)	47.5	7.9	45.0	7.8	-3.30	S	0.864	S
240	Peak Torque (Nm)	33.2	7.3	30.2	7.0	-4.37	S	0.860	S
240	TAE (Joules)	15.76	3.50	14.78	3.58	-3.50	S	0.875	S
240	TW (Joules)	1127.9	302.3	1011.2	304.4	-3.80	S	0.847	S
240	AP (Watts)	74.5	21.3	67.8	22.0	-3.30	S	0.868	S

NS : no statistically significance ($p > 0.05$)
S : statistically significance ($p < 0.05$)

Table 4. Mean and standard error for isokinetic measures for 11 badminton players, paired t-test value and correlation coefficients, both with significant levels for the bilateral analysis.

SHOULDER EXTENSION

Testing speed (deg/sec)	Measures	Dominant		Non-Dominant					
		X	SE	X	SE	t-value	p	Corr. Coef.	p
60	Peak Torque (Nm)	97.9	15.0	72.7	18.2	5.24	S	0.553	NS
240	Peak Torque (Nm)	67.9	11.0	50.5	6.1	6.70	S	0.623	S
240	TAE (Joules)	26.65	3.46	20.76	2.37	9.19	S	0.798	S
240	TW (Joules)	2306.9	544.2	1732.5	324.9	3.64	S	0.360	NS
240	AP (Watts)	146.9	31.2	105.9	19.9	5.51	S	0.611	S

NS : no statistically significance ($p>0.05$)
S : statistically significance ($p<0.05$)

Table 5. Mean and standard error for isokinetic measures for 11 badminton playres, paired t-test value and correlation coefficients, both with significant levels for the bilateral analysis.

SHOULDER FLEXION

Testing speed (deg/sec)	Measures	Dominant		Non-Dominant					
		X	SE	X	SE	t-value	p	Corr. Coef.	p
60	Peak Torque (Nm)	63.6	11.2	59.5	10.3	1.60	NS	0.679	S
240	Peak Torque (Nm)	46.5	8.4	42.5	6.4	2.25	S	0.699	S
240	TAE (Joules)	22.19	3.16	20.93	2.82	2.01	NS	0.761	S
240	TW (Joules)	1837.1	321.7	1587.1	294.0	3.68	S	0.735	S
240	AP (Watts)	113.6	19.8	97.9	17.9	3.65	S	0.718	S

NS : no statistically significance ($p>0.05$)
S : statistically significance ($p<0.05$)

Table 6. Mean and standard error for isokinetic measures for 5 swimmers, paired t-test value and correlation coefficients, both with significant levels for the bilateral analysis.

SHOULDER EXTENSION

Testing speed (deg/sec)	Measures	Dominant		Non-Dominant					
		X	SE	X	SE	t-value	p	Corr. Coef.	p
60	Peak Torque (Nm)	106.4	22.1	102.6	18.4	0.67	NS	0.820	NS
240	Peak Torque (Nm)	84.2	20.8	78.2	18.5	1.30	NS	0.869	NS
240	TAE (Joules)	29.77	6.80	27.67	4.58	1.41	NS	0.901	S
240	TW (Joules)	3571.8	1409.2	3266.4	1007.9	1.08	NS	0.916	S
240	AP (Watts)	206.6	66.4	189.0	52.0	1.20	NS	0.874	NS

NS : no statistically significance ($p>0.05$)
S : statistically significance ($p<0.05$)

Table 7. Mean and standard error for isokinetic measures for 5 swimmers, paired t-test value and correlation coefficients, both with significant levels for the bilateral analysis.

SHOULDER FLEXION

Testing speed (deg/sec)	Measures	Dominant		Non-Dominant					
		X	SE	X	SE	t-value	p	Corr. Coef.	p
60	Peak Torque (Nm)	63.6	12.3	58.0	10.5	2.85	S	0.939	S
240	Peak Torque (Nm)	49.4	12.3	42.8	12.2	12.94	S	0.996	S
240	TAE (Joules)	22.79	6.02	20.37	4.97	3.81	S	0.985	S
240	TW (Joules)	2091.6	666.3	1665.2	439.2	2.98	S	0.913	S
240	AP (Watts)	121.8	33.7	96.2	24.6	3.69	S	0.904	S

NS : no statistically significance ($p>0.05$)
S : statistically significance ($p<0.05$)

Table 8. Correlation matrix of isokinetic measures for the dominant shoulder in shoulder extension movement test.

Correlations :	Peak Torque (60 deg/sec)	Peak Torque (240 deg/sec)	TAE (240 deg/sec)	TW (240 deg/sec)	AP (240 deg/sec)
Peak Torque (60 deg/sec)	1.000	0.763	0.819	0.619	0.616
Peak Torque (240 deg/sec)	0.763	1.000	0.888	0.896	0.899
TAE (240 deg/sec)	0.819	0.888	1.000	0.777	0.738
TW (240 deg/sec)	0.619	0.896	0.777	1.000	0.986
AP (240 deg/sec)	0.616	0.899	0.738	0.986	1.000

Table 9. Correlation matrix of isokinetic measures for the dominant shoulder in shoulder flexion movement test.

Correlations :	Peak Torque (60 deg/sec)	Peak Torque (240 deg/sec)	TAE (240 deg/sec)	TW (240 deg/sec)	AP (240 deg/sec)
Peak Torque (60 deg/sec)	1.000	0.824	0.729	0.758	0.744
Peak Torque (240 deg/sec)	0.824	1.000	0.841	0.866	0.873
TAE (240 deg/sec)	0.729	0.841	1.000	0.825	0.808
TW (240 deg/sec)	0.758	0.866	0.825	1.000	0.983
AP (240 deg/sec)	0.744	0.873	0.808	0.983	1.000

Table 10. Correlation matrix of isokinetic measures for the non-dominant shoulder in shoulder extension movement test.

Correlations :	Peak Torque (60 deg/sec)	Peak Torque (240 deg/sec)	TAE (240 deg/sec)	TW (240 deg/sec)	AP. (240 deg/sec)
Peak Torque (60 deg/sec)	1.000	0.888	0.838	0.836	0.838
Peak Torque (240 deg/sec)	0.888	1.000	0.932	0.916	0.927
TAE (240 deg/sec)	0.838	0.932	1.000	0.836	0.851
TW (240 deg/sec)	0.836	0.916	0.836	1.000	0.984
AP (240 deg/sec)	0.838	0.927	0.851	0.984	1.000

Table 11. Correlation matrix of isokinetic measures for the non-dominant shoulder in shoulder flexion movement test.

Correlations :	Peak Torque (60 deg/sec)	Peak Torque (240 deg/sec)	TAE (240 deg/sec)	TW (240 deg/sec)	AP (240 deg/sec)
Peak Torque (60 deg/sec)	1.000	0.771	0.775	0.683	0.667
Peak Torque (240 deg/sec)	0.771	1.000	0.940	0.876	0.883
TAE (240 deg/sec)	0.775	0.940	1.000	0.872	0.881
TW (240 deg/sec)	0.683	0.876	0.872	1.000	0.978
AP (240 deg/sec)	0.667	0.883	0.881	0.978	1.000

Table 12. R square resluts (stepwise multiple regression) of each of the measure of dominant shoulder in shoulder extension movement test.

Dependent variables (dominant shoulder)	Independent variables (non-dominant shoulder)	R square	Variables in the equation
Peak Torque (60 deg/sec)	TAE, TW	0.7885	TAE
Peak Torque (240 deg/sec)	TAE, TW	0.8052	TAE
TAE (240 deg/sec)	TAE, TW	0.7230	TAE
TW (240 deg/sec)	TAE, TW	0.8229	TW
AP (240 deg/sec)	TAE, TW	0.8413	TW

Table 13. R square resluts (stepwise multiple regression) of each of the measure of dominant shoulder in shoulder flexion movement test.

Dependent variables (dominant shoulder)	Independent variables (non-dominant shoulder)	R square	Variables in the equation
Peak Torque (60 deg/sec)	Peak Torque (60 deg/sec), AP	0.8641	Peak Torque (60 deg/sec)
Peak Torque (240 deg/sec)	Peak Torque (60 deg/sec), AP	0.8599	Peak Torque (60 deg/sec), AP
TAE (240 deg/sec)	Peak Torque (60 deg/sec), AP	0.7565	AP
TW (240 deg/sec)	Peak Torque (60 deg/sec), AP	0.8853	Peak Torque (60 deg/sec), AP
AP (240 deg/sec)	Peak Torque (60 deg/sec), AP	0.8682	Peak Torque (60 deg/sec), AP

Table 14. Statistical models for determining the expected measures of dominant shoulder from non-dominant shoulder measures.

Shoulder Movement	Expected measurs (Dominant shoulder)	Model	R square
EXTENSION	AVERAGE POWER	0.07*(TOTAL WORK)+15.27	0.841
FLEXION	TOTAL WORK	8.80*(AVERAGE POWER)+12.41(PEAK TORQUE AT 60 deg/sec)-27.62	0.885

REFERENCE

1. Alderink, G.J. and Kuck, D.J. Isokinetic shoulder strength of high school and college-aged pitchers J Ortho Spts Phy Ther 1986, **7**, 163-172

2. Brown, L.P., Niehues, S.L., Harrah, A., Yavorsky, P. and Hirshman, H.P. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players Am J Spts Med 1988, **16**, 577-585

3. Cisar C.J., Johnson G.O., Fry A.C., Housh T.J., Hughes R.A., Ryan A.J. and Thorland W.G. Preseason body composition, build, and strength as predictors of high school wrestling success J App Spts Sci Res 1987, **1**, 66-70

4. Connelly Maddux, R.E., Kibler, W.B. and Uhl, T. Isokinetic peak torque and work values for the shoulder J Ortho Spts Phy Ther 1989, **10**, 264-269

5. Cybex, Division of Lumex, Inc, Isolated Joint Testing and Exercise : A Handbook for Using Cybex II and UBXT, Bay shore, NY (1980)

6. Day, R.W., Moore, R.J. and Patterson, P. Isokinetic torque production of the shoulder in a functional movement pattern Ath Training 1988, **23**, 333-338

7. Hinton, R.Y. Isokinetic evaluation of shoulder rotational strength in high school baseball pitchers Am J Spts Med 1988, **16**, 274-279

8. Housh, T.J., Johnson, G.O., Hughes, R.A. Housh, D.J., Hughes, A.S., Fry, A.S., Kenney, K.B. and Cisar, C.J. Isokinetic strength and body composition of high school wrestlers across age Med Sci Spts Ex 1989, **2**, 105-109

9. Ivey, F.M. and Calhoun, J.H. Isokinetic testing of shoulder strength : Normal values Arch Phys Med Rehab 1985, **66** ,384-386

10. Johansson C., Lorentzon R. and Fugl-Meyer A.R. Isokinetic muscular performance of the quadriceps in elite ice hockey players Am J Sports Med 1989, **17**, 30-34

11. Otis, J.C., Warren, R.F., Backus, S.I., Santner, T.J. and Mabrey, J.D. Torque production in the shoulder of the normal young adult male Am J Sports Med 1990, **18**, 119-123

12. Pawlowski. D, and Perrin, D.H. Relationship between shoulder and elbow isokinetic peak torque, torque acceleration energy, average power, and total work and throwing velocity in intercollegiate pitchers Ath Training 1989, **24**, 129-131

13. Perrin, D.H., Robertson, R.J. and Ray, R.L. Bilateral isokinetic peak torque, torque acceleration energy, power, and work relationships in athletes and nonathletes J Ortho Spts Phys Ther 1987, **9**, 184-189

14. SPSS PC+ V 3.0, SPSS Inc Chicago Illinois, 1989

15. Weldon, G., Snouse, S.L. and Shultz, S. Normative strength values for knee, shoulder elbow and ankle for females ages 9-73 as determined by isokinetic testing Ath Training 1988, **23**, 325-331

Hong Kong Sports Development Board
Research Program

Mathematical modeling on the isokinetic muscle characteristics of elite athletes among different sports

Cardiorespiratory fitness and isokinetic muscle strength of elite Asian Junior soccer players

Chin Ming-kai

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Cardiorespiratory Fitness and Isokinetic Muscle Strength of Elite Asian Junior Soccer Players

Ming-Kai Chin[1*], Raymond C.H. So[1], Yvonne W.Y. Yuan[2]
Raymond C.T. Li[3] and Alison S.K. Wong[1]

[1]Human Performance Laboratory, Sports Science Department,
Hong Kong Sports Institute, Shatin, Hong Kong
[2]Hong Kong Centre of Sports Medicine and Sports Science,
Chinese University of Hong Kong, Shatin, Hong Kong
[3]Department of Orthopaedics and Traumatology, Chinese
University of Hong Kong, Shatin, Hong Kong

*To whom correspondence should be addressed

Running head: JUNIOR SOCCER

Abstract

There is a scarcity of descriptive data on the physiological characteristics of elite Asian junior soccer players. The purpose of this study was to evaluate the cardiorespiratory fitness and isokinetic muscle strength of elite junior soccer players in Hong Kong. It was conducted in conjunction with the selection of the Hong Kong team to the 1989 Gothia Cup held in Sweden. Twenty-one top junior soccer players were selected as subjects for the study. The following means (±SD) were observed : age 17.3±1.1 years; height 172.5±6.2 cm; weight 62.8±7.0 kg; body fat 5.2±1.8%; forced vital capacity (FVC) 4.6±0.6 L; maximum oxygen uptake (VO_2max) 58.6±2.9 ml kg^{-1} min^{-1}; anaerobic threshold (AT) 76.7±10.2% of VO_2max; peak isokinetic dominant knee extensor and flexor strengths 3.28±0.37 Nm kg^{-1} and 1.84±0.24 Nm kg^{-1}; hamstring to quadriceps peak torque ratio (H/Q) 56±0.6% measured at $60°s^{-1}$. Hong Kong players appeared to have comparable aerobic power, light body weight, poor flexibility and above average isokinetic muscle strength. In view of these findings, it is suggested that improved nutritional intake and flexibility are necessary to furthur enhance force generation and reduce injury rate. Furthermore, training programs to improve the contralateral knee muscle imbalance and to increase the fast speed movement capability of the non-dominant knee flexors are recommended.

Keywords: Soccer, elite junior athletes, body composition, cardiorespiratory fitness, maximal oxygen uptake, anaerobic threshold, isokinetic muscle strength.

Introduction

Despite the large number of soccer players in Asia, research dealing with the performance capacity of elite Asian soccer players is lacking (Chin et al., 1992; Chook et al., 1986; Togari et al., 1979). Most physiological data on elite soccer players originates from Western Europe and North America (Raven et al., 1976; Oberg et al., 1986; Oberg et al., 1984; Rhodes et al., 1986; Ramadan and Byrd, 1987; Mangine et al., 1990; Nowacki et al., 1988; Bunc et al., 1992; Faina et al., 1988). Studies of physiological characteristics of elite junior soccer athletes are very scarce (Leatt et al., 1987; Nowacki et al., 1988; Garganta et al., 1992; Tumility and Smith, 1992; Jones and Helms, 1992). To the best of the authors' knowledge, there has been only one study to describe the biological growth and cardiorespiratory fitness of elite Asian junior soccer players published in Chinese (Liu et al., 1989). Another study in relation to isokinetic muscle strength of elite Japanese junior soccer players was reported in the English scientific literature (Togari et al., 1988).

Soccer is the most popular sport in Hong Kong (HK) and the under-19 (U-19) squad of the national soccer teams won a gold medal in the 15th Gothia Cup held in Göteborg, Sweden in 1989, defeating 115 participating teams including finals teams from Sweden, Austria, Germany, Mexico and Norway. Gothia Cup is considered to be one of the largest international junior soccer tournments since its establishment in 1975. An examination of the physiological characteristics of these top junior soccer players may provide some baseline data to be utilized by coaches, sports scientists and future investigators. The data will allow comparison with that obtained on similar level performers in other parts of the world and between local junior athletes in other sports. The purpose of this study was to measure and describe the cardiorespiratory fitness and isokinetic muscle strength of elite Asian junior soccer players.

Methods

Twenty-one top HK junior soccer players of ethnic Chinese origin volunteered to participate in the study prior to selection of the U-19 squads of the national junior soccer team for the 1989 15th Gothia Cup held in Göteborg, Sweden. The subjects were selected from a total sample of 3700 school soccer players aged between 16 and 18 years involved in the HK Youth Football Promotion Scheme. All subjects were scholarship athletes of the Hong Kong Sports Institute (HKSI), having a mean of 7 years soccer playing experiences. Athletes lived in the HKSI and underwent training three hours a day, 6 days per week, and 10 months per year. An average 60 matches were played during the whole season. Informed consent was obtained from all subjects prior to the testing process. The test battery included measures of body composition, pulmonary function, maximal aerobic power, anaerobic threshold (AT), flexibility and isokinetic muscle strength. All tests took place at the Human Performance Laboratory of HKSI.

Percentage body fat was estimated from skinfold measurements using a Harpenden skinfold caliper (Quinton Instrument Co., 212 Terry Avenue, Seattle, WA) at three different sites of the body surface (Jackson and Pollock, 1978). The Vitalograph-COMPACT spirometer (Vitalograph Ltd., Maids Moreton House, Buckingham, MK18 ISW, UK) was used to evaluate pulmonary functions by calculating the forced vital capacity (FVC), forced expired volume in one second ($FEV_{1.0}$) and maximal voluntary ventilation (MVV).

Maximal oxygen uptake (VO_2max) was measured using a continuous running test performed on a Quinton 65 treadmill (Quinton Instrument Co., 212 Terry Avenue, Seattle, WA). All subjects were familiarized with the testing procedures prior to data collection. Following a 10 min warm-up at 8.05 km hr^{-1} (0% grade), the subject began running at a velocity of 12.1

km hr^{-1} (0% grade). Every two minutes thereafter, the grade was increased by 2.5% until volitional exhaustion. Metabolic and respiratory measurements were obtained using a Sensormedics 2900 Energy Expenditure Unit (formerly Gould 2900, Sensormedics, 22705 Savi Ranch Parkway, Yorba Linda, CA) and included VE, VO_2, VCO_2, RQ, $FECO_2$, and FEO_2 which were computed and displayed every 20 s. Anaerobic threshold measurements were determined by observing the onset of the non-linear relationship between VO_2 and VE-VCO_2; and were expressed relative to oxygen consumption (% VO_2max) and heart rate (% HRmax).

Maximal knee strength was measured using a Cybex II+ isokinetic dynamometer (Lumex Inc., NY) set at a damping ratio at 2. Extension and flexion were tested for each knee at speeds of $60°s^{-1}$ and $240°s^{-1}$. After a warm-up of two to three submaximal contractions, five definite efforts were made at each speed; applying an approxpriate gravity correction. Peak torque (Nm) was recorded as the highest value of the trial. In addition to peak torque (Nm) value, Newton-meter per kilogram (Nm kg^{-1}) was also calculated. The strength ratio between knee flexors and knee extensors of each leg, hamstring/quadriceps (H/Q) ratio, was also calculated at both speeds.

Flexibility of the hip joint, trunk and hamstring muscles was tested by the sit-and-reach test (Wells & Dellion, 1952). After gentle stretching by two or three warm-up on the hamstring muscles, three trials were carried out with the maximal value recorded.

Student's paired-t statistics were used to test for differences between dominant and non-dominant leg results. The level of significance was set at two tailed 5% for all statistics comparisons.

Results and discussion

Anthropometry

The physical characteristics of the subjects, with comparative figures of Chinese national junior soccer players (1988) measured at our laboratory in Hong Kong, are presented in Table 1. Height (172.0 cm), weight (62.8 kg) and body fat (5.2%) tended to be lower compared with the Chinese national junior players (177.2 cm; 71.0 kg; 5.0%); Canadian national junior soccer team (175.8 cm; 69.1 kg; 8.0%); (Leatt et al., 1987); US junior team (178.3 cm; 72.3 kg; 9.4%) (Kirkendall, 1985); and French Junior soccer players (68.2 kg) (Rochcongar et al., 1988). It is interesting to note that with similar % body fat, the difference of almost 8.2 kg in body weight between the HK and Chinese team is due to the lean body weight (LBW). Body composition is an important aspect of fitness for soccer as the game now demands more physical contact. Heavier soccer players with above average LBW will generate higher forces for jumping, kicking and tackling. The low % body fat and LBW of the HK junior soccer players may reflect an insufficient total energy intake through an optimal diet. Aside from the limits imposed by heredity and physical improvements associated with training, it is suggested that no factor plays a bigger role to ensure optimal athletic performance than does nutrition (Costill, 1988).

Pulmonary function

All pulmonary function variables (Table 2) measured in this study were comparable to the age group between 17-18 of the Hong Kong Chinese (Lam et al., 1982). The FVC of 4.60 L appears to be comparable to the Chinese elite junior soccer team (4.43 L) (Liu et al., 1989), but lower than that of elite junior Hungarian club soccer players (5.1 L) (Apor, 1988). The mean $FEV_{1.0}$ (3.98 L; %FVC=85.2), and MVV (148.0 L) observed in this study demonstrated a high efficiency of the respiratory muscles by which air can be breathed in and out to furnish the oxygen transport system. The lower pulmonary value in soccer players compared with other junior athletes such as swimmers ($FEV_{1.0}$ = 5.62 L; %FVC=93.4) (McKay et al., 1983) was consistent with the fact that soccer requires intermittent bursts of intense action in which players frequently rely on anaerobic mechanisms.

Cardiorespiratory fitness

Data on selected aerobic capacity and cardiorespiratory fitness of the subjects are presented in Table 2. The maximal aerobic power of elite soccer players appears to have values around 65 to 67 ml $kg^{-1}min^{-1}$ (Ekblom, 1986; Rost, 1983), which reflects the fairly high aerobic demand to run efficiently for a period of 90 minutes and to control the ball under fatigue. Since maximal aerobic capacity reaches its peak in both males and females between the ages of 18-20 (Astrand and Rodahl, 1986), it seems reasonable to assume that elite junior soccer players who experience intensive training, can achieve comparable aerobic power to professional players (Apor, 1988; Nowacki et al., 1988).

Mean VO_2max values (58.6 ml $kg^{-1}min^{-1}$) for the subjects in this study appeared to be lower than those values reported for the Hungarian national junior soccer team (70 ml $kg^{-1}min^{-1}$), the elite Hungarian junior club players (66 ml $kg^{-1}min^{-1}$) (Apor, 1988), and the US junior team (61.8 ml $kg^{-1}min^{-1}$) (KirKendall, 1985). These values were, however, comparable to that of the top Canadian junior team (58.3 ml $kg^{-1}min^{-1}$) (Leatt et al., 1987) and higher than those of elite Chinese junior players (54.4 ml $kg^{-1}min^{-1}$) (Liu et al., 1989). As soccer is a high intensity, non-continuous intermittent exercise, VO_2max values are not expected to reach the same level as in endurance sports such as cycling, distance running and rowing. The HK U-19 junior road cycling team (N=5) tested in our laboratory had a mean value of 68.4±2.1 ml $kg^{-1}min^{-1}$ which seems to reflect the higher aerobic demand of the sport.

It is recorded that the German youth team who in 1981 were both European and World champions, when tested on a bicycle ergometer, achieved an average maximal oxygen uptake of 58.3±6.9 ml $kg^{-1}min^{-1}$ (Nowacki et al., 1988). The low values achieved by this group of German world champions may due to the test methodology and effects of sports specificity. Studies have shown the VO_2max values obtained from the bicycle ergometer test are on average 7 to 8% below the treadmill value (Saltin and Astrand, 1967; Miyamura et al., 1978). Sportsmen who run regularly are recommended to be tested on the treadmill in order to measure the real VO_2max (Potiron-Josse, 1983).

The mean maximal heart rate (185.2 ±8.0 beats min^{-1}) of the subjects tended to be lower than that of the top Canadian junior soccer players (200 beats min^{-1}) (Leatt et al., 1987), but similar to that of elite Chinese junior players (184.5±7.6 beats min^{-1}) (Liu et al., 1989). Reported values of VEmax for soccer players varied from 108.3±16.9 L min^{-1} (Williams et al., 1973) to 153.6±4.1 L min^{-1} (Raven et al., 1976). The values found in the current study (127.7±19.5 L min^{-1}) were within this range but are tended to be lower than the Hungarian national junior team (149.3±17.4 L min^{-1}) and elite Hungarian junior club players (142.7±17.8 L min^{-1}) (Apor, 1988). It is suggested that VEmax should be high in soccer players because of the requirement of furnishing the oxygen transport system with the necessary supplies of air throughout 90 min of play (Reilly, 90). The oxygen pulse value of the subjects (20.3±3.0 ml $beat^{-1}$) appeared to be similar to that of the German national junior team (21.9±2.5 ml $beat^{-1}$) (Nowicki et al., 1988) and elite Hungarian junior club players (21.0±2.6 ml $beat^{-1}$) (Apor, 1988).

The measured anaerobic threshold (AT) as a percent of VO_2max (76.7%) for the HK junior team is comparable to that for the HK national soccer team (80.0%) (Chin et al., 1992); the Canadian national soccer team (80.5%) (Rhodes et al., 1986); and the Engish league first division players (77%) (White et al., 1988). The high AT of the HK junior soccer players can be attributed, at least in part, to the specific inclusion of intermittent, high intensity exercise in their training program.

A reported study (Smodlaka, 1978) on heart rate values during the games indicated that the heart rate was above 85% of maximum for two-thirds of the time and it is suggested that the average oxygen consumption during a normal game can be close to 80% of the maximal oxygen uptake (Ekblom, 1986). Ali and Farrally (1991) recorded mean heart rates of 172, 167 and 168 beats min^{-1}, respectively from semi-professional, university and recreational players for an entire game. The overall mean heart rate obtained for these three levels of players was about 170 beats min^{-1} during the match. It is interesting to note that the AT data collected during the present study (76.7% VO_2max, 87.6% of HRmax and 163 beats min^{-1}) is similar to the above report and previous studies on the heart rates of elite soccer players during a match (Agnevik, 1970b; Reilly, 1986; Rohde and Espersen, 1988). It is reasonable to suggest that a competitive soccer match may require HK junior soccer players to exercise at close to their anaerobic thresholds for long periods of the game.

Flexibility

Soccer players in general have been found to be less flexible than non-players with the exception of goalkeepers (Ekstrand, 1982), and 67% of all players in one study had one, or several, tight muscles in the lower extremities (Ekstrand and Gillquist, 1982). The mean sit-and-reach value measured in the present study (29.0±6.0 cm) was lower than that for the average untrained individual (35-40 cm range)(Ekstrand, 1982), U-18 and U-16 squads of the Canadian national junior soccer team (37.2±7.4 cm) (Leatt et al, 1987), the HK national soccer team (31±7.0 cm) (Chin et al, 1992), the Canadian Olympic soccer team (40.5±6.3 cm) (Rhodes et al, 1986) and

Dallas soccer team (51.3±1.8 cm) (Raven et al., 1976). This poor flexibility indicated tight hamstrings which may be due to the design of soccer training and the need for specific stretching to increase the range of motion so as to reduce the incidence of injuries. One study has shown that the greatest development in flexibility is made during pre- and post-puberty prior to 14 years of age (Butgskowa and Woroncow, 1980). Therefore, it would appear, that from approximately this age onwards, that flexibility training is essential for soccer players to reach or maintain optimal levels.

Isokinetic muscle strength

The mean values (±SD) for isokinetic muscle strength of knee extensors and knee flexors are presented in Table 3 and 4. Oberg et al (1986) studied the strength of knee extensors and knee flexors isokinetically and isometrically in Swedish soccer players from the first and fourth division respectively. Differences in strength were shown between players from different divisions with the national team players being the strongest. Leatt et al (1987) suggested that the development of leg muscle function would offer a significant advantage to the elite soccer athletes. HK junior soccer players tended to score higher absolute peak torque on both knee extensors and knee flexors than the U-18 squads of the Canadian national junior soccer team measured at $60°s^{-1}$ and $240°s^{-1}$ (Leatt et al., 1987) and the US national junior soccer players, measured at $60°s^{-1}$ (Kirkendall, 1985). Moreover, the knee extensors and flexors isokinetic peak torque results of the subjects, measured at both speeds, appeared to be higher than those of Chinese national soccer team (Li et al., 1988).

Comparisons of the dominant and non-dominant legs indicated no significant bilateral difference in the knee extensors (except the absolute peak torque measured at $60\ °s^{-1}$), and such results were consistent with previous findings (Oberg et al., 1986; Rhodes et al., 1986;

Rochcongar et al., 1988). These data provided strong evidence that the strength capabilities of soccer players were similar in both legs. For the knee flexors, the dominant leg scored significantly higher results than the non-dominant leg ($P<0.05$) at both speeds. This may due to the difference in muscle involvement in the ball kicking action. The quadriceps strength of both kicking and non-kicking legs are important for leg swing action in ball kicking, while only the kicking (dominant) leg flexor is important in the action which causes deceleration of the leg and foot following the kick (Olson et al., 1985)

Previous studies have shown that a contralateral strength difference of 10% or greater may be a contributing factor to injury (Wyatt et al., 1981; Nosse et al., 1982; Grace et al., 1984). In the present study, although the mean contralateral difference was less than 10% for both knee extensors and knee flexors, measured at $60^{\circ}s^{-1}$, the standard error of these two ratios was comparatively very high (Table 5). There were respectively eight and ten out of twenty-one subjects who had contralateral quadriceps imbalance ratios greater than 10% when meas3 red at slow and fast isokinetic test speeds. For contralateral hamstring imbalance ratios, of twenty-one subjects, eight and twelve respectively, had values well over 10% when measured at slow and fast isokinetic speed. Kirkendall (1985) stated that soccer players were within clinical norms (10%) in contralateral muscle balance. Therefore, it is more likely that specific weight training is required to correct the subjects' contralateral muscle imbalance to avoid sports injuries.

Restoring the correct relationship between hamstring and quadriceps musculature pattern is a very important preventive measure that should be a primary concern in the training and rehabilitation program (Poulmedis, 1985). The H/Q ratio varies between 50% and 62% in healthy people (Knapik, 1980). Li et al (1986) showed that the flexion/extension ratio was 51.7% at

$60^{\circ}s^{-1}$ and 51.9% at $240^{\circ}s^{-1}$ for the Chinese national soccer team. Poulmedis (1985) suggested that hamstring muscles must be strengthened to at least 60% of the quadriceps at a speed of $30^{\circ}s^{-1}$. In an investigation of US national soccer team players, the average H/Q ratios at $60^{\circ}s^{-1}$ were 56.0% (right) and 56.6% (left) (Mangine et al., 1990). At slow speed test, the H/Q ratio found in this study was 56% for both dominant and non-dominant legs (Table 6). These ratios are close to the findings listed above. Studies found an increasing ratio with increasing velocity of testing in soccer players (Leatt et al., 1987; Poulmedis, 1985; Oberg et al., 1986; Mangine et al., 1990). In this study only the dominant leg produces significantly higher H/Q peak torque ratio measured at fast speed than that of the ratio measured at slow speed($P<0.05$), while the non-dominant leg generates similar results in both speed tests (Table 6). In reference to the strength of the dominant leg results and other studies listed above, the subjects' knee flexors in non-dominant legs seem to be weak in high speed movements. As the muscles' fast speed capability is an important skill in top level soccer (Oberg et al., 1986), fast movement training on knee flexors is vital for the subjects in this study.

CONCLUSION

This is the first physiological study of Hong Kong elite junior soccer players. The test data do provide a good baseline and reference for coaches, sports physiologists, physiotherapists and future investigators. Physiological data shows that the players tend to be light in weight and low in lean body mass, average in aerobic power, poor in flexibility and appear to be above average in isokinetic knee muscle strength. The attainment of high aerobic capacity should be supported by an optimal body fat content, preferably 8-10% and should be accompanied by high lean body mass. Increasing body weight and lean body mass through optimal diet and weight training is essential for the Hong Kong junior players as the modern soccer game now demands more physical contact. The poor flexibility of the athletes should be improved in order to reduce injury caused by tight hamstring. Training programs designed to improve the contralateral quadriceps and hamstring muscle imbalance and to increase the high-speed movement capability of the non-dominant knee flexors are recommended.

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References

Agnevik, G. (1970b). *Fotboll Idrottsfysiologi, Report no. 7.* Stockholm: Trygg-Hansa.

Ali, A. and Farrally, M. (1991). Recording soccer players heart rates during matches. *Journal of Sports Science*, **9**, 183-9.

Apor, P. (1988). Successful formulae for fitness training. In *Science and Football* (edited by T. Reilly, A. Lees, K. Davids and W. J. Murphy), pp.95-107. London : E & F.N. Spon.

Astrand, P.O. and Rodahl, K. (1986). *Textbook of Work Physiology* (3rd ed.) New York: McGraw-Hill.

Bunc, V., Heller, J. and Prochazka, L. (1992). Physiological characteristics of elite Czechoslovak footballers. *Journal of Sports Science*, **10**, 149

Butgskowa, N.Z. and Woroncow, A.R. (1980). Selection and training of young swimmers. *Sports Sypoczywowy (Poland)*, **18**, 39-45.

Chin, M.K., Lo, Y.S., Li, C.T. and So, C.H. (1992). Physiological profiles of Hong Kong elite soccer players. Accepted for publication. *British Journal of Sports Medicine*.

Chook, K.K., Teh, K.C. and Giam, C.K. (1986). The isokinetic strength of dominant quadriceps and hamstring muscles of 47 Singapore National sportsmen. In *Proceedings of 2nd International Sports Science Conference* - Toward Sports Excellence, pp.127-33.

Singapore : Singapore Sports Council.

Costill, D.L. (1988). Carbohydrates for exercise : dietary demand for optimal performance. *International Journal of Sports Medicine*, **9**, 1-18. Ekblom, B. (1986). Applied physiology of soccer. *Sports Medicine*, **3**, 50-60.

Ekstrand, J. (1982). Soccer injuries and their prevention (thesis) Linkoping University Medical Dissertation 130.

Ekstrand, J. and Gillquist, J. (1982). The frequency of muscle tightness and injuries in soccer players. *American Journal of Sports Medicine*, **10**, 15-8.

Faina, M., Gallozzi, C., Lupo, S., Colli, R., Sassi, R. and Mavini, C. (1988). Definition of the physiological profile of the soccer players. In *Science and Football* (edited by T. Reilly, A. Lees, K. Davids and W.J. Murphy), pp.158-63. London : E. & F.N. Spon.

Garganta, J. Maria, J. and Pinto, J. (1992). Somatotype, body composition and physical performance capacity of elite young soccer players. *Journal of Sports Science*, 10, 157

Grace, T.G., Sweeter, E.R., Nelson, M.A. and Yders, L.R. (1984). Isokinetic muscle imbalance and knee joint injuries. *Journal of Bone and Joint Surgery*, **66**, 734-40.

Jackson, A.S. and Pollock, M.L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition*, **40**, 497-504.

Jones, A. and Helms, P. (1992). Cardiorespiratory fitness in young British soccer players. *Journal of Sports Science*, 10, 156.

Kirkendall, D. (1985). The applied sports science of soccer. *Physician and Sportsmedicine*, **13**, 53-9.

Knapik, J. and Ramos, M. (1980). Isokinetic and isometric torque relationships in the human body. *Archives of Physical Medicine and Rehabilitation*, **61**, 64-7. Lam, K.K., Pang, S.C., Allan W.G., Hill, L.E., Snell, N.J., Nunn, A.J. and Prime, F.J. (1982). A survey of ventilatory capacity in Chinese subjects in Hong Kong. *Annals of Human Biology*, **9**, 459-72.

Leatt, P, Shephard, R.J. and Plyley, M.J. (1987). Specific muscular development in under-18 soccer players. *Journal of Sports Science*, 165-75.

Li, G., Chen, X. and Zhang, W. (1986). Isokinetic strength and endurance of quadriceps and hamstring muscles in elite Chinese athletes. *Chinese Journal of Sports Medicine*, **6**, 143-8.

Liu, H. et al. (1989). A longitudial study of growth and maximal aerobic power in young footballers. *Journal of National Research Institute of Sports Science*, **2**, 28-31.

Mangine, R.E., Noyes, F.R., Mullen, M.P. and Barber, S. (1990). A physiological profile of the elite soccer athlete. *Journal of Orthopaedic and Sports Physical Therapy*, **12**, 147-52.

McKay, E.E., Braund, R.W., Chalmers, R.J. and Williams C.S. (1983). Physical work capacity and lung function in competitive swimmers. *British Journal of Sports Medicine*, **17**, 27-33.

Miyamura, M., Kitamura, K., Yamada, A. and Matsui, H. (1978). Cardiorespiratory responses to maximal treadmill and bicycle exercise in trained and untrained subjects. *Journal of Sports Medicine and Physical Fitness*, **18**, 25-32.

Nosse, L.J. (1982). Assessment of selected reports on the strength relationship. *Journal of Orthopaedic and Sports Physical Therapy*, **4**, 78-85.

Nowacki, P.E., Cai, D.Y., Buhl, C. and Krummelbein, U. (1988). Biological Performance of German soccer players (professional and juniors) tested by special ergometry and treadmill meth3

. In *Science and Football* (edited by T. Reilly, A. Lees, K. Davids and W.S. Murphy), pp.145-57. London : E. & F.N. Spon.

Oberg, B., Ekstrand, J., Moller, M. and Gillquist, J. (1984). Muscle strength and flexibility in different positions of soccer players. *International Journal of Sports Medicine*, **5**, 213-6.

Oberg, B., Moller, M., Gillquist, J. and Ekstrand, J. (1986). Isokinetic torque levels for knee extensors and knee flexors in soccer plays. *International Journal of Sports Medicine*, **7**, 50-3.

Olson, J.R. and Hunter, G. (1985). Anatomic and biomechanical analysis of the soccer style free kick. *National Strength and Conditioning Association Journal*, **7**, 4-9

Potiron-Josse, M. (1983). Comparison of three protocols of determination of direct VO_2max amongst twelve sportsmen. *Journal of Sports Medicine*, **23**, 429-35.

Poulmedis, P. (1985). Isokinetic maximal torque power of Greek elite soccer players. *Journal of Orthopaedic and Sports Physical Therapy*, **6**, 293-5.

Ramadan, J., and Byrd, R. (1987). Physical characteristics of elite soccer players. *Journal of Sports Medicine and Physical Fitness*, **27**, 424-8.

Raven, P.B., Gettman, L.R. and Pollock, M.L. (1976). A physiological evaluation of professional soccer players. *British Journal of Sports Medicine*, **10**, 209-16.

Reilly, T. (1986). Fundamental studies in soccer. In Beitrage zur sportspielforschung : *Sportwissenschaft und Sportpracis* (edited by R. Andresen), pp. 114-20. Hamburg: Verlag Ingrid Czwalina.

Reilly, T. (1990). Football. In *Physiology of Sports* (edited by T. Reilly, N. Secher, P. Snell and C. Williams), pp.371-424. London : E. & F.N. Spon.

Rhodes, E.C., Mosher, R.E., McKenzie, D.C., Franks, I.M., Potts, J.E. and Wenger, H.A. (1986). Physiological profiles of the Canadian Olympic soccer team. *Canadian Journal of Applied Sports Science*, **11**, 31-6.

Rohde, H.C. and Espersen, T. (1988). The work intensity during soccer training & match play. In *Science and Football* (edited by T. Reilly, A. Lees, K. Davids and W.J. Murphy), pp.68-75. London

: E. & F.N. Spon.

Rost, R. and Hollmann, W. (1983). Athlete's heart - a review of its historical assessment and new aspects. *International Journal of Sports Medicine*, **4**, 147-65.

Rochcongar P., Morran, R. Jan, J. Dassonville, J. and Bellot J. (1988). Isokinetic Investigation of knee extensors and knee flexors in young French soccer players. *International Journal of Sports Medicine* **9**, 448-50.

Saltin, B. and Astrand, P.O. (1967). Maximal oxygen uptake in athletes. *Journal of Applied Physiology*, **23**, 353-8.

Smodlaka, V.N. (1978). Cardiovascular aspects of soccer. *Physician and Sportsmedicine*. **6**, 66-70.

Togari, H., Asami, T., Adachi, N., Yamamoto, K., Sugiyama, S. and Ohashi, J. (1979). A study on physical fitness of the top soccer players in Japan. *The Proceedings of the Department of Physical Education, College of General Education, College of General Education, University of Tokyo*, **13**, 33-42.

Togari, H., Osashi, J. and Ohgushi, T. (1988). Isokinetic muscle strength of soccer players. *In Science and Football* (edited by T. Reilly, A. Lees, K. Davids and W.J. Murphy), pp.181-5. London : E & F.N. Spon.

Tumility D.M. and Smith, R.A. (1992). Results of physiological tests and a game simulation for junior soccer players. *Journal of Sports Science*. **10**, 162.

Wells, K.F. and Dellion, E.K. (1952). The sit and reach of back and leg flexibility. *Research Quarterly*, **23**, 115-8.

White, J.E., Emergy, T.M., Kane, J.L., Groves, R. and Risman, A.B. (1988). Preseason fitness profiles of professional soccer players. In *Science and Football* (edited by T. Reilly, A. Lees, K. Davids and W.J. Murphy), pp. 164-71. London: E. and F.N. Spon.

Williams, G., Reid, R.M. and Coutts, R. (1973). Observations on the aerobic power of University rugby players. *British Journal of Sports Medicine*, **7**, 390-1.

Wyatt, M.P. and Edwards, A.M. (1981). Comparison of quadriceps and hamstring torque values during isokinetic exercise. *Journal of Orthopaedic and Sports Physical Therapy*, **3**, 48-56.

Table 1. Physical Characteristics of Hong Kong elite junior soccer players (N=21) and 1988 Chinese national junior soccer team (N=17)

	Hong Kong juniors (present study)	Chinese national juniors (1988)
Variables	Mean±SD	Mean±SD
Age (years)	17.3±1.1	19.0±1.2
Height (cm)	172.0±6.2	177.2±4.0
Weight (kg)	62.8±7.0	71.0±6.0
Lean body weight (kg)	59.5±6.3	67.5±5.4
Body fat (%)	5.2±1.8	5.0±1.2

Table 2. Selected aerobic capacity and cardiorespiratory fitness of Hong Kong elite junior soccer players (N=21)

Variables	Mean±SD	Range
FVC(l)	4.6±0.62	3.6-5.0
$FEV_{1.0}$(l)	3.98±0.46	3.42-5.03
$FEV_{1.0}$(%)	85.2±4.0	79.0-91.2
MVV(l min^{-1})	148.0±20.0	107.0-187.2
VO_2max (l min^{-1})	3.72±0.45	2.91-4.80
VO_2max (ml $kg^{-1}min^{-1}$)	58.6±2.9	53.5-64.0
HRmax (beats min^{-1})	185.2±8.0	171.0-195.0
VEmax (l min^{-1})	127.7±19.5	96.4-177.1
O_2 Pulse (ml $beat^{-1}$)	20.3±3.0	14.9-27.6
Respiratory exchange ratio (RQ)	1.14±0.05	1.02-1.20
VO_2 at anaerobic threshold (ml kg^{-1} min^{-1})	45.7±6.0	34.3-54.2
AT (%VO_2max)	76.7±10.2	59.4-89.3
HR at anaerobic threshold (beats min^{-1})	163.4±10.2	148.0-178.0
AT (% HRmax)	87.6±5.1	74.0-94.1

FVC = forced vital capacity; $FEV_{1.0}$ = forced expiratory volume at 1.0s; MVV = maximum voluntary ventilation

Table 3. Mean±SD of peak isokinetic torque for knee extensors at $60^{\circ}s^{-1}$ and $240^{\circ}\ s^{-1}$. Data for 21 junior soccer players.

	Dominant		Non-Dominant	
Tested Speed	Peak torque (Nm)	Peak torque/ Weight ($Nm\ kg^{-1}$)	Peak torque (Nm)	Peak torque/ Weight ($Nm\ kg^{-1}$)
$60^{\circ}s^{-1}$	270±27	3.28±0.37	198±33	3.16±0.45
$240^{\circ}s^{-1}$	122±13	1.95±0.15	126±18	2.02±0.25

Table 4. Mean±SD of peak isokinetic torque of knee flexors at 60°s^{-1} and 240°s^{-1}. Data for 21 junior soccer players.

	Dominant		Non-Dominant	
Tested Speed	Peak torque (Nm)	Peak torque/ Weight (Nm kg^{-1})	Peak torque (Nm)	Peak torque/ Weight (Nm kg^{-1})
60°s^{-1}	116±21	1.84±0.24	111±22	1.76±0.26
240°s^{-1}	77±14	1.28±0.24	70±14	1.12±0.19

Table 5. Mean±SD of peak torque contralateral imbalance ratio for knee extensors and knee flexors. Data for 21 junior soccer players.

Tested Speed	Knee extensors	Knee flexors
$60^{\circ}s^{-1}$	7.8±5.6	8.6±6.6
$240^{\circ}s^{-1}$	10.8±7.0	13.8±8.7

$$*\text{Contralateral imbalance ratio} = \frac{(\text{Stronger}-\text{Weaker})}{\text{Stronger}} \times 100$$

Table 6. Mean±SD of knee flexors/knee extensors peak torque ratio (H/Q ratio). Data for 21 junior soccer players.

Tested Speed	Dominant	Non-Dominant
$60°s^{-1}$	56±6	56±9
$240°s^{-1}$	63±9	56±7