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Original Article

Bilateral deficit in vertical jumping in pre-pubertal boys and girls

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Abstract
The purpose of the study was to compare bilateral deficit in jumping (i.e. when the sum of left and right leg jump height is greater than the two-leg jump) between pre-pubertal boys and girls. One hundred and seventy two children (83 boys and 89 girls between) were divided into two groups (10 and 12 years old) and performed one-leg and two-leg counter movement jumps without arm swing on a contact mat. The bilateral jump deficit index was calculated as: 1-(right+left leg jump height)/two-leg jump height x 100. Peak leg power output during jumping was also calculated and was scaled with body mass. Jump height and relative leg peak power were similar in boys and girls of both age groups. However, the bilateral jump deficit index was always greater and positive in boys compared with girls, indicating that the two-legged jump performance was better than the sum of right and left leg jumps. This difference between boys and girls remained even when training history was taken into account (trained vs. untrained children), indicating that it is independent of training status. Also, when differences in bilateral deficit were examined with analysis of covariance, with maturity offset (an index of biological maturation) as the covariate, boys still had greater values than girls (12.9±2.0 vs. -1.6±2.3%, $p<0.01$). In conclusion, the results of the present study indicated that the there was no bilateral deficit for vertical jumping for boys at this age range. In contrast, girls had a bilateral index that was close to zero, indicating equal two-leg and sum of two legs jumps. These differences between boys and girls may be explained by a reduced ability to activate motor units during pre-puberty and/or superior motor skill ability (i.e. balance on one leg and jump) of girls over boys at that age.
Key words: countermovement jump, muscle power, children, biological maturation

Introduction

The bilateral deficit in vertical jumping occurs when the summed unilateral jump height is greater than the bilateral jump height. This phenomenon has been described in early studies involving maximal voluntary isometric contractions of the legs in adult populations (Secher et al., 1978) and has been attributed to a reduced neural drive and failure to activate maximally the muscles of the two limbs when they contract together (Vandervoort et al., 1984; Kawakami et al., 1998). The bilateral deficit has been observed in both trained and untrained individuals (Secher et al., 1988; Archondides & Fazey, 1993) while the magnitude of the reduction in maximal isometric force may range from -3 to -25% (Secher et al., 1978, 1988)

The bilateral deficit has also been observed in explosive movements such as dynamic leg press (Hay et al., 2006) and vertical jumping (van Soest et al., 1985; Challis, 1998; Bobbert et al., 2006), but the proposed mechanisms explaining it at these movement patterns are not confined to neural drive, but are extended to muscle mechanics (Bobbert et al., 2006) and changes in muscle coordination patterns (Rejc et al., 2010). However, the reduction in two-legged jumps compared with the sum of one leg jumps is similar to that seen in isometric force (-17% to -20%; van Soest et al., 1985; Challis, 1998).

There are very limited data on bilateral deficit in young individuals. Kuruganti & Seaman (2006) examined the bilateral leg strength deficit in old, young and adolescent females using isokinetic knee exercise. They examined an adolescent population and found a bilateral deficit ranging from -20 to -32% that was similar in all age groups, with no change in myoelectric signal. It was suggested that the deficit was not solely the result of reduced motor unit activation. There is only one study comparing bilateral deficit between pre-pubertal, pubertal and post-pubertal males and females (Dunstheimer et al., 2001). However, testing was performed with one or two legs on a cycle ergometer, where participants sprinted for 30 s. The bilateral deficit in peak and mean power ranged from -8 to -20% and was more pronounced in females.

To our knowledge, no data exist on bilateral deficit in vertical jumping in pre-pubertal children. Since vertical jumping from one leg is a task that demands balance, coordination and power, the bilateral deficit may be different from that observed in static or seated exercise (e.g. Dunstheimer et al., 2001). Moreover, the decreased ability of pre-pubertal children to activate motor units may further affect bilateral deficit and this may change with maturation (Paasuke et al., 2000). Therefore, the purpose of the present study was to compare bilateral deficit in jumping between pre-pubertal boys and girls, taking into account biological maturation.

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Material & methods

Participants

One hundred and seventy two pre-pubertal children (83 boys and 89 girls) took part in this study. Participants were divided according to gender and their chronological age into two groups (10 and 12 years). The physical characteristics of the participants are shown in Table 1.

Table 1. Physical characteristics of the participants according to age and gender (mean ± SD)

Age group		Age (y)	Height (m)	Body mass (kg)	BMI (kg/m^2)	Leg length (m)	Maturity offset (y)
10	**Boys (n=59)**	10.1±0.4	1.39 ±0.07	36.6±7.9	18.7±0.4	0.68 ±0.04	-3.2±0.5†
	Girls (n=55)	9.9±0.4	1.39±0.07	35.3±6.1	18.4±0.3	0.68 ±0.04	-1.9±0.5
12	**Boys (n=24)**	11.5±0.4	1.49±0.06#	45.1±7.9#	20.2±0.7#	0.74±0.04#	-2.3±0.6†*
	Girls (n=34)	11.5±0.4	1.51±0.08#	45.4±7.5#	19.7±0.5#	0.75±0.04#	-0.4±0.6*

BMI: Body Mass Index; #: main effect for age group $p<0.01$; †: $p<0.01$ from girls in the same age group;
*: $p<0.01$ from corresponding gender in the 10 y age group

All children had experience in vertical jumping with one and two legs and were thoroughly familiarized with the measurements in three preliminary sessions. Prior to data collection, informed consent was obtained from a parent of each participant, after thorough description of the measurements to both the athletes and their parents. Training history was obtained by a personal interview. The study was approved by the local Institutional Review Board and all procedures were in accordance with the World Medical Association's declaration of Helsinki, as revised in 2008.

Data collection and analysis

Anthropometry: All measurements were taken in the morning (between 9:00 and 11:00) following standardized protocols (Lohman et al., 1988). Body mass was measured to the nearest 0.1 kg using a calibrated scale (Seca, Hamburg, Germany, model 888,). Height and sitting height were measured with a stadiometer (Seca, Hamburg, Germany model 217). Subischial height was determined by subtracting sitting height from height.

Biological maturity was estimated by calculating the "maturity offset", that is, time (in years) before or after peak height velocity (PHV), using the equation of Mirwald et al. (2002). The age of PHV is an indicator of maturity, and represents the time of maximum rate of growth during adolescence. For example, a maturity offset of -2.0 years indicates that measurements were taken 2 years before the PHV. The maturity offset was calculated using different equations for boys and girls (Mirwald et al., 2002) as follows:

Maturity offset for boys= -9.236 + 0.0002708 x leg length and sitting height interaction -0.001663 x age and leg length interaction + 0.007216 x age and sitting height interaction +0.02292 x weight by height ratio,
R^2 = 0.89 and SEE = 0.59.

Maturity offset for girls= -9.376 + 0.0001882 x leg length and sitting height interaction + 0.0022 x age and leg length interaction + 0.005841 x age and sitting height interaction -0.002658 x age and weight interaction + 0.07693 x weight by height ratio where R = 0.94,
R^2 = 0.89 and SEE = 0.57.

Length measurements are in centimetres and weight measurements are in kilograms; the weight by height ratio is multiplied by 100.

***Vertical jump performance**:* A standardized warm-up preceded the each testing session, consisting of 5 min light jogging, 2 x 15 s bouts of static stretching, followed by dynamic stretching of the quadriceps, gastrocnemius and hamstrings. On the first occasion, 5 min after the warm-up, participants performed one-leg and two-leg counter movement jumps (CMJ) with the arms held on the hips, on a contact mat connected to a clock counter (Lafayette Instrument, Models 63517 and 54060, respectively). Jump height was calculated from flight time as described by Bosco et al, (1983). Care was taken to maintain good technique in all jumps, leaving the mat with the knees and ankles extended and landing with straight knees on the same spot in the upright position. Three trials were made with 1 min rest in between and the best jumps (for each leg and for both legs) were kept for analysis. The intra-class correlation coefficient (ICC) for the CMJ tests was 0.98 ($p< .001$).
The bilateral jump deficit index was calculated as:
1-(right+left leg jump height)/two-leg jump height x 100
Peak leg power output during jumping was also calculated using the equation of Sayers et al. (1999) and was scaled with body mass.

***Sprint performance**:* On the second occasion, 10 and 30 m sprint time was measured using photocells (Brower Timing Systems). Following the standardized warm-up, participants performed two 10 m sprints separated by 3 min rest. Five minutes later, each participant stood with the preferred leg on a line placed 0.5 m from the first pair of photocells. Measurement of time started when the participant broke the beam from the first photocell and a lap time was taken when the beam from the second pair of photocells was broken (10 m) and again at 30 m. Participants performed two trials, separated by a 5 min rest and the best was kept for analysis.

Statistical analysis

All statistical analyses were performed using the STATISTICA for Windows version 8.0 (Statsoft Inc., OK, USA). Data are presented as means and standard errors of the mean (SE). Two-way factorial ANOVA was used to examine possible differences in performance variables between the two genders and the two age groups (age group x gender) and between the two genders and the trained/untrained participants (training history x gender). Furthermore, analysis of covariance (ANCOVA) was used to examine the differences in bilateral jump deficit between boys and girls with different training history and age, with maturity offset as a covariate. Due to the fact that the age groups had unequal number of participants, an unequal n HSD post – hoc test was performed whenever appropriate ($p<0.05$) to locate differences between means. Statistical significance was accepted at $p< 0.05$.

Results

Biological maturity

The calculated age at PHV was 13.5±0.5 and 11.8±0.5 years for boys and girls, respectively. The two-way ANOVA revealed main effects for both gender and age group ($p<0.01$), as well as a gender by age group interaction ($p<0.01$) for the maturity offset, i.e. the years remaining until PHV (Table 1). Thus, girls in the 12 y old group were very close to PHV (-0.4±0.6 years), while the boys in the same group were 2.3±0.6 years before PHV. Therefore, biological maturity was largely different between boys and girls in both age groups, despite the fact that their anthropometric characteristics were similar (Table 1).

Vertical jump performance

The height of the CMJ was similar for boys and girls in both age groups (Table 2). As expected, leg peak power (PP) in absolute units (Watt) was greater in the 12 y old group, due to the greater body mass. However, when scaled for body mass, PP was similar in both age groups and genders (Table 2).

Despite the similar CMJ and leg PP, the bilateral jump deficit index was greater in boys than in girls for both age groups (main effect gender, $p<0.01$) and was also greater in the 12 year old compared with the 10 year old group (main effect age group, $p<0.02$; Fig. 1). Thus, boys had always greater bilateral jump deficit index (mean value irrespective age groups, boys vs. girls: 9.0±1.6vs. 1.4±1.5%).

Table 2. Vertical jump performance for boys and girls in the two age groups (mean ± SD)

Age group		CMJ (cm)	PP (W)	PP/kg (W/kg)
10	Boys (n=59)	23.3±4.7	1015±409	27.3±8.7
	Girls (n=55)	22.4±6.0	912±358	25.6±8.5
12	Boys (n=24)	22.4±5.0	1343±568#	29.1±8.7
	Girls (n=34)	20.4±3.8	1210±454#	26.1±6.3

CMJ: countermovement jump; PP: peak power; PP/kg: peak power per kg body mass
#: main effect for age group

To examine any possible effects of training status on bilateral jump deficit, children were divided according to their participation in organized training in “trained” and “untrained”. Seventy percent of the boys and 62% of the girls were involved in organized training (at least 3 times per week, with at least one hour training time per session). Their training history (years of training) was 2.6±0.9 and 3.0±1.0 years for boys and girls, respectively. The physical characteristics when children were grouped according to gender and training status are shown in Table 3. As can be seen in Table 3, there was no difference in any anthropometric measurement between trained and untrained children of both genders. However, PP relative to body mass was greater in trained compared to untrained children (main effect training, $p<0.01$), with no differences between genders (Fig. 2). Again, the bilateral jump deficit index was much higher in boys compared with girls (main effect gender, $p<0.01$), with no main effect of training or a gender by training interaction.

Table 3. Physical characteristics of the participants according to gender and training status (mean ± SD)

Group		Age (y)	Height (m)	Body mass (kg)	BMI (kg/m^2)	Maturity offset (y)
Trained	Boys (n=58)	10.5±0.7	1.43 ±0.08	38.4±8.5	18.8±0.4	-3.0±0.7†
	Girls (n=55)	10.3±0.7	1.42±0.09	38.3±8.9	18.8±0.4	-1.5±0.8
Untrained	Boys (n=25)	10.6±0.7	1.41±0.09	40.5±11.0	20.1±0.7	-2.9±0.8†
	Girls (n=34)	10.7±0.9	1.45±0.10	40.6±9.1	19.0±0.5	-1.1±1.0

†: $p<0.01$ from girls

The two analyses of covariance of the bilateral jump deficit index (age group x gender, and training history x gender), with maturity offset as the covariate, revealed only a highly significant gender main effect ($p<0.01$), with no other significant differences. The least square adjusted means of the bilateral jump deficit index for boys and girls were 12.9±2.0 vs. -1.6±2.3%, ($p<0.01$) for the first analysis (age group x gender) and 12.3±1.9 vs. -1.1±1.9%, ($p<0.01$) for the second analysis (training history x gender).

Sprint performance

Sprint performance, as assessed by measuring the 30 m sprint time is shown in Fig. 3. A main effect was found for gender ($p<0.02$), with boys being faster than the girls. Also, a main effect for age group was found ($p<0.01$), with children in the 12 year old group being faster than those in the 10 year old group.

Discussion

The main finding of the present study was that the bilateral jump deficit index was high and positive (7-13%) for boys, indicating what was termed as "bilateral facilitation" (Howard and Enoka, 1991), i.e. the two-leg jump was higher than the sum of the right and left leg jumps. In contrast, girls had lower bilateral jump deficit index that was around zero, indicating similar two-leg and sum of right and left leg jumps. More importantly, these results were largely unaffected by training status, while there was an increase in bilateral jump deficit index with age (Fig. 1).

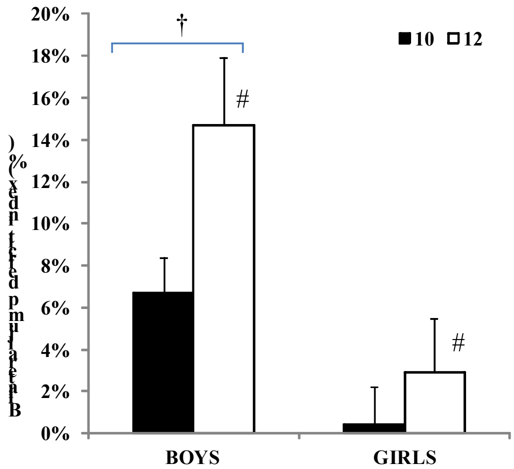

Fig. 1. Bilateral jump deficit index (%) for boys and girls in the 10 and 12 y old groups. A positive bilateral index indicates that the two-legged jump performance is better than the sum of right and left leg jump performance. There was a main effect for gender (†: $p<0.01$, boys had higher bilateral index than girls) and a main effect for age group (#: $p<0.02$, children in the 12 y old group had higher bilateral index than those in the 10 y old group).

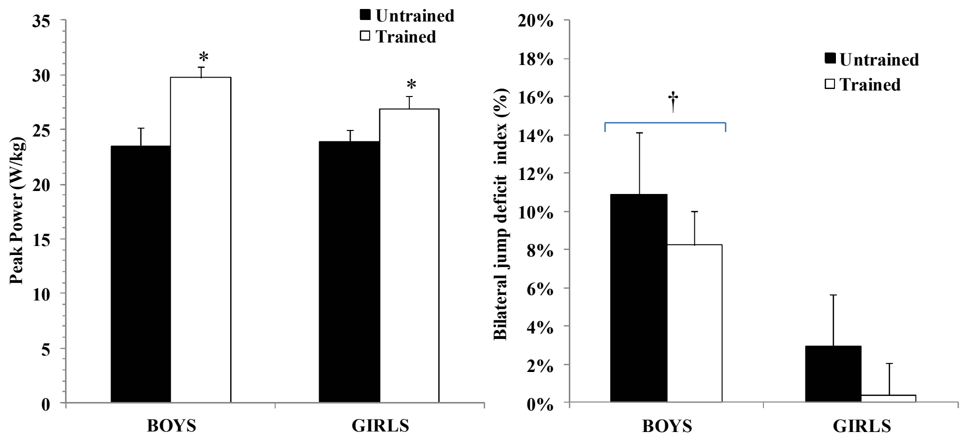

Fig. 2. Peak power expressed (W/ kg body mass; left panel) and bilateral index (right panel) for boys and girls classified as "trained" and "untrained". There was a main effect for training (*: $p<0.02$, trained children had higher peak power than untrained children, left panel). A main effect for gender was found for bilateral index (right panel; †: $p<0.01$, boys had higher bilateral index than girls)

Differences between pre-boys and girls in bilateral deficit have been previously reported, although not to such a large degree, in the study of Dunstheimer et al. (2011). In contrast with the present study, the bilateral jump deficit index in the study of Dustenheimer et al. (2001) was always negative in both boys and girls (-8 vs. -12%, respectively), indicating bilateral deficit. This may be explained by the mode of testing, that was sprint cycling in that study, compared with countermovement vertical jump in the present study. This is because countermovement jump, especially with one leg, is a skill that demands balance, coordination as well as muscle power (Bobbert and van Soest, 2001). Thus, besides the possible neural factors, causing the bilateral deficit, jump performance with one leg may also be influenced by balance and coordination.

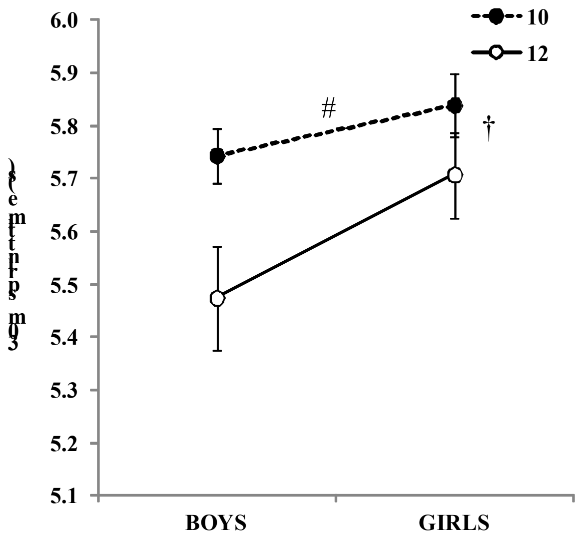

Fig. 3. Sprint performance (30 m) for boys and girls in the 10 and 12 y old groups. There was a main effect for gender (†: $p<0.02$, boys were faster than girls) and a main effect for age group (#: $p<0.01$, children in the 12 y old group were faster than those in the 10 y old group).

There are some indications in the literature suggesting that the gender differences in bilateral deficit found in the present study may be related with differences in balance and coordination (Stephens et al., 2007; Magnus and Farthing, 2008). Jurimae et al. (2007) observed secular declines over a 10 year period in flamingo stance test performance in children aged 11–12 years, suggesting that the sedentary lifestyle may have affected balance ability of children. Moreover, Hytonen et al. (1993) and Riach and Hayes (1987), reported differences in postural control between boys and girls, with girls being superior compared to boys, especially in the pre-pubertal period. Other studies have also shown a disadvantage of boys in motor skills during the pre-puberty (Prior et al., 1993). Krombhiltz (1997) found girls to be better than boys in some complex motor tasks such as jumping laterally and forward. Taken collectively, these findings support a possible difference in balance ability between boys and girls that may have affected single leg jump performance in the present study.

To our knowledge, this is the first study to report a positive bilateral jump deficit index. This means that for the boys there was not a bilateral deficit, but a bilateral facilitation, since the two-leg jump performance is greater than the sum of the right and left leg jump. A meta-analysis of data from a previous study (Shephard et al., 1988) reveals that this phenomenon has been previously recorded, although not analyzed. Calculation of bilateral deficit from data from males and females performing single and two leg incremental cycling in that study (Shephard et al., 1988), yielded a bilateral deficit index of -11% for females, and +8% for males. This may be related with neural mechanisms (Howard & Enoka, 1991), such as reduced motor neuron excitability, especially of the fast twitch fibres (Vandervoort et al., 1984; Kawakami et al., 1998). The sparse data on muscle fibre composition in children suggest that they have a lower percentage of fast twitch fibres compared with adults, while adult proportions of fast twitch fibres are attained during late adolescence (Jansson, 1996, Oertel, 1988). In fact, children under 9 years of age would have a higher percentage of the less fatigable type I fibres than young adults (Oertel, 1988). A possibly lower percentage of fast twitch fibres may partly explain the lack of bilateral deficit in boys and the observation that bilateral jump deficit index increases with age (Fig. 1).

From the above discussion, it seems that the difference in bilateral deficit between boys and girls is related with biological maturation. Several studies have examined the contribution of chronological age, biological maturation, and different anthropometric characteristics to performance in young athletes (Malina et al., 2005; Mujika et al., 2009; Mendez-Villanueva et al., 2011). In the present study, the maturity offset, an index of biological maturation quantifying the time distance of the chronological age from PHV (Mirwald et al., 2002) was lower in females, indicating a more advanced biological maturation compared with the boys. The more advanced biological maturation of the girls in the present study may result in superior motor skill abilities (Prior et al., 1993; Krombholz, 1997) and thus improved motor control when performing single leg jumps. Taniguchi et al. (2001) suggested that there may be a central component underlying the bilateral deficit, and thus a more mature motor cortex may explain the superior ability of girls to perform better in single leg jumps than the boys. Rejc et al. (2010) measured electromyographic activity of leg muscles during explosive contractions and found that the bilateral deficit may be due to differences in muscle coordination. Paasuke et al., (2000) also demonstrated a decreased ability to activate motor units during pre-puberty compared to puberty and adolescence. Thus, a more advanced biological maturation may also influence muscle coordination, and this may explain the differences between boys and girls as well as the differences between the 10 y and the 12 y old group in bilateral jump deficit index. An important finding of the present study was that the differences observed in bilateral deficit during jumping between boys and girls, were not affected by jump performance or training status. This suggests that these differences are due to a pure gender effect and not due to training or motor learning.

Conclusions

In conclusion, the results of the present study indicated that the there was no bilateral deficit for vertical jumping for boys at this age range. The bilateral index was high and positive (7 to 13%), indicating that boys cannot jump as efficiently with one leg, possibly due to lower balance ability and/or a reduced ability to activate motor units compared with the more biologically mature girls. In contrast, girls had a bilateral jump deficit index that was around zero, indicating similar two-leg and sum of right and left leg jumps. These results were largely unaffected by training status, while there was an increase in bilateral jump deficit index with age. The analysis of covariance, with maturity offset as the covariate, revealed the significant role of biological maturation on the change of bilateral deficit with age, but also showed that the differences between boys and girls do not only depend on biological maturation but are determined by gender-specific attributes in that period of growth.

Conflicts of interest: The authors declare that there are no conflicts of interest.

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