

# Peak-Power Estimation Equations in 12- to 16-Year-Old Children: Comparing Linear with Allometric Models

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This study examined the efficacy of peak-power estimation equations in children using force platform data and determined whether allometric modeling offers a sounder alternative to estimating peak power in pediatric samples. Ninety one boys and girls aged 12–16 years performed 3 countermovement jumps (CMJ) on a force platform. Estimated peak power ( $PP_{est}$ ) was determined using the Harman et al., Sayers SJ, Sayers CMJ, and Canavan and Vescovi equations. All 4 equations were associated with actual peak power ( $r = 0.893–0.909$ , all  $p < .01$ ). There were significant differences between  $PP_{est}$  using the Harman et al., Sayers SJ, and Sayers CMJ equations ( $p < .05$ ) and actual peak power ( $PP_{actual}$ ). ANCOVA also indicated sex and age effect for  $PP_{actual}$  ( $p < .01$ ). Following a random two-thirds to one-third split of participants, an additive linear model ( $p = .0001$ ) predicted  $PP_{actual}$  (adjusted  $R^2 = .866$ ) from body mass and CMJ height in the two-thirds split ( $n = 60$ ). An allometric model using CMJ height, body mass, and age was then developed with this sample, which predicted 88.8% of the variance in  $PP_{actual}$  ( $p < .0001$ , adjusted  $R^2 = .888$ ). The regression equations were cross-validated using the one-third split sample ( $n = 31$ ), evidencing a significant positive relationship ( $r = .910$ ,  $p = .001$ ) and no significant difference ( $p = .151$ ) between  $PP_{actual}$  and  $PP_{est}$  using this equation. The allometric and linear models determined from this study provide accurate models to estimate peak power in children.

## Introduction

The vertical-jump test is a component of various batteries used to assess physical ability in adults and children (19), as the ability to generate power is a key element to success in a number of sports (6,8,11,12,21). It is also important in terms of

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occupational tasks and tasks of daily living (11) and useful in talent-identification programs (8); there is also emerging evidence that jumping performance may be related to overweight and obesity risk (2). Specifically, Bovet et al. (2) reported an inverse J shape associated between overweight and obesity risk and scores on fitness tests, including vertical-jump performance, in adolescent boys and girls.

However, while the force platform—as it provides a precise, direct measurement of power—is widely used to assess power within laboratory settings (2,11), its use has been restricted in field settings due to its cost and inaccessibility outside of the laboratory. As a result, a number of estimation equations have been developed to estimate peak and average power from jump height and body mass.

Research (3,6) has, however, questioned the validity of the existing range of peak-power estimation equations. Studies validating peak-power equations (6,14) used separate tests to determine vertical-jump height and peak power instead of pairing these values from the same jump. Studies (7,18) also determined jump height using the jump and reach test. This is problematic in itself, as performing a jump against a wall—as in the jump and reach test—impedes jumping technique in comparison with jumping on a force platform (3). One study (18) also included a heterogeneous, mixed-sex sample from varied athletic backgrounds. As differences exist in jump technique and coordination between sexes and between athletic/non-athletic groups (1,4,8,10), a more homogenous sample was needed to fully validate these equations (1). Specificity would also dictate that a countermovement jump (CMJ) should be used when assessing athletes (3). However, Harman et al. (7) used squat-jump (SJ) height in their regression model, and Sayers et al. (18) reported that the equation derived from SJ was more accurate than the equation derived from CMJ. These factors may add to the variability of their regression models, which would in turn influence the accuracy of peak-power estimation (3,6).

In response to these criticisms, some authors (3,6) have compared actual peak power ( $PP_{\text{actual}}$ ), measured using a force platform, with commonly used peak-power estimations ( $PP_{\text{est}}$ ) in adult samples. In both cases, these researchers reported differences between existing peak-power estimation equations and  $PP_{\text{actual}}$ . However, Canavan and Vescovi (3) suggested their study was underpowered, and Duncan et al. (6) concluded that further research was needed to validate a biologically sound equation to estimate peak power in a comparable sample. This conclusion has been supported by other authors (6,8). However, all the previously validated equations used multiple linear regression as a means to examine their data. This process results in high negative intercept values that are biologically and biomechanically implausible. This is particularly the case within pediatric populations, due to their lower body mass compared with adults. When adult models are used, the lower body mass in children coupled with the higher negative intercept values from adult models may result in a misrepresentation of the actual power values generated in children.

Recent work by Taylor et al. (19) presented normative leg-power data for children aged 10–15 years based on the rationale that, to date, predicted peak leg power for jumping has not been reported for children. They subsequently used the Sayers et al. (18) equation to estimate peak power from jump height and body mass in their sample of 1,845 children. While the data they presented are useful, they noted that their power values were estimated from the Sayers et al. equation, as there was no model that had been validated with children. Moreover, the Sayers et

al. equation was validated on a homogenous sample of males and females with no control for age or sex differences. Both of these issues may be particularly important when examining physical capabilities in children. Consequently, the major conclusion from Taylor et al.'s (19) study was that jump height and body mass should be incorporated to develop a new set of age dependent regression equations based on force-platform-determined power values.

More recently, Duncan et al. (5) presented data comparing peak-power estimation equations from force platform derived peak power in a sample of 77 adolescent basketball players. Using allometric scaling, they identified a model to predict peak power in their sample that was superior to all previously validated peak-power equations. They suggested that allometric modeling provides a better alternative and a more biologically sound approach for this population group. Allometric scaling is not a new concept, and in the context of kinanthropometry, has an important role in understanding exercise performance as body size represents a factor that affects the outcome of physical tests (9). Prior studies have demonstrated the importance of using an allometric approach, normalizing for body size in explaining performance in a variety of functional and performance tests (9,14,15). This has included tests requiring rapid muscular movement and manipulation of external force (9,14). In the context of vertical jumping in particular, Markovic and Jaric (15) have noted that neglecting the body-size effect in such movements may result in inconsistent or incorrect conclusions being drawn from such data.

However, the sample used by Duncan et al. (5) was elite jump-based athletes, and it is not clear whether their allometric model is applicable to the broad range of jump abilities seen in the wider pediatric population. Thus, there is a need to refine and improve the methods used to estimate peak power, currently available to practitioners and coaches by attempting to address the aforementioned limitations of previously validated peak-power estimation equations in children (5). The aims of this study were twofold: to examine the efficacy of current peak-power estimation equations in children and to examine the efficacy of an allometric scaling approach in estimating peak power in pediatric samples.

## Method

### Participants

Ninety one children aged 12–16 years (40 male, 51 female, age =  $14.3 \pm 1.3$  years, mass =  $53.5 \pm 11.4$ kg, height =  $160.1 \pm 10.1$ cm) from one secondary school in Coventry, UK, volunteered to participate in this study, following informed written consent, informed written parental consent, and institutional ethics committee clearance.

### Procedures

Actual peak power ( $PP_{\text{actual}}$ ) and maximal CMJ height were assessed using a portable Quattro Jump Portable Force Platform System (Kistler, Amherst, NY) at a sampling rate of 500 Hz. Participants were instructed to begin from a standing position and to perform a countermovement action with an arm swing immediately followed by a jump for maximal height. Jump technique was demonstrated to each participant

and was followed by two submaximal attempts. Three maximal jumps, separated by ample rest (>5 min), were then completed. One week test-retest reliability was indicated by a high correlation ( $R = 0.96$ ) for vertical-jump height based on a subsample ( $n = 20$  boys, 20 girls) of the same participant group but assessed before the experimental testing described above. All testing took place in the mornings between 9:00 a.m. and 11:00 a.m. Before testing, the children completed 24-hr recall questionnaires to ensure that they were adequately fueled and hydrated to complete the experimental procedures, and to confirm that they had not participated in vigorous exercise in the 24 hr before testing.

## Statistical Analysis

All statistical analysis was performed with the Statistical Package for Social Sciences version 20 (SPSS Inc, Chicago, IL). Statistical significance was set, a priori, at  $p = .05$ . A priori power analysis indicated that a total sample of 68 subjects was needed with a medium effect size (Cohen's  $d = .05$ ), at 80% power, with a  $p$ -value of .05. Pearson product moment correlations were used to determine the relationship between estimated peak power ( $PP_{est}$ ) using the Harman et al. (7), Sayers SJ, Sayers CMJ (18), and Canavan and Vescovi (3) estimation equations. Linear regression was also employed to identify the amount of variance in  $PP_{actual}$  that could be predicted from the different  $PP_{est}$  equations. Paired samples  $t$  tests were employed to examine any differences between  $PP_{actual}$  and  $PP_{est}$  from the different equations used. Analysis of covariance (ANCOVA) was also employed to examine any differences in  $PP_{actual}$  between boys and girls controlling for age. Multiple regression analysis was then used to determine a new equation using both a linear additive model (Eq. 1) and a proportional allometric model (Eq. 2).

$$PP_{est} = a_1 + b_1 \times (\text{age}) + c_1 \times (\text{body mass}) + d_1 \times (\text{CMJ height}) \quad (1)$$

$$PP_{est} = a_2 \times \exp(b_2 \times \text{age}) \times (\text{body mass } c_2) \times (\text{CMJ height } d_2) \quad (2)$$

Following a logarithmic transformation, the allometric model was fitted using ordinary multiple regression to estimate the unknown parameters,  $a_2$ ,  $b_2$ ,  $c_2$ , and  $d_2$ :

$$\text{Log}(PP_{est}) = \log(a_2) + b_2 \times \text{age} + c_2 \times \log(\text{body mass}) + d_2 \times \log(\text{CMJ height})$$

Such methods have been previously used and recommended by previous authors (12,13).

To fit and then cross validate these models, we used a random two-third split of our sample ( $n = 91$ ) to create new linear (Eq. 1) and allometric (Eq. 2) regression models. We then used the remaining one-third of the sample to determine validity of both linear and allometric models. SPSS was used to select a random sample of 60 children (select cases option) to estimate both the linear and allometric models, leaving the remaining sample of 31 children to cross-validate the utility of the models.

## Results

Using the full sample of 91 children, results indicated significant correlations between  $PP_{actual}$  and  $PP_{est}$  via the Harman et al. ( $r = .909$ ,  $p = .001$ ), Sayers SJ ( $r = .909$ ,  $p = .001$ ), Sayers CMJ ( $r = .908$ ,  $p = .001$ ), and Canavan and Vescovi ( $r = .893$ ,  $p = .001$ ) equations. All of the previously validated adult-based equations

significantly predicted  $PP_{\text{actual}}$  (all  $p = .001$ , see Table 1) predicting in the range of 79.5–82.5% of the variance in  $PP_{\text{actual}}$ , depending on the regression equation used. Paired samples  $t$  tests also indicated significant differences between  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  using the Harman et al. ( $p = .05$ ), Sayers SJ, and Sayers CMJ (both,  $p = .001$ ) equations. There was no significant difference in  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  using the Canavan and Vescovi equation ( $p > .05$ ). However, in all these cases, there was evidence of heteroscedasticity within these data (i.e., when absolute residuals were plotted and then correlated against mean values, correlations were in the range  $r = .350$  to  $.423$ , all  $p = .0001$ ). Mean  $\pm$   $SD$  of  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  using the aforementioned equations is presented in Table 1. When the residuals, i.e., differences between the estimated and actual PP values ( $PP_{\text{est}} - PP_{\text{actual}}$ ) were examined more closely, significant sex differences were observed for all four models, and in the case of the Canavan and Vescovi equation, a significant age effect was detected. This confirms the inadequacy of the adult PP equations to predict the children's PP data.

**Table 1 Mean  $\pm$  SD and Adjusted  $R^2$  Values for  $PP_{\text{actual}}$  (W) and  $PP_{\text{est}}$  (W) from Four Different Prediction Equations in British School Children**

Measure	Mean	SD		Adjusted $R^2$
$PP_{\text{actual}}$	2452.8	854.3		
$PP_{\text{est}}$				
Harman et al.	2528.7	861.5	*	.824
Sayers SJ	2250.1	851.8	**	.825
Sayers CMJ	2662.5	919.6	**	.823
Canavan and Vescovi	2494.1	790.9		.795

\*  $p < .05$

\*\*  $p < .001$  compared with  $PP_{\text{actual}}$

ANCOVA analysis indicated significant sex differences in  $PP_{\text{actual}}$  ( $F 1, 86 = 10.9$ ,  $p = .001$ ) with boys evidencing greater peak-power values compared with girls. Mean  $\pm$   $SD$  of peak power was  $2603.2 \pm 974.7$  W and  $2337.8 \pm 735.1$  W for boys and girls respectively. Age was also significant as a covariate ( $F 1, 86 = 6.975$ ,  $p = .01$ ) with every year increase in age being associated with an 80.3 W increase in peak power.

Based on the random sample of 60 children and using linear multiple regression, an additive linear model significantly ( $p = .0001$ ) predicted  $PP_{\text{actual}}$  (adjusted  $R^2 = .866$ ) from body mass and CMJ height, with the resulting regression equation:

$$\text{Peak power} = -2732.5 + (309.2 \times \text{boys}) + (110.6 \times \text{age}) \\ + (35.5 \times \text{body mass}) + (38.4 \times \text{CMJ height})$$

Note this equation predicts PP for girls as the baseline group and the boys PP deviations are incorporated using a [0, 1] indicator variable.

Using the validation sample of  $n = 31$  children, there was no significant difference between  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  employing this equation (paired sample  $t$  test,  $p = .151$ ). There was also a significant positive relationship between  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  using this equation ( $r = .910$ ,  $p = .0001$ ). The standard deviation of differences between  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  was found to be 360.6 W and the corresponding coefficient of variation was  $CV = 14.4\%$ . Mean  $\pm SD$  of peak power was  $2539.4 \pm 868.6$  and  $2443.9 \pm 787.9$  W for  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  respectively.

Based on the random sample of 60 children, an allometric model (Eq. 2) was then developed following log transformations of  $PP_{\text{actual}}$ , CMJ height, and body mass—as CMJ and body mass are employed in all the other validated estimation equations for estimating peak power—plus age. This resulted in a significant model ( $p < .0001$ , adjusted  $R^2 = .888$ ) predicting 88.8% of the variance in  $PP_{\text{actual}}$ .

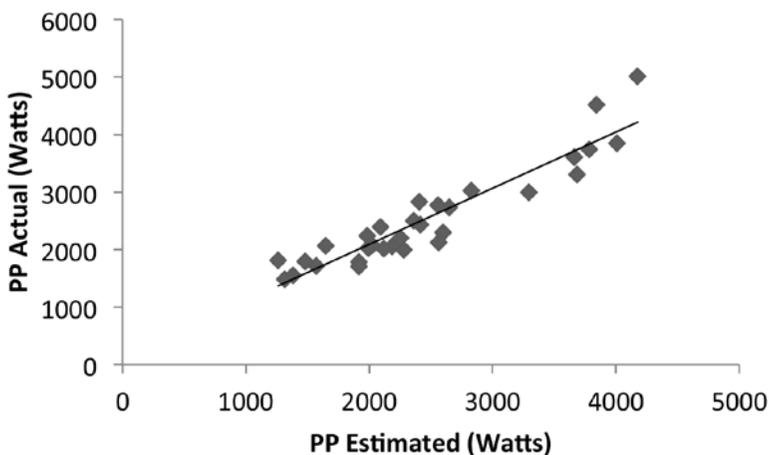
After taking antilogs, the model (Eq. 2) becomes:

$$\text{Peak power} = 3.717 \times (1.108 \times \text{boys}) \times \exp(0.054 \times \text{age}) \\ \times \text{body mass}^{0.829} \times \text{CMJ height}^{0.636}$$

Note this equation predicts PP for girls as the baseline group and the boys PP deviations are incorporated using an  $[0, 1]$  indicator variable.

The adjusted  $R^2$  increased from 0.866 to 0.888 when moving from the linear to the allometric model using the validation sample of  $n = 31$  children. The association between  $PP_{\text{actual}}$  (W) and  $PP_{\text{est}}$  (W) using the allometric model in this cross validation sample is shown in Figure 1.

Based on the paired sample  $t$  test, the allometric model's estimates were not significantly different ( $p > .05$ ) to  $PP_{\text{actual}}$ . The standard deviation of differences between  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  was found to be 304.5 W. The corresponding coefficient of variation was  $CV = 12.2\%$ . Mean  $\pm SD$  of peak power was  $2539.4 \pm 868.6$  W and  $2459.8 \pm 832.8$  W for  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  respectively.



**Figure 1** — The association between  $PP_{\text{actual}}$  (W) and  $PP_{\text{est}}$  (W) using an allometric modeling approach with a cross validation sample of 31 12- to 16-year-old children.

## Discussion

Previous research has identified that peak-power estimation equations developed on adult populations may not be suitable for predicting peak power in children and adolescents (19). Consequently, a need for authors to validate new equations using force platform data in this population has been identified (19). More recently, Duncan et al. (6) reported that using an allometric model produced an accurate estimation of actual peak power in elite adolescent basketballers. The results of the current study show that the peak-power estimation equations developed on adult samples are able to explain a significant amount of the variance in actual peak power in a pediatric, nonsports specialized sample. Despite this, there were significant differences in  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  using the Harman et al., Sayers SJ and Sayers CMJ. Although there was no significant difference between  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  using the Canavan and Vescovi equation, this particular equation was the poorest predictor of  $PP_{\text{actual}}$  in the current pediatric sample. The evidence of heteroscedasticity in all four adult-based models and examination of the residuals, which were unable to explain the differences between sexes and ages, confirm that these adult models are inadequate in explaining the known variance in peak power in pediatric populations. Thus, prompting a need to explore pediatric specific equations which account for sex and age.

The results of the current study also indicated that actual peak power varies between sexes and with age in children and adolescents. As such, if more accurate estimation of peak power is needed, these variables need to be accounted for. Moreover, prior equations (6,18) used the jump and reach test to assess vertical-jump height. Within this test, participants place a mark on a wall using chalk with their fingers at the top of their jump. The use of this method is problematic, as the contribution of trunk bend and shoulder elevation may not precisely measure the change in center of mass when jumping. In contrast, the current study avoided these methodological issues by using force-platform analysis to calculate jump height. In the current study, comparison of  $PP_{\text{actual}}$  and  $PP_{\text{est}}$  from the same jump offers a more valid method to determine precision of peak-power regression equations in jump-based athletes (6).

The results of the current study therefore support, at least partially, the claims made by Duncan et al. (5) that an allometric approach may be better suited in assessing peak power in children and adolescents. The regression equation developed in the current study from the current sample of trained, adolescent, jump-based athletes appears to be highly accurate. While the increase in the percentage variance predicted by the allometric model when compared with the linear additive model (2.2%) could be considered trivial and not meaningfully adding to the prediction of peak power, it is important—as any improvements from the existing models refines the estimation of peak power in pediatric samples. Previously validated equations based on additive models are less attractive than allometric models due to high negative intercept values that are biologically implausible. Despite this, the primary issue in this study is how well the models fit the data in the range of the data that actually exists.

Although few studies have compared allometric against linear models for estimating peak power in the literature, the finding that the allometric model was more strongly associated with peak power is not unexpected. The theoretical basis

for adjusting or normalizing for differences in body size has been employed since ancient Greek times (see 20 for a review) in understanding the geometry of and relationships between length, surface area, and volume in living things. Physiological and performance variables are frequently influenced by body size, and a number of prior studies have identified that allometric modeling better explains performance in a number of functional and performance tests in adult-based samples (9,14,15), including vertical-jump performance (14) in comparison with linear models. The performance capabilities of children are typically less than those of adults, and understanding to what extent performance differences are attributable to differences in body size is important in domains such as school physical education, sport performance, and talent identification. Moreover, allometric modeling has been demonstrated as superior in the prediction of children's physical performance (16,17). Although the outcomes of this study show some similarity between the linear and allometric models presented here, the allometric model performs marginally better than the linear model; this is because it predicts a greater amount of the variance in actual peak power and has a smaller coefficient of variation than the linear model. The allometric modeling approach also avoids the use of high negative intercept values, in some cases greater than  $-2000$  W, and has a zero intercept. This logically and statistically performs better than linear models. These assertions in regard to the current study are also consistent with prior studies on the same topic in adults (9,14,15) and children (16,17).

It can, however, be argued that the comparisons between the new and old equations are biased in favor of the new allometric equation generated in this study as a consequence of the statistical phenomenon of shrinkage. Shrinkage is associated with the quality of fit with a regression model. Common with any other research that generates a new regression model, it is possible that the results presented here are biased, as any regression equation will perform best on the sample it was derived from. However, the use of a two-thirds to one-third random split was employed to overcome this issue by creating a predictive model and cross-validating the model. The current results demonstrate that the peak-power regression equation developed in the current study was not significantly different from actual peak power when applied to an independent sample of 12- to 16-year-old children. It would, however, be useful for future research to cross validate the allometric equation presented in this study with other samples of children to confirm the findings presented here.

Accurate estimation of peak power is important in health and sport performance (2,6,19). The current study provides valid linear and allometric equations to estimate peak power in 12- to 16-year-old children that are not significantly different from actual peak power and are as accurate as previous adult-derived peak-power regression equations. These equations should therefore be considered for use by practitioners, physical educationalists, and coaches to estimate peak power from CMJ height in field-based settings where force-platform analysis is not available.

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