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

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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 rehabilitation¹⁻⁵. 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 dor-

siflexion movements of the ankle. By controlling speed, isokinetic exercise⁶ 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

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. 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 test. 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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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.

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 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.)

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

	<i>Nondominant side</i>	<i>Dominant side</i>
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 2. Ankle dorsiflexion:plantar-flexion peak torque ratio at 180°s^{-1} ; ■, dominant side; ▨, nondominant side **Figure 1.** Ankle dorsiflexion:plantar-flexion peak torque ratio at 60°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

	<i>Nondominant side</i>	<i>Dominant side</i>
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, Tippet⁷ 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 event⁸⁻¹³. Consequently, it is reasonable to hypothesize that specific muscular characteristics could be developed in ankle plantar-flexors and dorsiflexors. This is supported by Fugal-Meyer¹⁴, 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-Meyer¹⁵ 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, Falkel¹⁶ 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 elite 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}. Morris¹⁹ 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 splints²⁰. 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 strength²¹.

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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