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STRENGTH AND VERTICAL JUMPING PERFORMANCE CHARACTERISTICS IN SCHOOL-AGED BOYS AND GIRLS

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Abstract. The purpose of the present study was to investigate differences in performance, regarding strength and power components of physical fitness, between boys and girls (mean age 7.58 years). They participated in a maximum isometric push-off force test, and vertical jumping test on a Kistler force platform. Variables were, $F_{maxiso,}$ F_{100}, IRelF, IRFD, IReaF, body fat (BF) and jumping height for all jumps. One-way analysis of variance (ANOVA) was used to test for differences between genders. Differences in all variables between boys and girls were determined. Significant differences were reported in $F_{100,}$ IRelF, IRFD, DJ_{max}, SJ_{max} and BF between groups ($F_{(1,175)}$=21.516, $F_{(1,175)}$ =7.338, $F_{(1,175)}$=21.316, $F_{(1,175)}$=6.968, $F_{(1,175)}$=15.256, and $F_{(1,175)}$=19.447, respectively, $p<0.05$). It was concluded that gender differences should be considered in case of developing specific test batteries, when it comes to identify specific strength and power characteristics in children. ***(Biol.Sport 23:367-378, 2006)***

Key-words: Strength – Rate of Force Development - Relative force - Jumping ability - Explosive force

Introduction

The importance of strength and power in the majority of sports is well-accepted and early identification of high strength and power levels can be a useful tool for talent identification, strength diagnosis, development of sport specific profile, and to record the effects of training [1,7,37]. Recently, in the field of strength and power assessment new data have been added, using combined tests, regarding maximum isometric strength and vertical jumping tests [28,29].

According to Aragon-Vargas [3] vertical jump tests are common in physical education, fitness, and sports programs, as a means to assess lower limb "power".

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Different types of jumps, demand different motor programs by the central nervous system, in order to execute the neuromuscular coordination necessary for the specific jump. The squat jump can be used as the most basic functional expression of explosive muscle strength, as it requires only concentric activation. Drop jump requires high eccentric activation followed by high concentric activation, which requires a very precise coordination and extensive activation of the motor units. As a result, the squat jump can serve as a baseline for the potential of explosive muscle strength and drop jump may indicate development of this potential [8,26]. Research studies regarding differences in jumping ability between genders in young populations, indicated that there were no differences between genders for DJ and SJ performance, in a sample of 11-12 year-children participating in various sports [6]. Moreover, results from a study by Crasselt *et al.* [13] showed that boys begin to jump higher than girls at the age of 14 years, when performed countermovement jumps. However there is a lack of research regarding gender differences in children, because in the previously mentioned studies participants were pre-pubertal or pubertal boys.

Isometric tests involve the application of a force against some form of immovable measuring device during a maximum voluntary contraction [1] and they are popular tests, which assess the force producing capacity of the neuromuscular system [15,32]. Both the rate at which isometric force can be developed and the maximal isometric force have been shown, by some researchers, to be significantly related to performance [16,36]. Moreover, research studies in young populations, focused, only, on pubertal, and pre-and post- pubertal boys and girls, recording isometric strength data for lower limbs. However, no mention was made with regard to gender differences [17,22,27,31]. As a result, there is, however, a lack of research on gender differences in childhood, regarding lower limbs isometric strength. According to Blimkie and Sale [9], females demonstrate consistently lower absolute composite strength scores (summed measures from several muscle groups) than males, but a fairly similar rate of increase in strength during the pre-pubertal years. However, strength gains and gender differences in strength during childhood appear to be closely related to changes in somatic growth, muscle size, and neuromuscular and neuroendocrine development. Heredity and lifestyle factors such as physical activity and sports participation can, also, influence strength [9]. However, gender differences in relative strength (per kg body mass) before puberty, is probably due in part to the higher proportion of body weight as fat in females during this period and sociocultural factors [9,20].

The current study tried to use a combined test battery, consisted of lower limb isometric strength test and vertical jumps, in order to diagnose sport performance in both school-aged boys and girls. The parameters, which were used, have been reported in other studies [28,29]. Thus, the purpose of the current study was to investigate differences in performance, regarding strength and power components of physical fitness, between school-aged boys and girls.

Materials and Methods

Sample: 111 boys and 65 girls, who had been selected as prospective athletes by sports clubs in Greece, participated in the study. All participants' parents gave their informed consent for participation in the study. Body fat percentage was assessed from the measurement of the triceps and subscapular skinfolds (BF) [34]. Body height (BH) and body weight (BW) were, also, measured using Seca stadiometer and scales (220 telescopic height rod and 712 Alta balance beam scale), respectively. The age and anthropometric data of the subjects are presented in Table 1.

Table 1
Age and anthropometric data of boys and girls participated in the study

	Male (n=111)	Female (n=65)
Age (years)	7.6±0.4	7.5±0.3
Body Height BH (cm)	128.3±5.2	128.5±5.2
Body Weight BW (kg)	29.5±4.7	30.8±5.7
Body Fat BF (%)	13.8±5.3	17.6±5.4

Instrumentation: Assessment variables were derived by the following instruments: a) a uniaxial load cell (AMD Co. Ltd., LC 4204 – K600) with an aluminum rubber plate situated vertically to the ground (combined error 1% and sampling frequency 1000 Hz) was used for maximal isometric force measurement (F_{maxiso}). A specially designed leg press apparatus was used for the measurement. The device was consisted of a metallic frame, a chair and a metallic bar under which the loadcell was situated. A Velcro strap was placed around the waist to stabilize the body. Load cell was connected to an A/D (analog/digital) transformation card, a computer Pentium III with a mathematical processor and special designed software for data signal receipt and processing, b) a Kistler 9281CA force platform sampling at 1000 Hz, was, also, used for all vertical jumps and c) Harpenden Callipers (British Indicators Ltd., UK) were used for body fat percentage measurement.

Testing procedure: Measurements were carried out in the laboratory of Sports Biomechanics. Prior to testing procedure, the subjects completed a warm up session, consisted of ten min running and two slow and two fast 20 m-sprints. After the completion of the testing procedure, there was 5- min a cool down session, consisted of jogging.

Isometric strength test: Maximal isometric force and force-time curve parameters of the bilateral leg extensor muscles (hip, knee and ankle extensors) were measured in a sitting position, so that the knee and hip angles were 90^o. This angle was selected according to the squat jump test, which started from a static semi-squatting position with a knee angle 90^o based on Murphy *et al.* [25] who have recommended that isometric tests be performed at the angle at which peak force was achieved in the performance of interest. The hip angle was set at 90^o (perpendicular back chair) to offer the best support to the subject during maximum voluntary isometric effort. Participants placed their feet to the metallic bar that was adapted to the load cell and performed a maximum bilateral voluntary isometric contraction. During maximum isometric effort a non movable- back chair supported the trunk, while the hands were kept crossed on the chest to minimize contractions with other muscles, while a Velcro strap was placed around the waist to stabilize the body. Participants were instructed to exert their maximum bilateral leg extensor force, as fast and hard as possible [5] during a period of maximum 3 s [2]. Three trials were completed for each participant divided by three- min interval and the best performance trial with respect to maximal force was used for the subsequent statistical analysis [2]. Calibration of the measurement system was achieved by using weights (5, 10 and 20kg weight discs) from 50 to 600kg. Input (input = weights) and output values (output = electric signal) presented a distinct linearity.

Vertical Jumping Tests: The participants performed two different types of jumps; squat jump (SJ) and drop jump (DJ) from 10 cm, 20 cm and 30 cm heights (DJ_{10}, DJ_{20} and DJ_{30} respectively). Squat jump (SJ) started from a static semi-squatting position with a knee angle 90^o of the knee flexion, followed by subsequent action, during which the leg and hip extensor muscles contracted concentrically. The starting position during drop jump was from an upright position on a box of the three different dropping heights (10, 20 and 30 cm). The participant dropped from the box and rebounded after a short contact with the ground for maximal height. Subjects were urged to “jump as high as possible”. The leg muscle work during the ground contact constituted the stretch-shortening cycle. The participants were instructed to jump with their hands on the hips, so as to eliminate the influence of the arm swing impulse. The jumps were performed on the Kistler force platform. Each jump was repeated three times, and the best performance was used for further analysis according to jumping height. A rest period of 1 min was allowed between the jumps [27]. Reliability indexes (r) ranged from 0.95 to 0.98, for the isometric strength test and 0.90 to 0.98, for vertical jumping tests [28,29].

Table 2
Means, standard deviations and statistical significance in all variables for both genders

Variables	Male (n=111)	Female (n=65)	F-ratio	Sig.
F_{maxiso} (N)	630±139.6	593.4±167.2	2.5	0.12
F_{100} (N)	290.4±92.5	221.9±98.1	21.5	0.000*
IRelF (index)	2.3±0.5	2.1±0.4	7.3	0.007*
IRFD (index)	46.4±13.4	37±12.2	21.3	0.000*
IReaF (index)	15.1±12.5	16.1±13.9	0.3	0.61
SJ_{max} (cm)	15.7±3.5	13.7±3	15.3	0.000*
DJ_{max} (cm)	15.5±3.4	14.1±2.9	7	0.009*

*significant at p<0.05

Assessed variables: Based on previous research [28,29,33], the following variables were chosen for analysis and they are depicted in Table 2: a) Maximal isometric force (F_{maxiso}), b) F_{100} maximum force achieved during the first 100 ms of F_{maxiso}, c) index of relative force (IRelF = F_{maxiso} / Body Weight-transformed from Kg into N), which assesses the ability of the muscular system to produce maximal force, normalized with body weight. Maximal force is a voluntary maximal contraction that the neuromuscular system can develop, d) index of rate of force development (IRFD = (F_{100}/F_{maxiso}) 100), which assesses the ability of the muscular system to produce high amounts of force in the time unit, or the ability of the neuromuscular system to develop a high level push in the available time (fast force development-power) [33], e) reactive force index, which assesses the ability of muscular system to react effectively in conditions that are related to fast stretch-shortening cycle (SSC), [33] using the additional elastic muscular elements (IReaF is the percent difference of maximal vertical jumps (SJ & DJ), having as staring point (0) the best performance in SJ (IReaF = (DJ_{max} – SJ_{max}/SJ_{max} X 100). Reactive force is the ability of the neuromuscular system to develop a high level push related to the fast stretch-shortening cycle [33]. Also, the jumping height performance of all jumps (SJ_{max}, DJ_{max}) was calculated and included in the variables assessed in the present study.

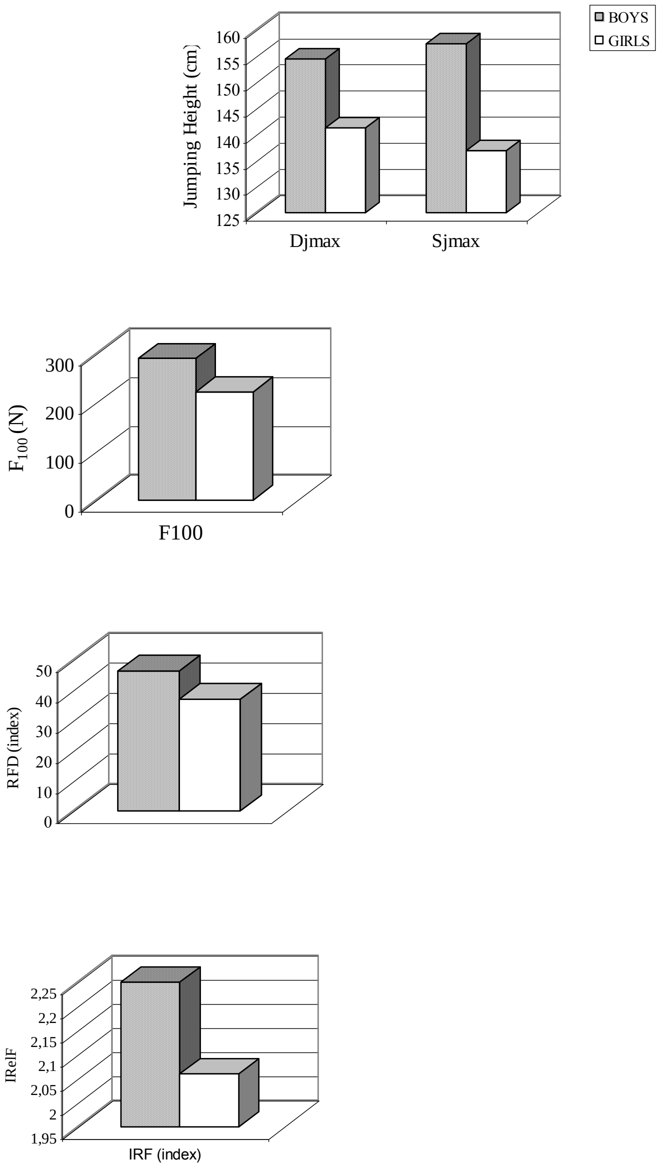

Fig. 1

Mean maximum vertical jumping height (Djmax, Sjmax), F_{100}, Index of Rate of Force Development (IRFD) and index of Relative Force (IRelF); $p<0.05$

Results

One-way analysis of variance (ANOVA) was used to test for differences between genders. Levene's test of homogeneity was, also, applied for all variables. A level of $p<0.05$ was selected to indicate statistical significance. The statistical package SPSS 10 for windows used for analysis of all variables.

Results showed that Levene's test of homogeneity was not significant ($p>0.05$), and as a result variances were not significantly different for all variables tested. Moreover, significant differences were reported in most of the variables examined. Thus, there was a significant effect of F_{100} on levels of gender ($F_{(1,174)}=21.52$, $p<0.05$). In addition, significant effects of IRelF and IRFD were reported with $F_{(1,174)}=7.34$ and $F_{(1,174)}=21.32$, respectively. Significant differences between groups were reported for vertical jumps DJ_{max} , SJ_{max} ($F_{(1,174)}=6.7$ and $F_{(1,174)}=15.26$, $p<0.05$). Greater values for boys were reported for the above variables compared to girls. All values for both groups are depicted in Table 2. In addition body fat (BF) between groups was significantly different ($F_{(1,174)}=19.45$, $p<0.05$). In all the above variables except BF, boys obtain greater values than girls illustrated in Fig. 1. No significant differences were observed in F_{maxiso} and IReaF between boys and girls ($p>0.05$).

Discussion

The purpose of the current study was to investigate differences in performance, regarding strength and power components of physical fitness, between school-aged boys and girls.

The study, indicated greater values for boys in $F_{100,}$ IRelF, IRFD, DJ_{max} , SJ_{max}, compared to respective values in girls. More specifically, with regard to $F_{100,}$ IRelF, IRFD, which are variables derived by isometric strength measurement, boys found to be better than girls. These results are in accordance with a study conducted by Kalogeropoulos, *et al.* [18]. According to literature, differences between boys and girls, regarding strength scores, are pinpointed during prepubertal years [9]. Blimkie and Sale [9] stated that strength gains and gender differences in strength during childhood appear to be closely related to changes in somatic growth, muscle size, and neuromuscular and neuroendocrine development. In addition, heredity, physical activity and sports participation patterns can, also, influence strength. Thus, gender differences in relative strength before puberty, is probably due in part to the higher proportion of body fat in females during this period and sociocultural factors [9,20]. Results also showed that, girls had greater values than boys, regarding body fat index. This is in agreement with a study conducted by Duncan, *et al.* [14] who reported that boys were leaner than girls in a large sample of 11-14 boys and girls. The above result, could explain the higher values reported by boys in relative strength and it is in agreement with previous studies [9,20].

Vertical jumps can be used as a model to study explosive force-generating capacity of the lower extremities. In the present study, vertical jumps were squat and drop jumps. DJ is a task characterized by stretch-shortening cycle, in which the action of the muscles during the eccentric phase influences the subsequent concentric phase [12]. The results of the present study showed that jumping height in SJ and DJ was higher in boys compared to girls and they are in agreement with previous research [18]. Bencke *et al.* [6] stated that, few studies have previously, examined differences in girls between sports or performance level in jumping performance. However, their data indicated that no differences were found between genders for DJ and SJ performance. Moreover, results from the study by Crasselt *et al.* [13] showed that boys begin to outperform girls at the age of 14 years, in countermovement jumps. This inconsistency in findings may be due to the difference in age groups, different testing methods used, different samples sizes, level of sport performance, level of sport experience. As a result, further research in the present age group should be encouraged, regarding the aforementioned various factors.

Moreover, the differences reported between boys and girls in the present study, regarding their vertical jumping performance could be explained in the context of the following factors. The vertical jumping height depends on the physiological processes that take place in the muscular and nervous systems. One finding of this study was a significantly higher force generating capacity of the knee extensor muscles in boys compared to girls. It is well known that force of the knee extensor muscles is one important factor limiting performance in jumping exercises. Another important factor is intramuscular co-ordination and co-activation of activity of the agonist-antagonist muscles involves in performing the jump [30]. Thus, the greater vertical jumping performance in boys compared to girls can be partly explained by an increase in the capacity for rapid neural activation of the extensor muscles of lower extremities. As a result coordination coupled with strength should be factors both of great importance. Moreover, Bencke *et al.* [6] stated that complex motor tasks as drop jump, based in neuromuscular coordination, might be affected by specific training, and especially before puberty. On the other hand, less complex, strength dependent tasks as squat jump may, also, be influenced by specific training, but not to the same extent, and hereditary plays a major role in performance in this task. Bobbert *et al.* [10] demonstrated that although muscle strength determines the maximal jump height achievement, actual performance depends on coordination patterns. According to Tittel [35], at the age of 8 or 9 years the speed coordination develops, in addition coordination motor skills, develop very well in physical active boys and girls during childhood together with the rapid development of the nervous system. Boys and girls are similar in speed-strength during the first decade [23]. According to the above notion, differences in jumping ability reported in the present study, may have been due to differences in muscle strength of the extensor muscles, which in turn might have been due to factors mentioned by Blimkie *et al.* [9]. Moreover, Mero *et al.* [24] found a relation between jumping performance and muscle fiber type composition and this may imply that jumping performance, to some extent can be regarded as inherited, since the fiber type composition basically is genetically determined [21] and can only to a lesser degree be altered by training [11]. The present study indicated a significantly higher index of rate of force development of the knee extensor muscles in boys compared to girls. The IRFD in isometric and dynamic contractions is related to the contractile speed. The maximum shortening speed determined from the force-velocity curve is closely related to the shortening speed of sarcomeres [4]. The development of the nervous system and the differentiation of muscle fiber types may influence the contractile speed of the muscle. As a result for IRFD differences between boys and girls in the present study, heredity factors might have been within the factors that accounted. However, possible explanations should be attributed to body fat and its relationship with strength and power variables. In a study conducted by Maridaki *et al.* [22] it was shown that in preadolescent girls' ectomorphy and strength values were negatively related, and as result linearity and low muscularity was related to a lower performance. Moreover, results of a study conducted by Katartzi *et al.* [19] showed high negative correlations between body fat and jumping height. As a result, high body fat percentage reported for girls might have been related to lower jumping performance compared to boys. Moreover, in the present study high body fat percentage might have been related to lower muscle proportion in lower limbs, and as a result related to lower values in isometric strength variables. It was shown differences ranging from 30.6%, 9.7% and 25.2% for F_{100} IRelF and IRFD respectively, between boys and girls. In addition, jumping performance showed differences of 14.8% and 9.4% for squat and drop jumps, respectively. On the contrary, index of reactive force (IReaF), although not significant, showed a difference of 6.9% between boys and girls, with girls to outperform boys. This difference coupled with small differences in jumping performance related to strength performance, should be explained in the context of possible increased coordination in girls. Thus, girls, in order to compensate for poor lower limbs strength due to increased body fat, used their better level of coordination to perform jumping tasks. In conclusion, research should be encouraged on this point, regarding coordination issues in both genders for this age group.

Conclusion

In physical activity and sport performance, along with strength and power, motor coordination plays an important role in the cooperative interaction between the nervous system and the skeletal muscles. The early development of motor coordination provides a large basis on which to improve skills, and especially speed ability, in many sport events [23]. As a result, the above notion would have a great impact in developing specific test batteries depending on gender differences, when it comes to identify specific strength and speed characteristics in future junior athletes. The role of coordination in strength and power development is also very poorly investigated in this age phase and needs further investigation. Moreover, the early development of the nervous system stresses the need for a timely diagnosis and assessment, which in turn could affect training, evaluation and planning, related to strength and power components of physical fitness in children. Moreover, physical activity and sports participation patterns of both boys and girls should be recorded, when it comes to testing, in order individual differences to be considered.

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