

Effects of age, gender and activity level on counter movement jump performance and variability in children and adolescents

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The aim of this study was to investigate counter movement jump performance and variability in a large population of children and adolescents with respect to age, gender and activity level. 1835 subjects performed three counter movement jumps with arms akimbo on a force platform. The subjects were divided into 6 age groups and three activity level groups. Jump height and maximum rate of force development were calculated for all jumps. The best trial out of three was considered for further calculations. Variability of both parameters was indicated by the coefficient of variation over three jumps. Both parameters increased with increasing age while their variability decreased. Boys jumped higher than girls. Regarding maximum rate of force development female subjects showed higher values. The active subjects jumped higher and with less variability than the sedentary group. Jump height and maximum rate of force development are good parameters to describe the development of jumping performance regarding age, gender and activity aspects. Due to the high variability of maximum force rate development, however, this parameter has to be interpreted with caution in subject-specific assessments.

KEY WORDS: jump height, maximum rate of force development, variability

INTRODUCTION: The counter movement jump (CMJ) is a commonly used method in performance diagnostics to measure leg power and explosiveness. Most of the previously reported studies involved adult male subjects (e.g. Harmann et al., 1990, Marcovic et al., 2004). Only few studies focused on age and gender effects in jumping performance (e.g. Temfemo et al., 2008). The studies investigating gender differences in jumping performance are based on a small group of individuals and are limited to specific age groups such as prepubertal children (e.g. Temfemo et al., 2008), adolescents (e.g. Temfemo et al., 2008) or adults (e.g. Artega et al., 2000). No study was found dealing with gender-related differences in jumping performance in a large population during childhood and adolescence. Besides age and gender the activity level might also be an important factor causing differences in jumping performance. Most previously published studies included only jumping experienced subjects (e.g. Marcovic, et al., 2004, Vanezis & Lees, 2005). Data of non-active subjects are rare although a comparison of different activity groups could provide important information about the application of vertical jumping in performance diagnostics for non-active subjects. To analyse age, gender or activity level related differences it could be helpful to consider parameters describing the variability of jumping performance. While commonly used parameters like maximum jump height or peak force only give information about mean or maximum performance, parameters describing the variability could be used to assess the stability of testing procedures and to explain differences between groups of subjects (Artega et al., 2000, Marcovic et al., 2004, Harrison & Gaffney, 2001). Harrison & Gaffney (2001) analysed coefficients of variation for different gender and age groups but they only compared children with adults and the sample size was restricted to 42 subjects. Artega et al. (2000) and Marcovic et al. (2004) did not consider age or gender effects on variability and none of the previously reported studies compared variability of jumping performance in subjects with different activity levels. Thus, the aim of this study was to investigate the effect of age, gender and activity level on jump height and maximum rate of force development and the

variability of these parameters in counter movement jumps in a large population from childhood to adulthood.

METHODS: In the context of a comprehensive motor ability and motor skill survey 1835 children and adolescents at the age between 4 and 17 years [10.6 ± 3.9 yrs, 39.8 ± 8.2 kg, 143.6 ± 22.0 cm] were selected for this study. Regarding age subjects were separated into six groups (4-5 yrs, 6-7 yrs, 8-9 yrs, 10-11 yrs, 12-14 yrs and 15-17 yrs). The activity level was determined using a detailed questionnaire. School sport, informal sport and organised sport activities of middle and high intensity were subsumed. An activity-index was established indicating the overall sport activities of each subject in hours per week. Based on these data the subjects were separated into three groups of activity level: 'active' (>8 hours sport activities per week), 'moderate' (3–8 hours sport activities per week) and 'sedentary' (<3 hours sport activities per week). All subjects performed three counter movement jumps with arms akimbo on a force plate. The instruction was to jump as high as possible. Vertical ground reaction forces were measured with a sampling rate of 1000 Hz. Maximum jump height (h) was calculated by integrating the force-time curve and equalizing the kinetic and potential energy. The best out of three trials was taken for further calculations. Maximum rate of force development (RFD) was calculated for the best trial with respect to jump height. In addition, the variability of these parameters [cv-h, cv-RFD] was quantified using the coefficient of variation over three jumps calculated as:

$$cv (\%) = [SD(\text{trial 1-3})/\text{mean}(\text{trial 1-3})] * 100.$$

A multivariate ANOVA with the factors age, gender and activity level was used to analyse differences between subgroups for all parameters. The level of significance for all tests was set a priori to 0.05.

RESULTS:

Age: Significant age effects were found for jump height and jump height variability (h: $p=0.000$ $\eta^2=0.468$, cv-h: $p=0.000$ $\eta^2=0.074$). Post hoc tests showed a significant increase in jump height with increasing age over all six age groups and a significant decrease in jump height variability until the age of 9 years. Significant age effects were also revealed for the maximum rate of force development (RFD: $p=0.000$ $\eta^2=0.238$) indicating a significant increase from 10 years of age onwards. No significant age effects were found for the coefficient of variation of the maximum rate of force development.

Gender: Regarding jump height and jump height variability significant gender effects were found (h: $p=0.000$ $\eta^2=0.079$, cv-h: $p=0.000$ $\eta^2=0.016$) indicating greater jump height, but also higher variability for boys than for girls. The maximum rate of force development was significantly higher in the female subjects (RFD: $p=0.000$ $\eta^2=0.026$), however, no significant gender differences were found for the variability of maximum rate of force development.

Interaction between age and gender: A significant interaction between age and gender was observed regarding jump height, jump height variability and maximum rate of force development (h: $p=0.000$ $\eta^2=0.080$, cv-h: $p=0.000$ $\eta^2=0.014$, RFD: $p=0.003$ $\eta^2=0.010$). From the age of 12 years onwards boys increased their jump height more than girls so that the difference of jump height between boys and girls changed from about 1.3 cm for the 4-11 years group to 9.4 cm for the group of 15-17 years old subjects. Jump height variability differed significantly between boys and girls in the younger age groups (4-5, 6-7 and 8-9 years) showing higher values for the boys. Regarding the maximum rate of force development boys and girls at first developed similarly with a higher increase from 10 years of age onwards while girls showed higher values than boys. This changed between the 12-14 and 15-17 years old subjects. From that age onwards the boys increased the maximum rate of force development much higher than the girls so that significant differences no longer were found between boys and girls at the age of 15-17 years. No significant interaction between age and gender was observed for the variability of the maximum rate of force development.

Activity level: Regarding the activity level of the subjects significant differences between the three groups were revealed for the maximum jump height and jump height variability (h: $p=0.018$ $\eta^2=0.005$, cv-h: $p=0.020$ $\eta^2=0.005$). Post hoc tests showed significant differences

only between the active and the sedentary subjects. While jump height increased with increasing activity level (sedentary: 20.0 cm, active: 21.2 cm) the jump height variability decreased with increasing activity level (sedentary: 9.1%, active: 6.8%). For the maximum rate of force development and its variability no significant differences between the three activity groups were observed.

Table 1.: Jump height, jump height variability, maximum rate of force development and variability of maximum rate of force development separated according to gender and age [mean (SD)]

		Age (years)					
Sex		4-5 (n=292)	6-7 (n=277)	8-9 (n=274)	10-11 (n=258)	12-14 (n=423)	15-17 (n=311)
h (cm)	Boys (n=792)	13.5 (5.6)	16.8 (5.4)	19.2 (5.2)	21.7 (5.1)	25.1 (5.9)	31.8 (6.1)
	Girls (n=1043)	12.0 (4.1)	16.0 (4.4)	17.6 (3.2)	20.4 (4.5)	21.9 (4.7)	22.4 (4.8)
cv-h (%)	Boys (n=792)	16.4 (15.4)	11.7 (11.5)	11.6 (17.9)	6.9 (7.8)	6.3 (8.0)	5.9 (5.8)
	Girls (n=1043)	11.2 (10.3)	8.2 (8.1)	6.6 (7.2)	5.3 (4.7)	6.6 (8.5)	6.1 (7.6)
RFD (kN/s)	Boys (n=792)	3.5 (2.0)	3.6 (18)	4.3 (3.1)	5.3 (2.7)	6.6 (3.6)	8.9 (5.4)
	Girls (n=1043)	4.0 (2.3)	4.6(25)	5.4 (3.4)	6.9 (3.4)	9.1 (4.7)	9.6 (4.9)
cv-RFD (%)	Boys (n=792)	23.1 (16.0)	25.8 (20.3)	22.9 (16.1)	22.5 (14.1)	20.0 (13.9)	20.5 (15.1)
	Girls (n=1043)	22.1 (13.5)	21.8 (15.0)	20.4 (13.6)	20.5 (11.8)	20.3 (12.7)	20.0 (11.9)

h: maximum jump height; cv-h: jump height variability; RFD: maximum rate of force development; cv-RFD: maximum rate of force development variability.

DISCUSSION:

Age: Nearly all investigated parameters in counter movement jumps were affected by age. Jump height and the maximum rate of force development are good parameters to describe the development of explosive leg extension power during maturation. As expected the highest jump height variability was observed in the 4-5 years old subjects and decreased with increasing age. The measured jump height variability of subjects from ten years of age onwards were in line with results of previously reported studies which found jump height variability between 2.8% and 6.3% (Arteaga et al., 2000, Marcovic et al., 2004). For younger subjects aged between 4 and 9 years the results of the present study showed higher values of jump height variability between 16.4% and 11.6% for the boys and 11.2% and 6.6% for the girls. The variability of maximum rate of force development was much higher with 22.6% for the 4-5 years old subjects and barely decreased to 20.3% for the 15-17 years old subjects. Stokes (1985) reported magnitudes of variability inherent in biological systems of 10% to 15% which emphasised the very high values for the variability of maximum rate of force development in all age groups. This leads to the conclusion that the maximum rate of force development is a very unstable parameter and may only be used for assessing group analyses. For individual assessments this parameter cannot be determined reliably enough in all investigated age groups.

Gender: The higher jump performance in boys is in line with previously reported studies and can be explained by different gender-related physical conditions (e.g. Temfemo et al., 2008, Harrison & Gaffney, 2001). Regarding maximum rate of force development boys developed lower values than girls. No other studies were found indicating these parameters between boys and girls during growth. In spite of the lower values in maximum rate of force development, boys jumped significantly higher than girls. The explosiveness in the eccentric phase obviously is not sufficient to guarantee high jumping performance. Boys are able to produce leg extensor muscle forces over a longer period of time leading to enhanced jumping heights. These abilities are better pronounced in boys than in girls.

Interaction between age and gender: Jump height was only slightly higher for boys until the age of 11 years. From the age of 12 years onwards the jump height difference between boys and girls increased continuously. This is in line with previously reported studies which showed increasing differences between boys and girls from the age of 11 or 12 years onwards (e.g. Temfemo et al., 2008). These different gender-related developments can be explained by different pubertal changes in boys which lead to an increase in leg lengths, leg muscle volumes, muscle forces and higher percentages of fast twitch muscle fibres (Temfemo et al., 2008). Regarding jump height variability boys showed significantly higher values up to the age of 9 years. Along with the pubertal change the gender differences disappear. Regarding the rate of force development significant differences between boys and

girls were found indicating higher values for the girls. From the age of 12 years onwards boys assimilated to girls and no significant gender differences for the maximum rate of force development were found from this age onwards. No significant interaction was found for the other parameters. At the current stage of data analysis this gender effect cannot be explained and has to be clarified by further detailed investigations.

Activity level: The activity level only affected jump height and jump height variability. Active subjects jumped higher than the sedentary group and showed lower variability during consecutive performance. These results suggest that physical activity and sport experience enhances jumping performance. Although the differences are significant, they are small and might be interpreted as irrelevant. Sport specific and age-related analyses have to be performed to provide stronger interpretations of these findings. The higher variability for the sedentary group showed that subjects with no or little sport experience were not able to reach his or her maximum performance repeatedly in consecutive jumping. Therefore, several trials should be performed in jumping performance diagnostics to provide a greater chance of measuring a subject's actual best performance, specifically in inexperienced children.

CONCLUSION: The study shows a substantial enhancement of jumping performance during childhood and adolescence, both in males and females. This indicates a high sensitivity for developing jumping related abilities during this specific life-span. Specific training is supposed to be very successful in reaching high jumping performance. This is important as jumping performance is one of the basic abilities in many sports. The different gender-related developments indicate specifically high adaptations to jump power in boys starting with puberty. The stability of jumping performance is rather high in both sexes up to the age of 10 years. From that age on jumping performance diagnostics is able to produce valid and reliable data. Prior to that age related data have to be interpreted with caution. Despite the relatively low variability in jumping performance it is necessary to provide at least three trials during diagnostic procedures. Otherwise it is not guaranteed to get sufficiently reliable data in jumping diagnostic testing. The data clearly show substantial enhancement of the maximum rate of force development in both sexes during maturation indicating the enhancement of leg extension power. So this parameter can be used for studying group effects. Due to the large variability, however, individual data analyses have to be interpreted cautiously. Furthermore, the results support the necessity to use force plates in jumping performance diagnostics as the maximum rate of force development cannot be determined with any other methodology. For the interpretation of jumping performance data in children and adolescence both the sport activity level and the area of sport activity have to be considered.

REFERENCES:

- Arteaga, R., Dorado, C., Chavarren, J. & Calbet, J. (2000). Reliability of jumping performance in active men and women under different stretch loading conditions. *Journal of Sports Medicine and Physical Fitness*, 40(1), 26-34.
- Harman, E., Rosenstein, M., Frykman, P. & Rosenstein, R. (1990). The effects of arms and countermovement on vertical jumping. *Medicine and Science in Sports & Exercise*, 22(6), 825-833.
- Harrison, A. & Gaffney, S. (2001). Motor development and gender effects on stretch-shortening cycle performance. *Journal of Science and Medicine in Sport*, 4(4), 406-415.
- Marcovic, G., Dizdar, D., Jukic, I. & Cardinale, M. (2004). Reliability and Factorial Validity of Squat and Countermovement Jump Tests. *Journal of Strength and Conditioning Research*, 18(3), 551-555.
- Stokes, M. (1985). Reliability and repeatability of methods for measuring muscle in physiotherapy. *Physiotherapy Theory and Practice*, 1(2), 71-76.
- Temfemo, A., Hugues, J., Chardon, K., Mandengue, S. & Ahmaidi, S. (2008). Relationship between vertical jumping performance and anthropometric characteristics during growth in boys and girls. *European Journal of Pediatrics*, 168(4), 1594-1603.
- Vanezis, A. & Lees, A. (2005). A biomechanical analysis of good and poor performers of the vertical jump. *Ergonomics*, 48(11-14), 1594-1603.