ACTA
ORTHOPAEDICA
et
TRAUMATOLOGICA
TURCICA

Acta Orthop Traumatol Turc 2009;43(6):484-490
doi:10.3944/AOTT.2009.484

Evaluation of knee peak torque in athletic and sedentary children

Atletik ve sedanter çocuklarda diz zirve torkunun değerlendirilmesi

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Objectives: We examined the influence of sex, level of activity, and pubertal status on knee extension (Ext) and flexion (Fl) peak torque (PT) in children using an allometric modeling approach.

Methods: A total of 140 students (67 males, 73 females) aged 12/13 years were enrolled from a Hong Kong junior high school, whose curricula were based on physical education (n=69) or arts (n=71). Isokinetic concentric Ext and Fl PT of the dominant leg was assessed at 1.04 rad/sec using a Cybex II+ dynamometer and body mass, stature, and pubertal stage were measured. A repeated-measures ANOVA test was performed on absolute PT data with muscle action (Ext and Fl) as a within-subject factor and between-subject factors including sex, group, and pubertal stage. To assess the effects on body size-adjusted PT, linear ANCOVA and log-linear ANCOVA techniques were used with body mass and stature taken as covariates.

Results: Peak torque was significantly greater in boys compared to girls, and in the physical education group compared to the arts group. When PT was adjusted for differences in body size, there was a greater difference in PT between girls in the two groups compared to boys, and there was a significant effect of pubertal stage. Allometric analysis showed that PT was influenced more by stature than body mass, and PT increased at a greater rate than body size (both $p<0.01$).

Conclusion: There may be a need for a physical activity intervention in sedentary 12/13 year old girls. Peak torque appears to increase disproportionately to body size. This may result from a greater increase in leg muscle mass relative to body mass.

Key words: Adolescent; anthropometry; body height; body weight; child development; exercise; isometric contraction; knee; muscle development; puberty; sex factors; torque.

Amaç: Çalışmada, alometrik model yaklaşımı kullanılarak, çocuklarda cinsiyet, aktivite düzeyi ve pubertal durumun diz ekstansiyon ve fleksiyonundaki zirve torku üzerindeki etkisi incelendi.

Çalışma planı: Çalışmaya Hong Kong ortaokuluna devam etmekte olan, 12-13 yaşlarında 140 öğrenci (67 erkek, 72 kız) alındı. Öğrencilerin 69'u beden eğitimi ağırlıklı, 71'i sanat ağırlıklı dersler görmekteydi. Tüm öğrencilerde baskın bacakta izokinetik konsantrik ekstansiyon ve fleksiyonda zirve torku Cybex II+ dinamometre ile 1.04 rad/saniyede ölçüldü; beden kütlesi, boy ve pubertal evreleri belirlendi. Mutlak zirve torku değerleri ile, kas hareketini (ekstansiyon ve fleksiyon) grup içi faktör ve gruplararası faktör olarak ele alan, cinsiyet, grup ve pubertal evrenin de katıldığı tekrarlı ölçümlerde ANOVA testi yapıldı. Beden ölçüsüne göre ayarlı zirve torkunun etkilerini değerlendirmek için, beden kütlesi ve uzunluğun eşdeğişken olarak alındığı lineer ANCOVA ve log-lineer ANCOVA teknikleri kullanıldı.

Sonuçlar: Zirve torku değerleri erkeklerde kızlara göre, beden eğitimi grubunda sanat dersleri grubuna göre anlamlı derecede yüksek bulundu. Zirve torku beden ölçüsündeki farklılıklara göre ayarlandığında, iki grupta kızlar arasında, erkeklere göre zirve torku daha fazla farklılık gösterdi ve pubertal evrenin bu farklılıkta anlamlı bir etkisi vardı. Alometrik analizde zirve torkunun beden kütlesine göre uzunluktan daha fazla etkilendiği ve vücut ölçülerine kıyasla daha büyük oranda artış gösterdiği görüldü ($p<0.01$).

Çıkarımlar: Bulgularımız 12-13 yaşlarındaki sedanter kızlarda fiziksel aktivite girişimlerine gereksinim olduğunu göstermektedir. Zirve torku, beden ölçüleriyle orantısız olarak artış göstermektedir. Bu durum, bacak kas kütlesinde beden kütlesine göre daha fazla artış olmasından kaynaklanabilir.

Anahtar sözcükler: Adölesan; antropometri; boy; vücut ağırlığı; çocuk gelişimi; egzersiz; izometrik kontraksiyon; diz; kas gelişimi; buluğ çağı; cinsiyet faktörü; tork.

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Submitted / *Başvuru tarihi:* 26.10.2008 **Accepted / *Kabul tarihi:*** 14.07.2009

Muscular strength is an important part of a child's physical fitness. It enables muscles to endure long periods of submaximal force production, thus delaying the onset of muscular fatigue, and may be an important factor in the development of healthy lifelong activity habits.[1] Muscle strength is an important health-related variable and significant reductions in blood lipid concentration have been found in children after a period of resistance training.[2]

Body mass and stature exert a definite influence on strength measures in children,[3-10] but few investigations[4-7,9,10] examined the effects of body size using the allometric approach to produce a performance variable with the effects of body size partitioned out. The allometric approach allows to reveal the true physiological reasons behind differences in strength.[11] Both the ratio standard[12] and linear regression ANCOVA analyses[13-15] have been criticized for not rendering the physiological variable independent of body size, as the ratio standard usually penalizes larger individuals, and linear regression creates positive intercepts, which imply the presence of a physiological response at zero body size.

In adults, the relationship between muscle strength and body mass may differ depending on whether joint torque or muscle force is recorded. Using allometry, Jaric et al.[16] demonstrated mass exponents of 1.1 for peak torque (PT) and 0.69 for force in adults and argues that since the area of geometrically similar objects is proportional to $m^{2/3}$, the recorded force (N), which is proportional to the muscle cross-sectional area (mCSA), should also be proportional to $m^{2/3}$, i.e. b=0.67. On the other hand, PT is proportional to mCSA x moment arm (the latter being proportional to stature) and therefore to m^1 ($m^{2/3} . m^{1/3} = m$). A limited number of strength studies have distinguished torque from force in this way.[17-19] Both body mass and stature should probably be investigated as concurrent covariates in the allometric model when investigating the physiological mechanisms behind muscle strength development.[5,20] Also, there are no studies of strength differences between teenagers following an arts-based or a physical education (PE)-based curricula. Therefore, this study assessed sex and arts *vs*. PE group differences in knee extension (Ext) and flexion (Fl) PT in 12/13-year-old healthy Chinese adolescents using the allometric method of normalization for body size.

Subjects and methods

Subjects

The study received ethical approval from the Medical School of the Chinese University of Hong Kong. Informed consent was obtained from the parents. A total of 140 students (67 males, 73 females) aged 12/13 years were enrolled from a Hong Kong junior high school. The pupils had been taking PE or Arts curriculum and 69 students were PE majors, and 71 were Arts majors. Dominance was ascertained by asking each participant to kick a ball.

Protocol

A Cybex II$^+$ dynamometer (Cybex, Lumex. Inc. Ronkonkoma, NY, USA) equipped with a HUMAC computer system (Computer Sports Medicine Inc., Totowa, NJ) was used. Before the test, each participant was familiarized with the isokinetic protocol. Immediately before the test, each participant performed a 3-min general warm-up including stretches of the knee extensors and flexors. Participants were secured to the dynamometer with chest, hip, and thigh straps. The seat back was aligned so that the hips were at an angle of 110° to the trunk. The axis of rotation of the dominant knee was aligned to the mechanical axis of the dynamometer, and the shin pad was secured just superior to the lateral malleolus. Each test consisted of a trial phase of two submaximal and one maximal continuous concentric extension-flexion cycles at 1.04 rad/sec, a one-minute rest, and an actual test phase of three cycles. Verbal encouragement was given throughout. The highest gravity corrected PT from a constant velocity period was selected for further analysis.

Anthropometry

Stature without shoes was measured to the nearest 0.1 cm using a portable Harpenden Stadiometer (Holtain, Crosswell, UK). Body mass in underwear was measured to the nearest 0.1 kg using a Seca Digital Physician's Scale (Seca Ltd., Bonn, Germany). Pubertal stage was assessed using the Tanner's criteria of pubic hair.

Data analysis

A repeated-measures ANOVA test was performed on absolute PT data with muscle action (Ext and Fl) as a within-subject factor and between-subject factors including sex, group, and pubertal stage. The

Table 1. Physical characteristics of the subjects

	Male (n=67) (Mean±SD)		Female (n=73) (Mean±SD)	
	Arts	PE	Arts	PE
Age (years)	12.9±0.3	12.8±0.4	12.8±0.4	12.7±0.5
Body mass (kg)	45.9±7.7	45.7±6.2	45.2±5.9	45.9±7.5
Stature (m)	1.59±0.08	1.60±0.07	1.58±0.07	1.56±0.06
Pubertal stage mode (range)	2.5 (1-5)	2 (1-4)	3 (1-5)	3 (1-5)

PE: Physical education curriculum; Arts: Arts curriculum.

analysis was repeated using both linear ANCOVA and log-linear ANCOVA techniques using body mass and stature as covariates.[11] The significance level was $P<0.05$.

Results

Absolute PT

Characteristics of the participants are displayed in Table 1, and PT values in Fig. 1. Girls were more mature than boys, but boys were significantly taller than girls (p=0.014). Extension and flexion PT values were significantly higher in males than females, in the PE group compared to the Arts group and in those with the highest pubertal stage (for all effects: p<0.01, power=0.92-1.0). There was also a significant group∗pubertal stage interaction effect on Ext and Fl PT (p<0.01), resulting in increased PT, with increases in pubertal stage in the PE group compared to the Arts group. The sex∗pubertal stage interaction was associated with a greater increase in PT with increasing pubertal stage in boys than girls (p<0.01).

Effects of muscle action

A significant main effect of muscle was found indicating a greater Ext PT compared to Fl PT (p<0.01). The overall Fl/Ext PT ratio was 63%. There was a greater relative difference between Ext PT and Fl PT in girls compared to boys, in the Arts group compared to the PE group (Fig. 1), and in those with a lower pubertal stage, as shown by the muscle∗sex (p=0.013), muscle∗group (p=0.018), muscle∗pubertal stage

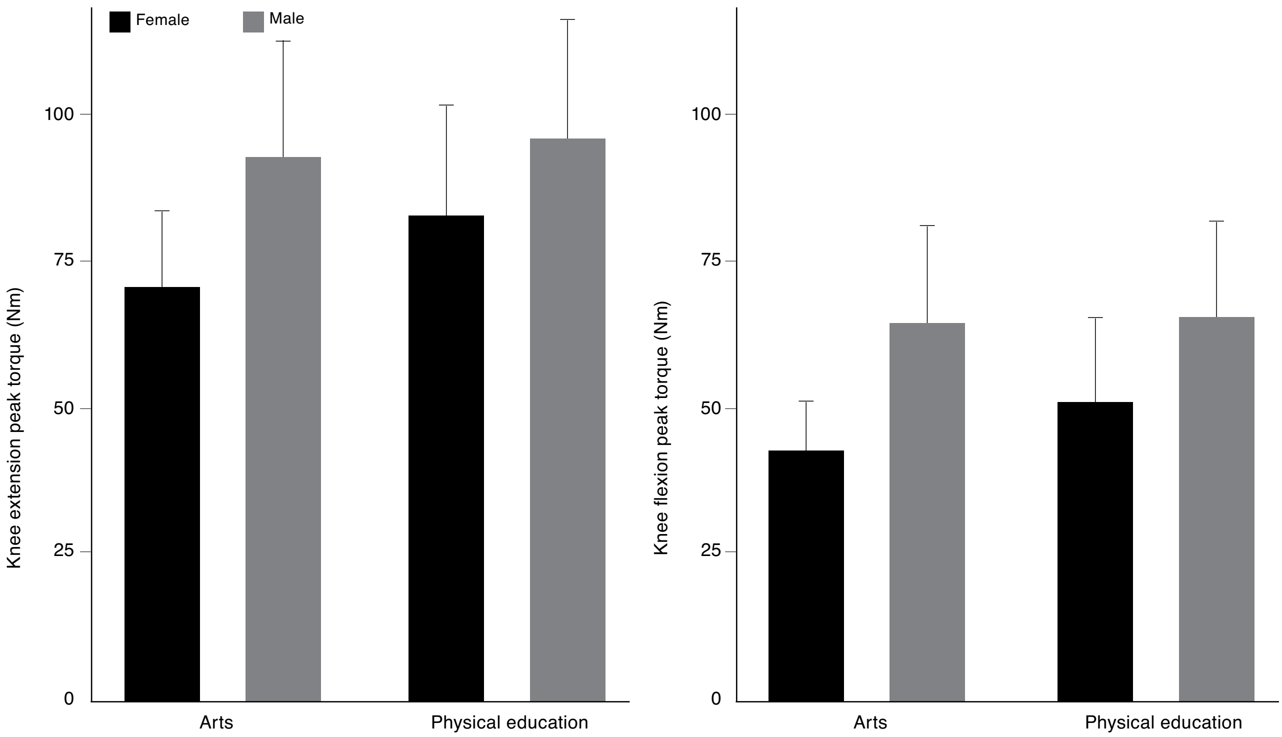

Fig. 1. Knee extension and flexion peak torque in males and females of the Arts and Physical Education groups. Error bars denote SD.

(p=0.038), and muscle∗sex∗pubertal stage (p=0.003) interaction effects.

PT adjusted for body mass and stature using linear ANCOVA

The means and standard error of the estimates (SEE) adjusted for body mass and stature are displayed in Table 2. Stature was a significant covariate for Ext and Fl PT (p<0.01). Mass was also a significant covariate for Ext PT (p=0.01), but not so for Fl PT (p=0.057). The body mass and stature exponents were 0.93 (SEE 0.21) and 1.22 (SEE 0.21) for Ext PT, and 0.51 (SEE 0.17) and 0.93 (SEE 0.17) for Fl PT, respectively.

There were significant effects of sex, group, pubertal stage, and sex∗pubertal stage (p<0.01). In addition, there was a significant sex∗group interaction (p=0.04, power=0.54), reflecting a greater education-group difference in girls compared to boys.

PT adjusted for body size using log-linear ANCOVA

Mass and stature were significant covariates for Ext PT (p<0.01) as was stature for Fl PT (p=0.001), although body mass was not significant (p=0.076). The mass and stature exponents were 0.49 (SEE 0.12) and 1.86 (SEE 0.41) for Ext PT, and 0.25 (SEE 0.14) and 2.37 (SEE 0.48) for Fl PT, respectively. With body mass and stature accounted for, there were significant effects of sex and group (p<0.01, power=1), pubertal stage (p=0.034, power=0.75), and sex∗group (p=0.02, power=0.65) (Fig. 2).

Table 2. Adjusted means (standard error of the estimates) from linear ANCOVA analysis

	Male		Female	
Peak torque (Nm)	Arts	PE	Arts	PE
Extension	91 (2)	93 (2)	71 (2)	85 (2)
Flexion	61 (2)	61 (2)	42 (2)	51 (2)

PE: Physical education curriculum; Art: Arts curriculum.

Discussion

One of the aims of this study was to assess the ability of body mass and stature to explain sex differences in leg strength. With and without body size appropriately controlled, boys had greater knee Ext and Fl PT than girls at age 12/13 years. Some studies found the same result in 13/14-year-old children,[3,10] whereas one reported no sex difference.[5] Our findings may be due to increased circulating testosterone in boys[9] which begins to rise at approximately 12.4 to 13.4 years.[21] Another possible reason is that girls are more advanced through puberty than boys and increasing levels of estrogen in girls with advancing puberty causes inhibition of muscle growth.[21] The significant main effect of pubertal stage indicates an independent contribution of pubertal status to knee Ext and Fl PT, irrespective of body size. In addition, we studied only children aged 12/13 years, and the wide range of PT indices highlights the importance of measuring pubertal status in studies of growth and maturation. However, whether the observed sex differences

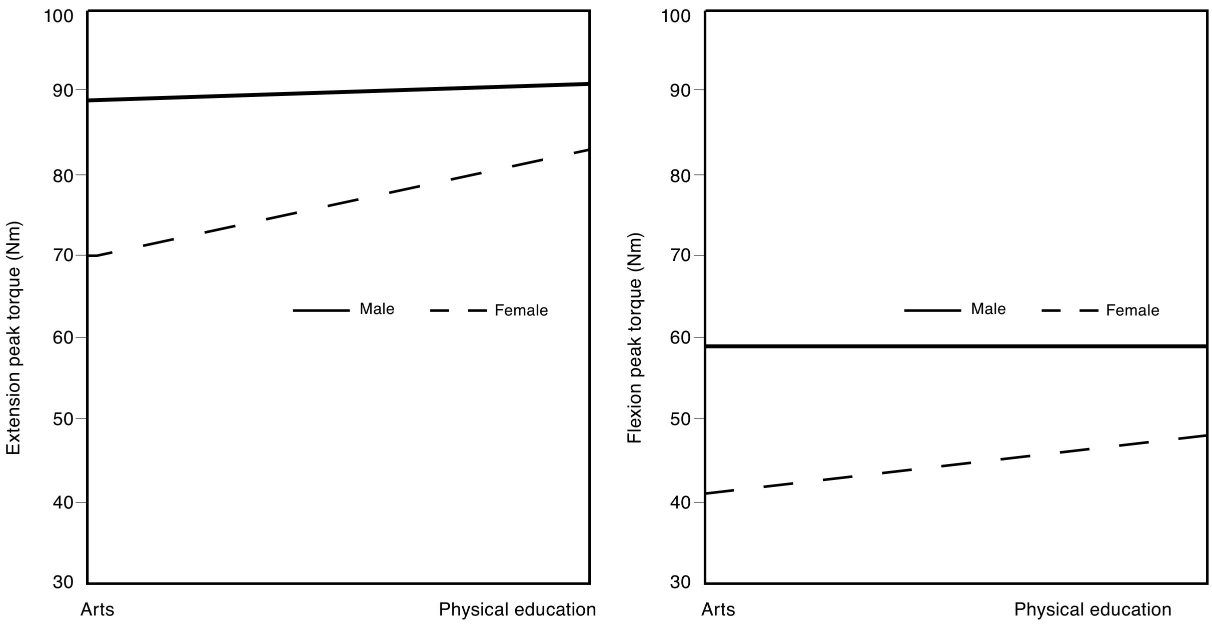

Fig. 2. Sex∗group interaction effect for peak torque. Values are adjusted means from log-linear ANCOVA.

are due to pubertal status alone or differences in the extent of motor unit activation cannot be determined from this study. Enhanced motor unit firing rate and changes in muscle fiber size have been implicated in gains in strength observed during adolescence.[3] Relating knee PT to muscle cross-sectional area measured by magnetic resonance imaging removes the sex difference in adults[22] and children.[5]

This study also found a greater relative difference between Ext and Fl PT in girls compared to boys, in the Arts group compared to the PE group, and in children at a lower pubertal stage: in other words, those groups which had a lower PT. This may have relevance to injury risk, as significant, moderate, negative correlations have been found between the Fl/Ext PT ratio and incidence of lumbar spine injury in active adults.[23]

A significant group effect in the present study indicated that PE students had higher PT scores than Arts students having controlled for differences in body size. This latter finding applied mainly to the girls as there was very little difference in PT between the boys in the PE and Arts groups. However, the sex*group interaction was significant only when body size was accounted for using both linear and log-linear ANCOVA, indicating that the difference between boys and girls in knee PT is significantly greater in the Arts group compared to the PE group having controlled for body size. The log-linear adjusted means for Ext and Fl PT in Arts girls were 84% and 82% of their PE counterparts. The reason for the stronger girls in the PE group may be that these girls had a greater level of physical activity due to their educational programme, but this argument does not apply to the males who demonstrated no difference in PT between the two educational groups. Such an education-related effect on girls' strength scores highlights the importance of physical activity in maintaining strength levels in girls. Interestingly, the observed power of the main effects and sex*group interaction was greatest in the allometric analysis, supporting the value of using the log-linear ANCOVA normalizing method.

In the present analysis, body mass and stature were both significant covariates. This agrees with previous studies[5,7] and highlights the importance of adjusting PT for both. The mass and stature exponents were 0.93 (SEE 0.21) and 1.22 (SEE 0.21) for Ext PT, and 0.51 (SEE 0.17) and 0.93 (SEE 0.17) for Fl PT, respectively, suggesting that the linear or stature dimension of knee Ext PT and particularly Fl PT are both numerically greater and more significant than the body mass exponents. The stature exponents were greater than 2 in both linear and log-linear analyses and certainly greater than the linear component ($L=m^{1/3}$) anticipated by Jaric[17] based on the assumption that body size dimensions are geometrically similar to each other (note that L denotes a linear dimension of body size and m is body mass). Jaric[17] proposed that torque should be proportional to the product of the cross-sectional area of the muscle (proportional to $L^2=m^{2/3}$) and the lever arm of the muscle (proportional to $L=m^{1/3}$), i.e., proportional to $m^{2/3}$. $m^{1/3} = m^1$. The fact that the stature exponent was greater than 2 is not consistent with this theory, suggesting that taller subjects benefit not only from having a longer lever arm but also from some additional, unknown advantage of being taller when recording PT using the Cybex II$^+$ dynamometer. Greater limb length provides a mechanical advantage not only due to joint structure but also to the angle of pennation to the long axis of the muscle.[24] Clearly, further studies are required to clarify the mechanisms associated with this unexpected advantage of being taller when recording PT using this particular apparatus.

If the mass (m) and stature ($L=m^{1/3}$) exponents are converted to a single mass exponent (assuming the two body size dimensions are geometrically similar to each other) by dividing the stature exponent by 3 and then summing the two exponents, the resulting 'combined' mass exponents become 1.11 for Ext PT and 1.04 for Fl PT. The exponent 1.11 is greater than the anticipated exponent 1 (unity), based on the theoretical model for normalizing torque[17,18] and based on the assumption that body-size dimensions are in geometric similarity to each other. These inflated exponents are consistent with the findings of Nevill,[25] who found that leg muscle mass of 11-15-year-old boys increased at a greater proportion to body mass, found to be $m^{1.1}$. The separate mass and stature exponents found in the present study are slightly lower than those of De Ste Croix et al.,[5] who obtained a mass exponent of 0.36 and a stature exponent of 2.55, translated into a 'combined' mass exponent of 1.21. This inflated exponent provides further support for a disproportionate increase in PT with body mass observed in the present study, a finding that may well be explained by a disproportionate increase in leg muscle mass with increasing body size.[25] Previous studies mainly focused on Caucasian children. The present investigation only involved Chinese adolescents. Differences in body composition, body proportions, and progression of growth and maturation in different ethnic groups[26] may account for at least some of the differences between this and previous studies.

Conclusion

We demonstrated the advantages of scaling or normalizing PT measures for differences in body size using both body mass and stature as covariates. Our study confirms the value of log-linear ANCOVA to gain greater insight into the mechanisms associated with knee PT, e.g. there was a greater association of stature with PT of the hamstrings than had previously been anticipated. Having adjusted for differences in body size, those children of a more advanced pubertal stage were stronger, and children studying an Arts-based curriculum had weaker thigh strengths than children enrolled in a physical education curriculum. This highlights the need to encourage physical activity in arts-based curricula, particularly in girls. Moreover, PT increases disproportionately to body size, possibly from a greater increase in leg muscle mass relative to body mass.

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