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Original Article

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Original Article drop

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Abstract

The purpose this study was to examine the effect of body size on countermovement jump (CMJ) kinetics in children. Participants (n = 160) aged 7-11 years, divided equally by sex and into primary school year groups (years 3, 4, 5 and 6), each performed one CMJ on a force platform. The variables bodyweight (BW), peak force (Fmax), in-jump minimum force (IMF), in-jump vertical force range (IFR) and basic rate of force development (BRFD) were attained from the force-time history and then subsequently scaled to account for body size. A significant age, sex and interaction effect were found for the absolute variables BW, IMF, Fmax and IFR ($P < 0.05$) between school year groups 3 and 4 against year's 5 and 6. Simple main effects highlighted no significant sex differences between the boys and girls for all variables ($P > 0.05$). No significant age or sex differences were observed for normalised or allometrically scaled values ($P > 0.05$). The results indicate that girls and boys can be grouped together but that body size must be accounted for to enable accurate conclusions to be drawn independent of growth. Body size significantly effects the representation of CMJ kinetic results and therefore, future studies should report both absolute and scaled values. Future research should develop an age-appropriate criterion method for children in order to determine processed CMJ variables to further investigate neuromuscular performance of children.

Keywords: Muscular power, Force platform, Children, Performance, Start time

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Introduction

Neuromuscular performance describes the force-generating capacity of the muscle (Weir, 2006; Yong & Schoonen, 2000), and can be measured via a range of different methods. One of the most common methods used in applied research utilises a countermovement jump (CMJ) to measure neuromuscular performance (Gissis et al., 2006; Owen, Watkins, Kilduff, Bevan, & Bennett, 2014).

The assessment of CMJ variables in children has traditionally been used as a surrogate measure of maturation and natural development (Malina, Bouchard, & Bar-Or, 2005). For example, Taylor et al. (2010) investigated the CMJ variables in 1845 school children aged 10-15 years demonstrating significant age effects on jump height (JH) and estimated peak power output (PPO). However the use of an instrumented jump mat, and arm swing to attain JH and application of an adult regression equation (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999) to attain PPO confounds further interpretation of their data, and accuracy of the results attained from estimate regression equations (Harman, Rosenstein, Frykman, Rosenstein, & Kraemer, 1991; Lara, Abián, Alegre, Jiménez, & Aguado, 2006). More recently, the assessment of CMJ variables has been applied as a potential screening tool for examining muscle function in children at risk of musculoskeletal impairment (Korff, Horne, Cullen, & Blazevich, 2009). However, the methods to determine CMJ variables, such as mechanical power and impulse, have been employed without first establishing the reliability, validity, and criterion method for determining specifications, making it inapplicable and limiting to the conclusions that can be drawn. A number of variables such as bodyweight (BW) and peak force (Fmax), can be identified regardless of age or sex. These variables are described as unprocessed variables as they are independent of the elite adult criterion method and can be calculated by inspection of the force-time history of a CMJ. In contrast a processed variables such as mechanical power, and jump height are all dependent on the elite adult criterion method and therefore cannot currently be used for children as no criterion method exists for children (Owen et al., 2014). Given the considerable anthropometric, physiological and biomechanical differences between children and adults, the elite adult criterion method is unlikely to provide valid and reliable measures in children. Indeed, differences in CMJ variables have not yet been fully characterised in children, and the concomitant influence of growth has not been accounted for; many neuromuscular performance variables demonstrate a strong positive relationship with body size (Jaric, 2002). Therefore, this must be considered when producing normative reference data or comparing across populations and participants

Statistical techniques may be used in order to remove the influence of body size on neuromuscular performance variables. This is typically achieved by dividing the value by BW, body height or body mass to attain a normalised value, commonly known as the "per ratio standard" (Nevill & Holder, 1995). The assumption is that this value is now independent of body size and valid comparisons between participants and population groups can be made. This ratio standard has been extensively used within the paediatric literature. For example, Focke et al, (2013) investigated the effects of age, sex and activity level on CMJ performance in children and adolescents, showing that absolute jump height (JH) increases significantly with age. However, when JH was normalised to body height, the influence of age was ameliorated. The use of the per ratio standard has come under significant criticism, as the statistical technique used to normalise neuromuscular performance variables may be invalid unless the relationship between neuromuscular performance and body size is directly proportional, which is rarely observed (Jaric, Mirkov, & Markovic, 2005; Nevill & Holder, 1995).

Allometric scaling/modelling has been deemed a more suitable and valid method for removing the influence of body size as allometric models naturally help to overcome the heteroscedasticity, non-normality and skewness observed with per ratio variables (Nevill & Holder, 1995). Limited research exists for the measurement of allometrically scaled CMJ variables measured via a force platform. For example, Duncan et al. (2013) investigated estimated peak power in junior basketballers comparing linear and allometric model. The author's concluded that the allometrically scaled regression model may provide a biologically sound and more accurate estimation of peak power in adolescent basketball players. This study highlights the need for further research to elucidate the influence of accounting for body size when interpreting the influence of age on CMJ performance parameters. Therefore, the aim of this study was to examine the effect of body size on unprocessed CMJ kinetics in children aged 7 to 11 years.

Methodology

Participants

Force-time histories were collected for 160 primary school children aged 7 to 11 years. The participants were comprised of four groups, with each group consisting of 20 boys and 20 girls. Anthropometric measures for the participants are presented in Table 1. Participants (n = 160) were randomly selected from school years 3, 4, 5 and 6 using a random number generator in EXCEL (Microsoft, 2013) to represent the 20 boys and 20 girls for each school year. The University Ethics committee approved all experimental procedures, and all participants were volunteers and gave informed written and verbal assent. Further permission for any participants under the age of 18 years was obtained from the children's parents/guardians.

Experimental Approach to the Problem

Each children performed one CMJ with hands on hips. The instruction given for the CMJ was to jump as high as possible, a reliability pilot study was previously performed, whereby 3 CMJs were performed in the morning and 3 CMJs were performed, with a 5 minute rest between each rep in the morning and afternoon. The results of the pilot study indicated that a CMJ is a very reliable neuromuscular performance test in primary school children, as there was no significant difference between attempt number ($P > 0.05$) or the combination of sex and attempt number ($P > 0.05$). Mean ICC values of 0.923 for girls and 0.971 for boys was found across 6 trials.

Experimental Procedure

All participants undertook a standardized warm up(2 minutes of sub maximal running which was then followed by 10 x squats, lunges, countermovement jumps, horizontal bounds and vertical hops) , prior to undertaking one maximal CMJ. All participants were given standardised instruction to stand on the force platform (model number 92866AA, Kistler Instruments Ltd., Farnborough, United Kingdom) with a 1 second period of quiet standing and to jump on the command of the tester. The analogue signal from the force platform was sampled at a frequency of 1,000 Hz chosen as this is the highest sampling frequency used to measure CMJ variables (Hatze, 1998; Kibele, 1998; Owen et al., 2014). A sample length of 10 seconds was used for all jumps. A 16-bit ADC resolution, 20 kN vertical force range was chosen according to the elite adult criterion method established by Owen et al, (2014). The force platform was factory calibrated and before testing underwent satisfactory calibration checks using masses that were traceable to national standards.

Measurements

The vertical ground reaction force (VGRF) measured by a force platform consists of the arithmetic sum of 4 individual vertical force signals originating from the 4 transducers of the platform. The force-time histories for each participant's CMJ were recorded and only unprocessed CMJ variables of the force-time history were determined for each participant as these variable can be used across age, sex and population.

Five unprocessed CMJ jump variables were identified and measured. Bodyweight was taken to be the mean value of the VGRF during a period 1 second of quiet standing of the CMJ test whilst the participant remained stationary prior to the signal to jump. Body mass was determined by dividing BW by acceleration due to terrestrial gravity (Thompson & Taylor, 2008). The Fmax of the jump was taken to be the one sample with the highest numerical value of the VGRF during the sampling period of the force-time history. The in-jump minimum value (IMF) of VGRF was taken as the sample with the lowest numerical value prior to Fmax force during the sampling period of the force-time history. The in-jump force range value (IFR) of VGRF was taken as the difference between the IMF and Fmax. In addition the time between these two points was also collected (in-jump vertical force range time (IFRt)). Basic rate of force development (BRFD) of the VGRF was taken as IFR divided by IFRt.

In order to control for the effects of BW on the CMJ variables. Each unprocessed CMJ variable was divided by BW. Units were then represented in BW's. In order to control for the effects of body mass an allometric modelling approach was used based on the recommendations of Nevill & Holder, (1995). This was preceded by Pearson product moment correlation coefficients to determine the degree of relationship between body mass and unprocessed CMJ variables. Logarithmic transformations were performed on each variable in addition to the variable body mass for boys and girls. A linear regression analysis was then applied to the logarithmic transformed data to determine the regression coefficients. Allometric scaled variables were then attained by

$$Allometric\ Scaled\ Variable = \frac{absolute\ variable}{BM^{b}} \qquad (2)$$

Whereby BM = body mass (kg) and ^{b} = coefficient

Statistical Analysis

Data was confirmed to be normal and variance was homogenous, a two-way analysis of variance (ANOVA) was used to determine the influence of age, sex and their interaction on absolute, normalised and allometrically scaled unprocessed CMJ force-time history variables. Bonferroni corrected post hoc t-tests and simple main effects (SME) were subsequently used to identify the location of significant differences due to sex and age. Statistical analyses were performed using SPSS software (Version 22; SPSS Inc., Chicago, IL), with significance set at $P \leq 0.05$. Effects sizes were determined using partial eta squared (n_p^2). Large magnitudes of effects were taken as $n_p^2 = 0.14$, medium-sized effects were $n_p^2 = 0.06$ and small effects were $n_p^2 = 0.01$ as proposed by Cohen, (1973). Data are presented as mean ± standard deviation.

Results

Participant anthropometric data are presented in Table 1.

******Insert Table 1 about here******

Absolute Countermovement Jump Variables

Significant age effects were found for BW, IMF, Fmax and IFR ($P < 0.0001$, $n_p^2 = 0.121$- 0.409; respectively) with post hoc t-test revealing the differences occurred between year groups 3 and 4 against year groups 5 and 6 ($P < 0.05$). No significant age effect was observed for BRFD ($P < 0.217$, $n_p^2 = 0.029$; respectively). No significant sex differences were observed between boys and girls ($P > 0.05$, $n_p^2 = 0.0001$- 0.015; respectively) or an interaction effect was observed for any of the absolute CMJ variables ($P > 0.05$, $n_p^2 = 0.002$-0.004; respectively) (Table 2; Figure 1). SME revealed no significant sex differences ($P > 0.05$) between boys and girls for any year group.

******Insert Table 2 about here******

******Insert Figure 1 about here******

Scaled Countermovement Jump Variables

No significant age differences occurred between any year group ($P > 0.05$, $n_p^2 = 0.017$- 0.052; respectively). No significant sex differences were observed between boys and girls ($P > 0.05$, $n_p^2 = 0.0002$- 0.011; respectively) or an interaction effect was observed for any of the normalised CMJ variables ($P > 0.05$, $n_p^2 = 0.003$-0.004; respectively) (Table 3). SME revealed no significant sex differences ($P > 0.05$) between boys and girls for any year group.

Results for logarithmic regression coefficient's for body mass to unprocessed CMJ variables were found for IMF (b = 1.540, P < 0.0001), Fmax (b = 0.752, P < 0.0001), IRF (b = 0.652, P = 0.756) and BRFD (b = 0.256, P = 0.076). No significant age differences occurred between any year group (P > 0.05, n_p^2 = 0.005- 0.042; respectively). No significant sex differences were observed between boys and girls (P > 0.05, n_p^2 = 0.0001- 0.008; respectively) or an interaction effect was observed for any of the allometrically scaled CMJ variables (P > 0.05, n_p^2 = 0.003- 0.005; respectively) (Table 3). SME revealed no significant sex differences (P > 0.05) between boys and girls for any year group.

****Insert Table 3 about here****

Discussion

The purpose of this study was to investigate the importance of accounting for body size in the interpretation of countermovement jump kinetics in children aged 7 to 11 years. This was achieved by comparing absolute, normalised and allometrically scaled unprocessed CMJ variables in children aged 7 to 11 years. The findings of this study demonstrated that sex does not influence CMJ performance in children aged 7 to 11 years however, a different cohort of children could still potentially show different results. The variables BW, IMF, Fmax and IFR were found to increase with age, although BRFD was not influenced. Normalising and allometric scaling to account for changes in body size ameliorated these apparent age-related effects, suggesting changes are not a function of age per se.

Absolute Countermovement Jump Variables

In agreement with previous studies (Sumnik et al., 2013; Temfemo, Hugues, Chardon, Mandengue, & Ahmaidi, 2009), no significant sex differences were observed for any absolute CMJ variables BW, MIF, Fmax, IFR and BRFD. CMJ sex differences appear to manifest from the ages of 12 in boys and girls, thought to occur as a result of the onset of puberty (Focke et al., 2013; Tanner, 1962; Temfemo et al., 2009), with boys developing greater leg lengths and muscle volumes than girls resulting in better CMJvalues (Bitar, Vernet, Coudert, & Vermorel, 2000; Temfemo et al., 2009). In contrast, Focke et al. (2013) observed significant age and sex effects in CMJ JH and normalised JH for all year groups in 1835 children and adolescents aged 4-17 years. It was not stated why significant sex differences occurred in children below the age of 11 years, though Focke et al, (2013) reported a high percentage of variability for the results of jump height in participants below 9 years of age (10-20%) stating that this CMJ performance variable should not be used for individuals.

The age-related effects observed in the present study where there was a significant difference between years 3 and 4 to years 5 and 6 may be attributable to the concomitant processes of growth and maturation; given that BRFD was not influenced by age this may suggest that this parameter is not sensitive to changes in body size and may be indicative that this is an appropriate parameter for use across the age and maturity spectrum. The findings of this study are in conjunction with Sumnik et al, (2013) who sought to develop reference data for jumping mechanography in 796 healthy children and adolescents aged 6-18 years, reporting that both peak mechanical power output (PPO) and Fmax values increased linearly with age in both sexes pre-puberty, with no significant difference between sexes. Significant differences were subsequently manifest in adolescents, with boys having significantly higher CMJ values. It should be noted, however, that fundamental details regarding the method of calculating PPO and specifications utilised to measure CMJ variable were missing from this study, thereby limiting inter-study comparison and the potential utility of this reference data. The current findings demonstrate similar patterns observed in other measured neuromuscular variables in paediatric populations. For example, previous research has demonstrated that sprint speed significantly increases every 2-3 years (Bassa, Kotzamanidis, Patikas, & Paraschos, 2001). The potential mechanisms for this increase is thought to be from increases in strength due to increases in body size (Bassa et al., 2001; Cherif et al., 2012), which is in agreement with the findings of this study. Furthermore, as there was significant differences between years 3 and 4 to years 5 and 6 this suggests that if absolute values are used for future studies investigating children they could potentially be divided into sub-groups years 3 and 4 combined and years 5 and 6 combined.

Scaled Countermovement Jump Variables

Age and sex had no effect on unprocessed CMJ variables normalised peak force (NFmax), normalised in-jump minimum force (NIMF), normalised in-jump force range (NIFR) and normalised basic rate of force development (NBRFD). The findings of this study were in accord with previous research which identified no significant age differences between NFmax and normalised RFD and no other studies have investigated NIMF and NIFR CMJ values. If significant differences had occurred across year groups for NFmax, in addition to the absolute findings of Fmax this would have identified the changes would have occurred independent of body size. The potential mechanisms would therefore be considered to be neuro-developmental changes in performance which is a common belief in pre-pubertal strength and conditioning research (Lloyd & Oliver, 2013). This study demonstrates that changes in absolute CMJ variables in primary school children are predominantly a result of increases in body size and therefore contradicts this common belief. Though NFmax remained constant previous research has found normalised RFD to actually decrease with age (Focke et al., 2013), this was also highlighted with the findings of this study though the decrease in NBRFD with age was not significant. The findings of this study (no sex differences between any primary school year group) is further supported by Busche et al. (2013) and Gabel et al. (2016) who investigated reference data for jumping in children, adolescent and young adults. The results of both studies highlighted significant sex and age differences but were not observed until the age of 11 years, after which boys demonstrated higher values of normalised PPO to body mass and normalised Fmax to BW. However, as previously stated the validity of the three studies highlighting normalised CMJ force-time variables may be questioned, which further highlights a need for a valid criterion method for determining processed CMJ variables in children.

Age and sex had no effect on unprocessed CMJ variables allometrically scaled peak force (AFmax), allometrically scaled in-jump minimum force (AIMF), allometrically scaled in-jump force range (AIFR) and allometrically scaled basic rate of force development (ABRFD). Allometric scaling seeks to enable inter-group comparisons independent of the potential confounding influence of differences in body size. In the present study, when CMJ variables were allometrically scaled, the previously observed age-related differences were ameliorated. There is a lack of research considering the influences of body size in the interpretation of age and sex related differences in CMJ performance. Although some previous studies have examined the allometric scaling of CMJ performance in children, it has been for the purpose of predicting performance by other means (Duncan et al., 2013) or by investigating intra-subject variability (Raffalt, Alkjær, & Simonsen, 2016). Specifically, Raffalt, Alkjaer & Simonsen (2016) demonstrated that allometrically scaled knee joint power and Fmax was greater in children when compared to adults, but the results were only reported graphically.

The results of this study demonstrate that, firstly, boys and girls can be grouped together as there are no significant differences between any absolute, normalised or allometrically scaled CMJ variables. If body size is accounted for children aged 7 to 11 years can also be represented as one homogenous group. Secondly, the effect of body size significantly effects the representation of results and, therefore, any future studies must consider and report both absolute and scaled variables in order to enable appropriate comparisons across studies. This is vital for research investigating changes in performance which should be considered independently of the natural increases in performance engendered by increases in body size with age. A potential limitation of this study is the use of school year groups to classify comparison groups. Indeed, whilst parametric assumptions of normality and homogeneity of variances were maintained for each group in the present study by taking randomised samples from a larger pool of data, the current method of assessing children by year group may not be representative as testing took place at only one time point in the year. This may result in a skewed distribution as the youngest and oldest possible ages are not measured in the year group. Previous research has suggested the 3 month intervals for the frequency of assessment for longitudinal tracking of maturation status as it enables worthwhile changes in growth to take place (Lloyd, Oliver, Faigenbaum, Myer, & De Ste Croix, 2014; Stratton & Oliver, 2013). Nonetheless, the applicability of this to CMJ variables remains to be elucidated.

Conclusion

This study has highlighted a number of significant findings for the application and representation of force-time history data collected from a CMJ in children. Absolute CMJ kinetic variables are sensitive to change and therefore within year groupings should occur. Body size significantly effects the interpretation of the results and, therefore, future studies must consider and report both absolute and scaled values. The development of an age appropriate criterion method for children should be developed in order to further investigate the neuromuscular performance of children aged 7 to 11 years.

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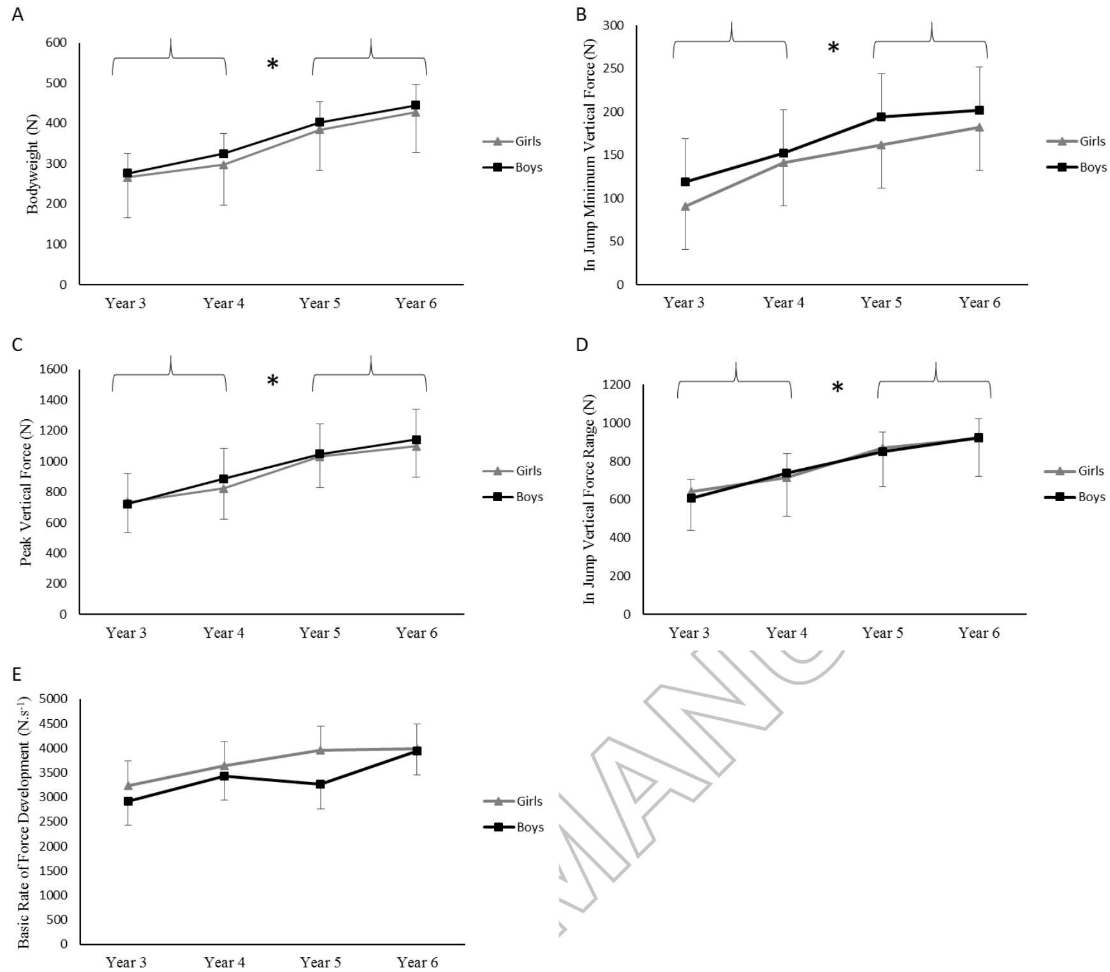

Figure 1. Effects of age and sex on absolute CMJ variables, bodyweight (A), in-jump minimum vertical force (B), peak vertical force (C), in-jump vertical force range (D) and basic rate of force development (E) of countermovement jumps by year groups; asterisk (*) indicates significant difference between school year groups 3 and 4 to school years 5 and 6 (P < 0.05)

Table 1. Anthropometric data by group and sex for age, stature and body mass

Group	Age (years)		Stature (m)		Body Mass (kg)	
	Girls (N = 20)	Boys (N = 20)	Girls (N = 20)	Boys (N = 20)	Girls (N = 20)	Boys (N = 20)
Year 3	8.0 ± 0.6	8.1 ± 0.7	1.29 ± 0.13	1.37 ± 0.16	27.1 ± 6.1	28.1 ± 7.9
Year 4	9.4 ± 0.5	9.2 ± 0.7	1.39 ± 0.19	1.49 ± 0.19	30.3 ± 6.2	33.2 ± 5.8

Year 5	10.2 ± 0.7	10.0 ± 0.7	1.39 ± 0.14	1.37 ± 0.06	36.2 ± 8.1	41.2 ± 10.4
Year 6	10.9 ± 0.8	10.8 ± 0.7	1.46 ± 0.11	1.43 ± 0.11	43.6 ± 10.6	37.8 ± 8.4

Mean ± standard deviation

Table 2. Effects of age and sex on absolute CMJ unprocessed variables

	Bodyweight (N)		In-Jump Minimum Vertical Force (N)		Peak Vertical Force (N)		In-Jump Vertical Force Range (N)		Basic Rate of Force Development (N/s)	
Group	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Year 3	266 ± 59	276 ± 77	91 ± 38	119 ± 79	733 ± 133	722 ± 150	641 ± 141	606 ± 134	3243 ± 1115	2926 ± 1643
Year 4	297 ± 61	325 ± 56	141 ± 160	152 ± 80	823 ± 177	885 ± 161	714 ± 171	740 ± 168	3638 ± 1797	3438 ± 2357
Year 5	384 ± 69	403 ± 10	162 ± 61	194 ± 68	1031 ± 230	1046 ± 202	868 ± 216	851 ± 173	3954 ± 2030	3265 ± 1343
Year 6	427 ± 103	445 ± 97	182 ± 95	202 ± 106	1098 ± 274	1140 ± 233	920 ± 248	924 ± 188	3991 ± 1743	3948 ± 2548
Age: P (n_p^2)	P < 0.0001 (0.409)		P < 0.0001 (0.121)		P < 0.0001 (0.381)		P < 0.0001 (0.295)		P = 0.217 (0.029)	
Sex: P (n_p^2)	P = 0.137 (0.015)		P = 0.126 (0.015)		P = 0.396 (0.005)		P = 0.851 (0.000)		P = 0.295 (0.007)	
Age * Sex: P (n_p^2)	P = 0.966 (0.002)		P = 0.961 (0.002)		P = 0.860 (0.005)		P = 0.990 (0.004)		P = 0.886 (0.004)	

Mean ± standard deviation

Table 3. Effects of age and sex on normalised and allometrically scaled CMJ unprocessed variables

Variable	Sex	Year 3	Year 4	Year 5	Year 6	Age, Sex, Age *Sex)
NIMF (BW)	Girls	0.35 ± 0.14	0.47 ± 0.56	0.42 ± 0.13	0.42 ± 0.18	P > 0.05
	Boys	0.40 ± 0.19	0.45 ± 0.20	0.47 ± 0.10	0.43 ± 0.15	P > 0.05
NFmax (BW)	Girls	2.80 ± 0.34	2.80 ± 0.51	2.68 ± 0.32	2.57 ± 0.25	P > 0.05
	Boys	2.69 ± 0.50	2.75 ± 0.50	2.65 ± 0.44	2.60 ± 0.41	P > 0.05
NIFR	Girls	2.44 ± 0.38	2.45 ± 0.58	2.25 ± 0.35	2.15 ± 0.34	P > 0.05

(BW)	Boys	2.29 ± 0.61	2.31 ± 0.62	2.17 ± 0.48	2.13 ± 0.44	P > 0.05
NBRFD ($BW.s^{-1}$)	Girls	12.44 ± 3.91	12.75 ± 6.64	10.08 ± 4.14	9.26 ± 3.38	P > 0.05
	Boys	11.45 ± 7.31	11.14 ± 8.58	8.62 ± 4.53	9.20 ± 5.95	P > 0.05
AIMF ($N.BM^{b-1}$)	Girls	11.32 ± 4.45	15.98 ± 18.73	15.69 ± 5.14	16.42 ± 7.33	P > 0.05
	Boys	13.58 ± 7.12	16.08 ± 7.61	18.02 ± 4.33	17.28 ± 7.28	P > 0.05
Afmax ($N.BM^{b-1}$)	Girls	55.85 ± 5.62	57.39 ± 9.82	58.16 ± 7.48	56.98 ± 6.29	P > 0.05
	Boys	53.89 ± 8.72	57.43 ± 9.66	57.74 ± 8.19	58.05 ± 7.98	P > 0.05
AIFR ($N.BM^{b-1}$)	Girls	68.61 ± 9.88	71.16 ± 15.74	71.69 ± 12.30	70.58 ± 12.24	P > 0.05
	Boys	64.41 ± 14.7	69.34 ± 16.86	69.26 ± 12.88	70.16 ± 12.19	P > 0.05
ABRFD ($N.s.BM^{b-2}$)	Girls	990.51 ± 308.05	1077.48 ± 534.91	1044.50 ± 491.18	1016.63 ± 405.40	P > 0.05
	Boys	900.00 ± 523.84	990.91 ± 706.95	871.06 ± 384.99	1006.64 ± 629.53	P > 0.05

Mean ± standard deviation