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RELATIONSHIPS BETWEEN VARIABLES DESCRIBING VERTICAL JUMP AND SPRINT TIME

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ABSTRACT

Effectiveness when playing in team games depends on speed-strength (jumping) abilities. The manifestations of these abilities are usually measured using tests based on vertical jumps and sprinting. This raises the question as to whether relationships exist between variables that describe the vertical jump and running time. The aim of this study was to evaluate the relationships between jumping variables, namely the height of the countermovement jump (CMJ) with arm swing and relative peak muscle power and time of the 30m-sprint (in a straight line and with direction changes) in a group of 187 young athletes who practised team sports. Measurements used a force plate and Fusion Smart Speed System. Strong significant relationships were found between the variables of the CMJ and sprint time along individual sections of the straight line and direction changes of running. However, these relationships differed between subgroups in terms of age, sporting discipline and gender. The height of the CMJ with arm swing is likely to represent a universal variable that could be used to predict the level of motor abilities among young athletes.

Key words: Countermovement jump; Motor abilities; Relative power, Sprint run; Young athletes.

INTRODUCTION

The level of motor abilities of an athlete in team sports determines their effectiveness under game conditions. The main motor ability that determines the effectiveness of a player during a game is speed. This ability depends on a variety of factors that help perform a motor task in the shortest time possible. One example of a popular test that evaluates the level of speed abilities is running in a straight line over a specific distance. Time taken to run while changing direction represents a determinant of the level of another ability, namely agility, while the main variable affecting the final result is lower limb power. A high level of power in the lower limbs, which is the mathematical product of force and velocity, is much appreciated by players of team sports, who often perform rapid accelerations, sudden stops or jumps (Impellizzeri *et al*., 2008; Lehnert *et al*., 2009; Karahan & Cecilia, 2011; Rubley *et al*., 2011; Alemdaroğlu, 2012; Buśko *et al*., 2013). The effective achievement of the aims on the field depends on the athlete's ability to perform short bouts of exercise at peak power that result from fast transitions from rest to exercise and the rate of these changes. The periods of a game during which a player is standing or running at lower speeds are interspersed with so called "explosive" movements, such as rapid accelerations, sudden cuts and changes in direction of movement or jumps (Lehnert *et al*., 2009; Alemdaroğlu, 2012).

Plyometric training aims to enhance lower limb power, with a high level being desirable in team games (Bobbert *et al*., 1987; Kotzamanidis *et al*., 2005; Kotzamanidis, 2006; Lehnert *et al*., 2009; Sugisaki *et al*., 2013). Numerous reports have demonstrated the benefits of plyometric training in improving the variables of the vertical jump and running speed (time) (Chimera *et al*., 2004; Kotzamanidis *et al*., 2005; Kotzamanidis, 2006; Markovic *et al*., 2007; Impellizzeri *et al*., 2008; Lehnert *et al*., 2009; Benito-Martínez *et al*., 2011; Lima *et al*., 2011; Lockie *et al*., 2012). Kotzamanidis (2006) found improvements in the squat jump (SJ) height and running time after eight weeks of plyometric training in a group of boys aged 11. The running speed test was carried out over a distance of 30m in a straight line and the running time improved after training for the sections of 0 to 30m, 10 to 20m, and 20 to 30m. It was interesting to note that improvements were recorded mainly in the phase of maximum velocity rather than the acceleration phase. The application of a training method that improves both the variables of the vertical jump and running time suggests that the two motor tasks are interrelated.

The effectiveness of running is represented by the velocity (the mathematical product of the stride length and frequency), which is determined by the level of speed abilities. On the other hand, the vertical jump depends on the speed-strength and coordination abilities. Cronin and Hansen (2005) demonstrated weak and negative relationships between the variables of the countermovement jump (CMJ) and SJ (the jump height and relative power output) and running time measured over 5m, 10m and 30m. Further, Chelly and Denis (2001) reported strong and positive correlations between the level of muscle power and acceleration and maximum velocity during 40m sprints. Hennessy and Kilty (2001) demonstrated strong and negative relationships between the height of CMJ and running time over 30m, 100m and 300m. On the other hand, Alemdaroğlu (2012) found strong and significant correlations between the height of CMJ and 30m running time. However, these relationships were not replicated between the CMJ height and the time taken to run over 10m. Vescovi and McGuigan (2008) also observed that the height of CMJ shows a poor correlation with running time measured over shorter distances.

Studies on relationships between the variables that describe vertical jump and running time were carried out mainly on groups of adults rather than young athletes. Those reports do not give definite answers. Thus this raises the question whether there are relationships between the variables that describe vertical jump and running time (especially for short distances) in a group of young players from different sport (basketball, volleyball, handball and soccer), with different gender and age. A question arose as to whether similar relationships between the variables that describe vertical jump and running distance will occur in the present study.

PURPOSE OF RESEARCH

The aim of this study was to evaluate the relationships between jumping variables (the height of the CMJ with arm swing and relative peak muscle power) and time of 30m-sprint (in a straight line and with direction changes) in a groups of young athletes while also examining the effect sizes of age, sport discipline and gender.

METHODOLOGY

Participants

The study involved young people (younger juniors and juniors, from 11 to 16 years) from junior voivodeship teams in the Lower Silesia region in Poland playing team sports, such as basketball, volleyball, football and handball. Before the tests, each participant was familiarised with the aim of the research and the parents were informed about the purpose of the study and had given written consent for the tests. The tests were administered in the Ball Games Research Laboratory (PN-EN ISO 9001:2009 certificate) where 187 boys and girls were evaluated. All participants took part in the experiment voluntarily and signed a written consent form. The characteristics of the study groups are presented in Table 1.

Table 1. **CHARACTERISTICS OF RESEARCH GROUPS (M±SD)**

Groups	n	Age (years)	Body height (cm)	Body mass (kg)	Training experience (months)
BMY	14	13.9±0.2	187.1±7.6	73.3±9.0	38.3±10.9
BMJ	14	15.0±0.2	183.3±12.6	72.5±10.2	67.4±27.3
BFY	12	14.1±0.5	169.3±8.2	56.6±7.2	46.0±12.1
BFJ	13	14.8±0.5	171.6±5.9	61.9±7.6	50.5±23.1
VMY	13	14.1±0.3	179.1±5.9	65.2±7.2	34.1±18.6
VMJ	14	15.1±0.2	187.7±6.9	72.5±8.0	33.2±18.4
VFY	9	13.9±0.9	174.8±5.0	61.3±6.4	36.7±13.7
VFJ	13	14.3±0.1	173.6±5.2	62.9±8.8	63.0±12.4
HMY	18	15.2±0.2	183.0±4.4	72.5±6.9	55.4±17.7
HMJ	14	16.1±0.2	185.3±6.8	79.8±19.5	49.7±17.7
HFY	11	14.0±0.3	168.8±3.4	64.4±8.6	43.9±15.0
HFJ	14	14.7±0.5	170.7±6.8	59.9±7.7	47.9±13.2
SMY	16	12.1±0.3	153.7±5.9	41.3±5.0	59.5±11.0
SFJ	12	15.1±1.0	163.6±6.3	60.5±7.5	50.0±19.0
Total	187	14.5±1.1	175.4±12.0	64.8±13.1	48.6±19.5

B=Basketball; V=Volleyball; H=Handball; S=Soccer M=Male F=Female Y=Youth J=Junior

Ethical clearance

The study was conducted according to the principles expressed in the Declaration of Helsinki and received the approval of the Senate Ethics Committee of the University School of Physical Education in Wroclaw (ethical issue date 05.13.2013).

Procedure

A 15-minute warm-up was administered, with static stretching excluded in order to prevent any negative effect on the scores (Vasconcellos *et al*., 2012). Each participant performed 2 series of maximum countermovement jumps with arm swing to reach the peak height (Figure 1A), a 30m-sprint in a straight line (Figure 1B) and a 30m-sprint with direction changes (Figure 1C). The athletes practised each test once before measurements were recorded. The higher jump and shorter running time were analysed for each participant.

Recording the ground reaction forces during jumping was performed using an ACCUPOWER force plate manufactured by AMTI (with ACCUPOWER software). The sampling frequency for the signal from the platform was set at 240Hz. When accurately measured, the take-off time and landing time help to evaluate the duration of the flight phase and consequently calculate the jump height (h_{max}) using the following formula:

$$h_{max} = \frac{1}{8} g \cdot t_f^2$$

where t_f is the flight time and g is the gravitational acceleration.

Instantaneous peak muscle power in the take-off phase (P_{max}) was computed as the product of instantaneous ground reaction forces and the velocity of the general centre of the body mass. The instantaneous velocity of the general centre of body mass in the take-off phase was evaluated based on the integration of the vertical component of the ground reaction forces (reduced by the weight of a participant) with respect to time. The value of relative peak muscle power was obtained by dividing peak muscle power by the participant's body mass.

Running time was measured using the Fusion Smart Speed System (Fusion Sport, Coopers Plains, QLD, Australia). The system is comprised of gates (each gate is equipped with a photocell with an infrared transmitter and a light reflector) and a mat (Smart Jump) integrated with the photocell and RFID reader for athlete identification. The 30m-sprint test was carried out using 7 gates. The distance between the photocell and the respective reflector was 2m. The mat was placed 30cm before the starting line. Starting from the start line, the gates were placed every 5m to record running time. The gate placed 30m from the starting line represented the finishing line. Split times at 5m and 10m were also recorded during running.

After the green light, in the photocell unit connected to the RFID reader, lit up, the participant touched the reader with their wrist band and waited for a signal. After the signal, the blue light in the photocell column lit up and the participant stood in the starting position. One foot was placed in front of the starting line, while the other remained on the Smart Jump mat, which caused the blue light to switch off. The test started when the green lights in the gates lit up again. The 30m-sprint test with direction changes while running was performed similarly to the 30m-sprint test. A graphical illustration of the tests (with the layout of the gates during running tests) is presented in Figure 1.

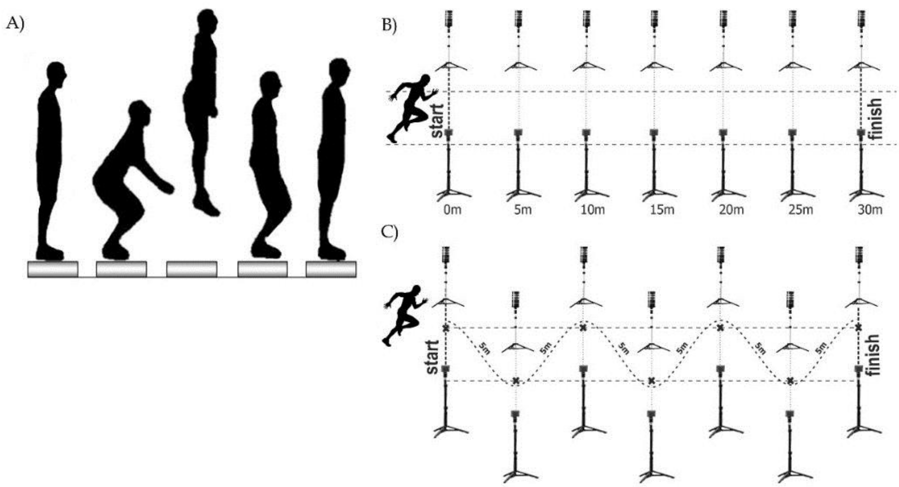

Figure 1. **GRAPHICAL LAYOUT OF TESTS**

A) Countermovement Jump; B) 30m-sprint, straight line; C) 30m-sprint, direction changes

Statistical analyses

Normality of distributions of each variable were tested using the Shapiro-Wilk and Lilliefors tests. The relationships between variables describing the jumping abilities (h_{max}, P_{max}) and running times (t_s, t_z) were assessed using Spearman's correlation coefficient due to the lack of a normal distribution. In addition, analyses of variance (partial eta-squared) were used to test effect sizes of age, sport discipline and gender in the studied relationships. Statistical significance was determined at an alpha level of 0.05 for all the tests. The reliability and repeatability of vertical jump and sprint tests are well established and unquestioned (Moir *et al*., 2004).

RESULTS

Table 2 shows the mean values (±SD) of the variables of the CMJ and running times for the 30m-sprint in a straight line and the 30m-sprint with direction changes while running. Table 3 presents the relationships between the variables of the CMJ and running times for specific distance sections.

Statistically significant strong negative correlations were found between CMJ, height and running time for the 30m-sprint in a straight line and with direction changes and between relative peak muscle power during the take-off phase of the CMJ and running time for the 30m-sprint in a straight line and with direction changes for the whole population studied. However, these relationships differed between subgroups divided according to age, sport discipline and gender. The factor that had the greatest effect on the relationships between the variables that describe the vertical jump and running time was gender (Table 4).

Table 2. **MEAN±SD FOR CMJ HEIGHT (h_{max}), CMJ POWER (P_{max}), TIME 30M-SPRINT STRAIGHT (t_s), TIME 30M-SPRINT DIRECTION CHANGES (t_z)**

Groups	h_{max} (cm)	P_{max} (W/kg)	t_s (s)	t_z (s)
BMY	45.2±6.6	60.4±7.9	5.4±0.3	10.7±0.6
BMJ	45.6±4.3	59.2±5.1	5.2±0.2	9.3±0.3
BFY	33.0±4.7	49.8±4.1	5.8±0.2	11.0±0.4
BFJ	35.6±6.7	52.9±5.9	5.6±0.2	10.5±0.5
VMY	42.0±6.6	58.6±8.3	5.5±0.2	10.8±0.5
VMJ	48.1±4.7	62.8±4.7	5.3±0.2	10.8±0.7
VFY	34.9±5.8	47.9±7.9	6.0±0.3	11.6±0.4
VFJ	31.9±3.4	45.4±3.2	5.9±0.3	11.4±0.3
HMY	41.5±5.0	57.3±5.7	5.2±0.1	10.3±0.3
HMJ	43.6±5.7	58.9±6.7	5.1±0.1	10.3±0.6
HFY	30.4±3.9	44.1±3.9	5.8±0.2	11.5±0.5
HFJ	35.2±5.7	50.1±5.6	5.5±0.2	10.9±0.3
SMY	33.9±3.6	52.0±4.4	5.6±0.2	10.4±0.4
SFJ	30.6±3.8	45.9±3.2	5.7±0.2	11.0±0.3
Total	38.7±7.7	54.1±8.1	5.5±0.4	10.7±0.7

Table 3. **SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR ITEMS**

Group	Item	t_s	t_z	Group	Item	t_s	t_z
BMY	h_{max}	-0.57*	-0.53*	HMY	h_{max}	-0.68*	-0.62*
	P_{max}	-0.34	-0.58*		P_{max}	-0.65*	-0.57*
BMJ	h_{max}	0.32	0.04	HMJ	h_{max}	-0.13	-0.29
	P_{max}	0.09	0.02		P_{max}	0.02	-0.11
BFY	h_{max}	-0.69*	-0.49	HFY	h_{max}	-0.8*	-0.72*
	P_{max}	-0.78*	-0.48		P_{max}	-0.8*	-0.67*
BFJ	h_{max}	-0.95*	-0.84*	HFJ	h_{max}	-0.8*	-0.53
	P_{max}	-0.67*	-0.55*		P_{max}	-0.43	-0.04
VMY	h_{max}	-0.74*	-0.54	SMY	h_{max}	-0.63*	-0.01
	P_{max}	-0.66*	-0.52		P_{max}	-0.23	-0.01
VMJ	h_{max}	0.15	-0.03	SFJ	h_{max}	-0.89*	-0.55
	P_{max}	0.29	-0.04		P_{max}	-0.5	-0.1
VFY	h_{max}	-0.70*	-0.78*	Total	h_{max}	-0.71*	-0.56*
	P_{max}	-0.37	-0.68*		P_{max}	-0.64*	-0.53*
VFJ	h_{max}	-0.60	-0.6				
	P_{max}	0.30	-0.7				

h_{max} =CMJ height P_{max} =CMJ power
t_s =Sprint straight t_z =Sprint direction changes

* $p<0.05$

Table 4. **EFFECT SIZES OF AGE, SPORT DISCIPLINE AND GENDER INTO RELATIONSHIPS BETWEEN JUMPING ABILITIES (h_{max}, P_{max}) AND RUNNING times (t_s, t_z).**

Variables	$h_{max} - t_s$	$h_{max} - t_z$	$P_{max} - t_s$	$P_{max} - t_z$
Age	0.14*	0.16*	0.15*	0.14*
Sport discipline	0.24*	0.22*	0.17*	0.18*
Gender	0.51*	0.52*	0.52*	0.52*

* p<0.05 Values of partial eta-squared

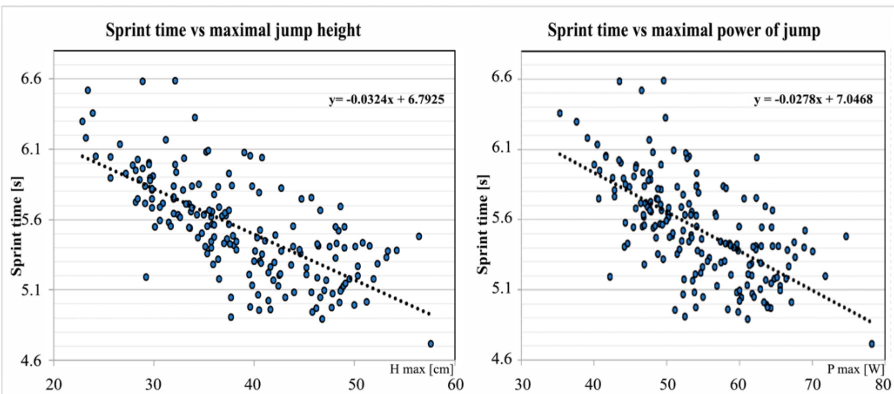

Figure 2. **RUNNING TIME 30m-SPRINT STRAIGHT DEPENDING ON CMJ HEIGHT (on the left) AND CMJ POWER (on the right)**

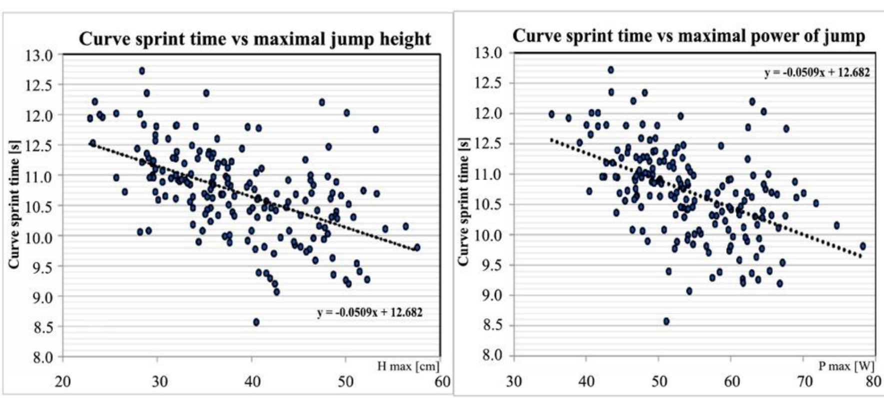

Figure 3. **RUNNING TIME 30m-SPRINT DIRECTION CHANGES ON CMJ HEIGHT (on the left) AND CMJ POWER (on the right)**

Figure 2 presents the relationships between the variables of the CMJ and running time measured for the 30m-sprint in a straight line. Figure 3 illustrates the relationships between the variables of the CMJ and running time measured for the 30m-sprint with direction changes in running. Table 5 shows the relationships between the variables of the CMJ and running time for the first 5m and 10m for the whole population studied.

Table 5. **SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN CMJ HEIGHT AND POWER AND SPRINTING TIMES FIRST 5M AND 10M**

	Sprint straight		Sprint direction changes	
CMJ	t_{s-5m}	t_{s-10m}	t_{z-5m}	t_{z-10m}
Height h_{max}	-0.52*	-0.64*	-0.35*	-0.45*
Power P_{max}	-0.45*	-0.54*	-0.34*	-0.45*

* $p<0.05$

The correlation coefficients between the variables of the vertical jump and running time for the first 5m and 10m in a straight line and with changes in direction of running were lower than those between the variables of the vertical jump and running time for the 30m-sprint in a straight line and with direction changes. However, the relationships remained statistically significant and negative.

DISCUSSION

As in most previous studies (Hennessy & Kilty, 2001; Kotzamanidis, 2006; Bissas & Havenetidis, 2008; Vescovi & McGuigan, 2008; Young *et al*., 2011; Alemdaroğlu, 2012; Martínez-Valencia *et al*., 2013), a statistically significant strong negative relationship was found between variables that describe the CMJ and running time in individual sections of the straight line sprint and with changes in direction of motion for the groups studied. For example, Alemdaroğlu (2012) found strong and statistically significant relationship (r= -0.62) between the height of CMJ and running time over 30m. In the current study the relationships between the jump height and running times were observed in 10 of the 14 studied young athlete subgroups. However, these relationships differed significantly between subgroups divided according to age, sport discipline and gender. No such relationships were found in the subgroups of male junior basketball players, male and female junior volleyball players, and male junior handball players.

This suggests the lack of a relationship between the variables of vertical jump and running times in athletes aged 15 to 16 years who practise team sports. This is likely to be due to the critical period of human life typical of this age (puberty effect) with respect to develop speed abilities (Osiński, 2003) and a sensitive period in terms of develop jumping abilities (Radzińska & Starosta, 2002). However, the analyses of variance (Table 4) showed that the factor which has the greatest effect on the relationship between the variables that describe the vertical jump and running time was gender. Those relationships were observed more often in female groups. Girls grow up faster than their male peers, thus girls may be more stable in terms of development and moulded in terms of level of motor abilities, which can translate into the relationship between jumping and speed abilities.

Significant negative correlations were found between the variables of the vertical jump and running time for the sprint in a straight line and with direction changes over the 5m, 10m and 30m sections for the whole sample studied. The correlation coefficients between the variables of the vertical jump and running time for the first 5m and 10m in a straight line and with direction changes were lower than those between the variables of the vertical jump and running time for the 30m-sprint in a straight line and with changes in direction of running. These relationships remained significant and negative.

Previous studies mostly found a lack of correlation between the running time along short sections (5m and 10m) and variables that describe the vertical jump (Kotzamanidis, 2006; Alemdaroğlu, 2012), or a decline in the strength of the relationship for shorter running distances (Vescovi & McGuigan, 2008). These findings in previous studies might have been due to an insufficient level of coordination abilities, which prevented the athletes from performing the phase of acceleration correctly. Also, the type of starting position (low or high), starting signal (auditory or light stimulus) or reaction time may possibly play a great role.

The relative peak muscle power developed during the CMJ was more poorly correlated than the maximum height of the jump with all variations of the running time. This finding may seem surprising since the level of muscle power has been shown to determine acceleration and ability to maintain maximum speed during sprinting (Chelly & Denis, 2001; Hudgins *et al*., 2013). Furthermore, Vescovi and McGuigan (2008) found stronger correlations between CMJ height and running time in a straight line than in correlations with the scores recorded during agility tests (which indirectly determine the level of lower limb power). The opposite tendency to that found in this study was demonstrated by Martínez-Valencia *et al*. (2013), since the sprint time showed weaker correlations with the height of CMJ (r= -0.65) and SJ (r= -0.4) than with peak power (r= -0.7 and -0.66, respectively) obtained during these vertical jumps. Young *et al*. (2011) reported the strongest correlations between CMJ height and 10m-running time (acceleration) and relative peak power and 20m-running time (maximum speed).

One limitation of the current study may be different size of the groups. In all cases, the groups contain fewer than 30 people. It should be emphasised that the use of the force plate allowed the computation of the jump height based on the duration of the flight phase, which eliminated the effect of individual variables (such as foot length). It is understood that determination of the jump height based on the flight phase duration has some limitations and is not a perfect method. However, the measurement error is relatively small compared to other methods used currently.

PRACTICAL APPLICATIONS

Jump height is not only a good indicator of the effectiveness of a vertical jump (Moir *et al*., 2004; Boullosa *et al*., 2011), but might also be used to predict sprint time. This leads to the conclusion that jump height (and, to a lesser extent, relative peak muscle power during a vertical jump) represents a universal variable that might be used to predict the potential motor abilities (jumping and speed) in almost all of the studied young athletes. Coaches of team sports might use the vertical jump test to evaluate motor abilities of young athletes, which can help with practice and control routine. It should be noted, that not in each age group (15–16 years) might jump height be used to predict sprint time.

CONCLUSIONS

Significant relationships were found between running times (in a straight line and with changes in direction of running) over 5m, 10m, and 30m, and the jumping variables (height of CMJ with arm swing and relative peak muscle power during a take-off phase). Higher values of variables of the vertical jump were associated with shorter running times. The magnitude of the above relationships differed depending on the group of athletes studied. The factor that had the greatest effect on the relationships between the variables that describe the vertical jump and running time was the gender of the participants. The height of the CMJ with arm swing might represent a universal variable that might be used to predict the motor abilities in many of the young athletes studied.

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REFERENCES

ALEMDAROĞLU, U. (2012). The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. *Journal of Human Kinetics*, 31(1): 149-158.

BENITO-MARTÍNEZ, E.; LARA-SÁNCHEZ, A.J.; BERDEJO-DEL-FRESNO, D. & MARTÍNEZ-LÓPEZ, E.J. (2011). Effects of combined electrostimulation and plyometric training on vertical jump and speed tests. *Journal of Human Sport and Exercise*, 6(4): 603-615.

BISSAS, A.I. & HAVENETIDIS, K. (2008). The use of various strength-power tests as predictors of sprint running performance. *Journal of Sports Medicine and Physical Fitness*, 48(1): 49-54.

BOBBERT, M.F.; HUIJING, P.A. & VAN INGEN SCHENAU, G.J. (1987). Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Medicine and Science in Sports and Exercise*, 19(4): 332-338.

BOULLOSA, D.A.; TUIMIL, J.L.; ALEGRE, L.M.; IGLESIAS, E. & LUSQUIÑOS, F. (2011). Concurrent fatigue and potentiation in endurance athletes. *International Journal of Sports Physiology and Performance*, 6(1): 82-93.

BUŚKO, K.; LEWANDOWSKA, J.; LIPIŃSKA, M.; MICHALSKI, R. & PASTUSZAK, A. (2013). Somatotype-variables related to muscle torque and power output in female volleyball players. *Acta of Bioengineering and Biomechanics*, 15(2): 119-126.

CHELLY, S.M. & DENIS, C. (2001). Leg power and hopping stiffness: Relationship with sprint running performance. *Medicine and Science in Sports and Exercise*, 33(2): 326-333.

CHIMERA, N.J.; SWANIK, K.A.; SWANIK, C.B. & STRAUB, S.J. (2004). Effect of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of Athletic Training*, 39(1): 24-31.

CRONIN, J.B. & HANSEN, K.T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research*, 19(2): 349-357.

HENNESSY, L. & KILTY, J. (2001). Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *Journal of Strength and Conditioning Research*, 15(3): 326-331.

HUDGINS, B.; SCHARFENBERG, J.; TRIPLETT, T. & MCBRIDE, J.M. (2013). Relationship between jumping ability and running performance in events of varying distance. *Journal of Strength and Conditioning Research*, 27(3): 563-567.

IMPELLIZZERI, F.M.; RAMPININI, E.; CASTAGNA, C.; MARTINO, F.; FIORINI, S. & WISLOFF, U. (2008). Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine*, 42(1): 42-46.

KARAHAN, M. & CECILIA, G. (2011). A comparative study: Differences between early adolescent male indoor team sports players' power, agility and sprint characteristics. *Ovidius University Annals, Series Physical Education and Sport/Science, Movement and Health*, 11(2): 185-189.

KOTZAMANIDIS, C. (2006). Effect of plyometric training on running performance and vertical jumping in pre-pubertal boys. *Journal of Strength and Conditioning Research*, 20(2): 441-445.

KOTZAMANIDIS, C.; CHATZOPOULOS, D.; MICHAILIDIS, C.; PAPAIAKOVOU, G. & PATIKAS, D. (2005). The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players. *Journal of Strength and Conditioning Research*, 19(2): 369-375.

LEHNERT, M.; LAMROVA, I. & ELFMARK, M. (2009). Changes in speed and strength in female volleyball players during and after a plyometric training program. *Acta Universitatis Palackianae Olomucensis. Gymnica*, 39(1): 59-65.

LIMA, J.C.B.; MARIN, D.P.; BARQUILHA, G.; DA SILVA, L.O.; PUGGINA, E.F.; PITHON-CURI, T.C. & HIRABARA, S.M. (2011). Acute effects of drop jump potentiation protocol on sprint and countermovement vertical jump performance. *Human Movement*, 12(4): 324-330.

LOCKIE, R.G.; MURPHY, A.J.; SCHULTZ, A.B.; KNIGHT, T.J.; JANSE, D.E. & JONGE, X.A.K. (2012). The effects of different speed training protocols on sprint acceleration kinematics and muscle strength and power in field sport athletes. *Journal of Strength and Conditioning Research*, 26(6): 1539-1550.

MARKOVIC, G.; JUKIC, I.; MILANOVIC, D. & METIKOS, D. (2007). Effects of sprint and plyometric training on muscle function and athletic performance. *Journal of Strength and Conditioning Research*, 21(2): 543-549.

MARTÍNEZ-VALENCIA, M.A.; LINTHORNE, N.P. & ALCARAZ, P.E. (2013). Effect of lower body explosive power on sprint time in a sled-towing exercise. *Science and Sport*, 28(6): e175-e178.

MOIR, G.; BUTTON, C.; GLAISTER, M. & STONE, M.H. (2004). Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. *Journal of Strength and Conditioning Research*, 18(2): 276-280.

OSIŃSKI, W. (2003). *Antropomotoryka* (2nd ed.) [*trans*.: *Kinesiology*]. Poznań (Poland): AWF.

RADZIŃSKA, M. & STAROSTA, W. (2002). *The importance, kinds and structures of the jumping ability and its determining factors* (1st ed.). Gorzów: IKF Poznańskiej AWF w Gorzowie.

RUBLEY, M.D.; HAASE, A.C.; HOLCOMB, W.R.; GIROUARD, T.J. & TANDY, R.D. (2011). The effect of plyometric training on power and kicking distance in female adolescent soccer players. *Journal of Strength and Conditioning Research*, 25(1): 129-134.

SUGISAKI, N.; OKADA, J. & KANEHISA, H. (2013). Intensity-level assessment of lower body plyometric exercises based on mechanical output of lower limb joints. *Journal of Sports Sciences*, 31(8): 894-906.

VASCONCELLOS, F.V.A.; DE SALLES, P.G.C.M.; ACHOUR JUNIOR, A.; DE MELLO, D.B. & DANTAS, E.H.M. (2012). The vertical jump height of soccer players after static overstretching. *Human Movement*, 13(1): 4-7.

VESCOVI, J.D. & MCGUIGAN M.R. (2008). Relationships between sprinting, agility, and jumping ability in female athletes. *Journal of Sports Sciences*, 26(1): 97-107.

YOUNG, W.; CORMACK, S. & CRICHTON, M. (2011). Which jump variables should be used to assess explosive leg muscle function? *International Journal of Sports Physiology and Performance*, 6(1): 51-57.

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