

Log-linear Adjusted Lower Limb Muscle Power of Boys and Girls 以對數－線性修正法對少年下肢力量的研究

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Abstract

The study investigated the log-linear muscle power of the lower limbs in a group of 13 to 14 year old boys and girls. Participants were 48 boys (stature: 1.69 ± 0.05 m; body mass: 57.9 ± 11.8 kg; lower limb muscle mass: 16.4 ± 2.5 kg) and 38 girls (stature: 1.59 ± 0.06 m; body mass: 57.7 ± 7.6 kg; lower limb muscle mass: 12.5 ± 1.2 kg). Lower limb muscle mass (LLMM) was determined using a dual energy X-ray absorptiometric (DEXA) procedure. Participants completed a 30s Wingate Anaerobic Test (WAnT) where peak power (PP) and mean power (MP) were expressed in relation to LLMM using log-linear adjustment procedures. Boys and girls had similar log-linear adjusted PP (495W vs. 488W, $p > 0.05$) and MP (423W vs. 422W, $p > 0.05$) when they were expressed in relation to LLMM. However, common b exponents that defined the allometric relationship between PP and MP, and LLMM in both boys and girls were 1.26 (SE 0.15), and 1.21 (SE 0.15), respectively. These were markedly different from the b exponent of 1.0 used in the ratio standard, or the 0.67 value predicted from geometric similarity theory. Despite a similar interpretation of data (i.e. no sex difference in lower limb muscle power in boys and girls) using either allometric modeling, allometric modeling of sample-specific exercise data is recommended to produce an appropriate size-independent variable, to allow appropriate comparisons in performance between boys and girls.

摘要

本文以對數－線性修正法對13－14歲少年下肢力量進行了研究。測試對象為48名男孩（身高為 1.69 ± 0.05 米，體重為 57.9 ± 11.8 公斤，下肢去脂體重為 16.4 ± 2.5 公斤）和38名女孩（身高為 1.59 ± 0.06 米，體重為 57.7 ± 7.6 公斤，下肢去脂體重為 12.5 ± 1.2 公斤）。以雙光能X光吸收儀（DEXA）測定受試者下肢的去脂體重。受試對象在自行車功率儀上完成30秒溫蓋特無氧功率測試（Wingate Anaerobic Test, WAnT），以對數－線性修正法表示最高功率和平均功率與下肢去脂體重的關係。其結果顯示，男孩與女孩的最高功率分別為495瓦與488瓦（ $p > 0.05$ ），平均功率分別為423瓦與422瓦（ $p > 0.05$ ）。根據對數－線性修正法所得的最高功率和平均功率與下肢去脂體重關係的b指數分別1.26（SE為0.15）與1.21（SE為0.15），男女相同。此結果與常用標準比b指數為1，或應用幾何相似理論推測值0.67等方法所得的結果明顯不同。應用異速生長模型（對數－線性修正法）可測得與其實驗對象和運動形式相適應的形態機體指標，因而可較正確地比較少年男女之間的運動能力。

Introduction

Performance in the Wingate Anaerobic Test (WAnT), an all-intensity cycle test, is often described in relation to a body

size descriptor (e.g. stature, body mass, fat-free mass), so as to facilitate comparisons between boys and girls, or between distinctive groups. The capability to generate muscle power can be explained to a significant extent by the total mass of the muscle that is

involved in producing the power (Chia, 2000). In exercise that involves moving and bearing the entire body mass such as during treadmill running, it is logical to express the performance in relation to body mass or to stature, in the attempt to produce a size-independent variable (e.g. body mass-accounted power) for ease of comparison between groups. However, in seated sprint cycling exercise (e.g. in the WAnT), where the body mass of the participant is supported, it may be more appropriate to describe the performance (e.g. power) to some indicator of size of the active muscle mass such as thigh muscle mass (TMM) or lower limb muscle mass (LLMM). Indeed, some researchers have described young people's exercise performance in relation to leg muscle volume using anthropometric methods (Docherty, & Gaul, 1991; Winsley, Armstrong, & Welsman, 1995) or thigh muscle volume (TMV) using magnetic resonance imaging (Welsman, Armstrong, Winsley, Parsons, & Sharp, 1997), in attempts to better describe the exercise performance in more defensible terms, where the involvement of the active muscles is better taken into account. Increasingly, the use of dual energy X-ray absorptiometry (DEXA) to determine bone mineral content and density, body composition and changes in body composition is gaining in popularity (Ellen, Saunders, Spano, Armbriansson, Lewis, & Cureton, 1999). Moreover, the use of DEXA has gained widespread acceptance as a valid and reliable procedure for scientific research in adults and in young people as it is easy to administer and most established research centers will be able to afford its intermediate cost of operation (Gotfredsen, Baeksgaard, & Hilsted, 1997). The use of DEXA to quantify LLMM so that exercise performance can be more appropriately described in relation to the active muscle tissue during cycling can yield valuable data and perhaps provide additional insights that can better explain the performances of exercising young people.

Researchers commonly use the ratio standard to address differences in body size but there is a growing conviction that the ratio method may not appropriately normalise exercise data or produce a size-independent variable that appropriately take into account differences in body size (Armstrong, & Welsman, 1997; Nevill, Ramsbottom, & Williams, 1992). The main aim of using the simple ratio standard is that it is assumed that the simple division of the variable of interest (e.g. peak power) by a body size descriptor (e.g. LLMM) will provide a size-free variable. However, the simple ratio standard often fails to achieve this; instead individuals who are very light in body weight are advantaged whereas individuals who are very heavy are penalized (Armstrong, & Welsman, 1997). Prior to using the scaling method of choice, researchers should be mindful that the use of the method must not violate the assumptions for its use based on the characteristics of the specific data set.

These criteria for the use of the ratio standard, linear-adjustment methods and allometric modeling, in an attempt to create a size-independent variable have been described elsewhere (Armstrong, & Welsman, 1997; Nevill, Ramsbottom, & Williams, 1992).

It is critical that the appropriate normalization of exercise data for differences in body size is used as it allows the researcher to correctly interpret the results of the research. Conversely, the inappropriate use of scaling methods can lead to erroneous interpretations and consequently cloud our understanding of the exercising child.

Allometric (log-linear) methods are recommended as more appropriate in accounting for body size effects as they are able to accommodate data that are heteroscedastic (Nevill, Ramsbottom, & Williams, 1992) in nature, that is, as body size increases (e.g. LLMM), so does the variability of the performance variable of interest (e.g. PP). In essence, the technique requires the derivation of the b exponent by applying the least-squares regression to logarithmically transformed data (e.g. PP and LLMM) (Armstrong, & Welsman, 1997).

Log-linear methods have apparently not been used to describe young people's power performances in relation to LLMM. Therefore, the aim of the study was to examine the lower limb muscle power of boys and girls, as determined in the WAnT that are described in relation to LLMM using allometric methods.

Methods

The study had the required ethical institutional approval. Forty-eight boys and 38 girls with the appropriate written informed consent participated in the study. Age and anthropometric variables—body mass and stature, were measured using standard procedures and that used calibrated machines. An experienced female physician assessed the sexual maturity of the boys and the girls, one participant at a time, in a private setting, in accordance to the criteria that were popularized by Tanner (1962). In essence, ratings of pubic hair development for both sexes were noted and recorded. The boys and girls were assessed separately, in two groups and over two separate sessions.

Familiarization sessions with cycle sprinting in the WAnT were organized and each participant completed a minimum of three abbreviated sprints of 15-seconds' duration before the actual test session. This was done to minimize differences in performance that might be attributed to learning effects among the participants.

During the test session, each performance was preceded by a standardized warm-up, which consisted of four minutes of pedaling at 60 rev.min⁻¹ that was interjected with three maximal effort sprints of 2-3 seconds' duration, conducted at the start of each minute. Thereafter, the participants were taken through two minutes of stretching exercises for the quadriceps, hamstrings and groin muscles.

After the standardized warm-up, participants completed a 30s WAnT on a cycle ergometer (Monark 834E), from a rolling start of 60 rev.min⁻¹, with the applied force set at 0.74 N.Pkg⁻¹ body mass. Inertia-adjusted 1-s peak power (PP) and mean power over 30s (MP) were computed according to standard procedures that have been previously described (Chia, 2000; Chia, Armstrong, & Childs, 1997).

The DEXA equipment used was a QDR 4500 Hologic model manufactured in Waltham, MA, USA. Lower limb muscle mass (LLMM) was determined using a DEXA procedure that involved the participant, dressed in shorts and a T-shirt, lying still in a supine position on the scanning table with both feet rotated inward toward each other, and with arms placed by the side with the palms pronated. The participant was instructed to remain still throughout the scan, which took about seven minutes. The lights were switched off and soothing music was played to help the participant remain relaxed and still throughout the scan. After the scan, image adjustment and region selection was carried out to generate the required reports. LLMM was derived from the Hologic computer software (Version 9.80).

The data were stored in computer and analysed using the Statistics Package for Social Sciences (SPSS for Windows Version 10.0). Descriptive statistics of the participants-namely, means and standard deviations for stature, body mass, and LLMM were generated. Sex differences in descriptive characteristics and WAnT performances (peak power, PP and mean power, MP) were analysed using one-way analysis of variance (OW-ANOVA). Allometric scaling factors for PP and MP for the boys and girls were identified from log-linear analysis of covariance (ANCOVA), with LLMM entered as the covariate, to derive a common b exponent (Armstrong, & Welsman, 1997). Adjusted means for PP and MP that are size-independent were subsequently computed from the log-linear ANCOVA (Armstrong, & Welsman, 1997; Nevill, Ramsbottom, & Williams, 1992). The level of statistical significance was set at $p < 0.05$.

Results

The physical and anthropometric characteristics of the boys and girls are presented in Table 1.

Table 1. Anthropometric and Descriptive Characteristics of the Participants.

Variable	Boys(N=48)	Girls(N=38)
Age (y)	14.5±0.4	13.9±0.6
Stature (m)	1.69±0.05	1.59±0.06*
Body mass (kg)	57.9±11.8	57.7±7.6
Lower limb muscle mass (kg)	16.4±2.5	112.5±1.2*
Tanner stages 3 & 4	86%	89%
Pubic hair criterion only		

* Significantly different at $p < 0.05$.

Eighty-six percent of the boys and 89% of the girls were assessed as Tanner stages 3 and 4 for sexual maturity status, based on the pubic hair criteria. Boys were significantly, taller and had greater LLMM than the girls.

Log-transformed data analysed by ANCOVA that described the allometric relationships between WAnT performances and LLMM, revealed common b exponents for PP as ($b=1.26[SE\ 0.15]$) and for MP as ($b=1.21[SE\ 0.15]$) for boys and girls. Despite the boys being taller than the girls, the inclusion of stature into the log-linear equation(s) did not make a significant additional contribution to the b exponent. WAnT performances in absolute terms and described in relation to LLMM are shown in Table 2.

Table 2. Peak and Mean Power of the Participants in Absolute Terms and Described in Relation to LLMM.

Variable	Boys (N=48)	Girls (N=38)
Peak power (W)	619±89	471±61*
Log-linear adjusted peak power(W)	95	488
Mean power (W)	459±91	422±58
Log-linear adjusted mean power(W)	423	422

* Significantly different at $p < 0.05$.

Discussion

The DEXA data demonstrated that boys had greater LLMM than girls, in contrast to previous reported data, that showed no gender difference in TMV of seven to 15 year old children, measured using anthropometric methods (Van Praagh, Fellman, Bedu, Falgairette, & Coudert, 1990). Inter-study participant differences and the limitations of anthropometric techniques to estimate TMV of the cited study could account for the dissimilar results between the cited study and the present study. A result of the present study showed that boys were significantly taller than the girls and this could explain the greater LLMM of the boys. Moreover, many studies have shown that after male puberty, lean muscle mass of boys increases sharply in contrast to girls of equivalent maturity status (Armstrong, & Welsman, 1997; Docherty, & Gaul, 1991). However in terms of sexual maturity, the girls in the present study was slightly more mature, based on the pubic hair criterion.

Peak power (PP) in absolute terms of the boys was 131% that of the girls but when PP was expressed allometrically to LLMM, the difference between the boys and girls did not attain statistical significance (see Table 2). Mean power (MP), in absolute terms and expressed allometrically to LLMM were similar in the boys and the girls. This result is supported by the findings of others (Armstrong, & Welsman, 1997; Carlson, & Naughton, 1994). In essence, results of the cited studies show that during a period between late childhood and early puberty, girls could be more powerful, or just as powerful as boys in the WAnT. One explanation for that is that at a similar chronological age, girls are more physically mature than boys and this may translate to an increased capability to generate power. Indeed, the girls in the present study were slightly more advanced in sexual maturity compared to the boys.

Peak power and MP that were allometrically modelled to LLMM (i.e. adjusted means for PP and MP), were similar for boys and girls (see Table 2), in agreement with the findings of no sex difference in peak oxygen uptake that was expressed allometrically in relation to TMV, reported by Welsman and her colleagues (1997) in 13 and 14-year-old boys and girls. Hence the view that adolescent girls can be as capable as adolescent boys in performing exercise, insofar as the performance is appropriately accounted for to take into account body size effects, is apparently reinforced and verified in a number of studies. This is in contrast to other studies that commonly show that boys are more powerful than girls after puberty because of increased musculature and the effects of circulating testosterone in the males (Docherty, & Gaul, 1991). However, it should be noted

that the performance comparisons have mainly been made using power expressed in ratio to body mass or to stature in the cited results of Docherty and Gaul (1991).

In the present study, common b exponents identified for PP and MP in relation to LLMM were markedly different from 1.0, the assumed b exponent in ratio-scaling of data in relation to the body size descriptor.

The result of the present study echoed the findings of others (Armstrong, & Welsman, 1997; Nevill, Ramsbottom, & Williams, 1992). In essence, these scientists argue that the conventional ratio technique inadequately adjusts for the effects of body size, and that the log-linear technique more appropriately adjusts for the effects of body size.

Additionally, the b exponents identified for PP and MP that were expressed in allometric terms in relation to LLMM in the present study, deviated from that which is predicted from geometric similarity theory (i.e. $b=0.67$) (Schmidt-Nielsen, 1984). Two explanations are plausible. Firstly, the participants in the study did not conform to an isometric pattern, that is, they did not grow as geometric entities, as demonstrated by the inflated b exponents that were identified for PP and MP. If this explanation is tenable, then sample-specific allometric modelling of exercise data is recommended in order to obtain meaningful information (Armstrong, & Welsman, 1997). Secondly, the limitations of the WAnT in its ability to measure PP and MP in young people (Armstrong, & Welsman, 1997; Van Praagh et al, 1990) may also explain the identified b exponents deviating from the expected value of 0.67. More research using force-velocity tests that use a participant-optimised applied force, to elicit PP in boys and girls may help to clarify the issue (Chia, 2000).

In conclusion, the data in the study do not support that there were sex differences in PP and MP generated by 13-14 year old boys and girls when the performances were allometrically adjusted in relation to LLMM.

Common b exponents, for boys and girls that defined the allometric relationship between PP and MP in the WAnT were not exactly 1.0 (i.e. b exponent used in the ratio standard), or equal to 0.67 as suggested by geometric similarity theory. Therefore it is strongly recommended that sample-specific allometric modeling of the data be used to appropriately describe the relationship between power elicited in the WAnT and the relevant body size descriptor.

References

- Armstrong, N., & Welsman, J. (1997). *Young People and Physical Activity*. Oxford University Press, pp. 5-258.
- Carlson, J., & Naughton, G. (1994). Performance characteristics of children using various braking resistances on the Wingate Anaerobic Test. *Journal of Sports Medicine and Physical Fitness*, 34, 362-369.
- Chia, M. (2000). Assessing young people's exercise using anaerobic performance tests. *European Journal of Physical Education*, 5(2), 231-258.
- Chia, M.Y.H., Armstrong, N., & Childs, D. (1997). The assessment of children's performance using modifications of the Wingate Anaerobic Test. *Pediatric Exercise Science*, 9, 80-89.
- Docherty, D., & Gaul, C. A. (1991). Relationship of body size, physique and composition to physical performance in young boys and girls. *International Journal of Sports Medicine*, 12, 525-532.
- Ellen, M., Saunders, M., Spano, M., Arnbrimsson, S., Lewis, R., & Cureton, K. (1999). Body composition changes with diet and exercise in obese women: a comparison of estimates from clinical methods and 4-component model. *American Journal of Clinical Nutrition*, 70(1), 5-12.
- Gotfredsen, A., Baeksgaard, L., & Hilsted, J. (1997). Body composition analysis by DEXA using dynamically changing samarium filtration. *Journal of Applied Physiology*, 82, 1200-1209.
- Nevill, A., Ramsbottom, R., & Williams, C. (1992). Scaling physiological measurements for individuals of different body size. *European Journal of Applied Physiology*, 65, 110-117.
- Schmidt-Nielsen, K. (1984). *Scaling: Why is animal size so important?* Cambridge University Press, pp. 7-20.
- Tanner, J.M. (1962). *Growth at Adolescence*. Blackwell Scientific Publications, Oxford. pp. 12-25.
- Van Praagh, E., Fellman, N., Bedu, M., Falgairette, G., & Coudert, J. (1990). Gender difference in the relationship of anaerobic power output to body composition in children. *Pediatric Exercise Science*, 2, 336-348.
- Welsman, J.R., Armstrong, N., Winsley, R.J., Parsons, G., & Sharp, P. (1997). Exercise performance and magnetic resonance imaging determined thigh muscle volume in children. *European Journal of Applied Physiology*, 6, 388-394.
- Winsley, R. Armstrong, N., & Welsman, J. (1995). Leg volume is not related to peak oxygen uptake in 9-year-old boys. In: F.J. Ring (Ed.), *Children in Sport, Centre for Continuing Education*, Bath. pp. 70-76.

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