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Original Article

Static and Dynamic Balance in Elite Wrestlers: Is there a Meaningful Relationship with Muscle Power?

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ABSTRACT

The aim of the study was to verify the possible relationship between reactive strength index (RSI), jumping performance and static and dynamic balance parameters in elite wrestlers. Fourteen international level male wrestlers (mean age: 17.82±4.60 yrs) performed a standing stork balance test (SST), Y-balance test (YB), dominant-leg unilateral and bilateral vertical (CMJ-DL, CMJ), lateral (SLJ-DL, SLJ), 5 jump (FJT) and drop jumps (DJ-DL, DJ). Significant positive correlations were observed between the SST and bilateral vertical jump CMJ (r-range: 0.41 to 0.63; p<0.005) as well as unilateral vertical jump with the dominant leg (r-range: 0.58 to 0.64; p<0.005). Pearson's corelations portrayed significant relationship between SST and FJT and SLJ and SLJ-DL (r-range: 0.41 to 0.58; p<0.005). The composite score of the Y-balance test showed no correlation with DJ, SLJ or DJ-DL (r-range = 0.26 to 0.36; p<0.05). However, there were moderate to large positive correlations with CMJ-DL and CMJ (r-range: 0.54 to 0.71; p<0.005) as well as with FJT (r: 0.50; p<0.005) and SLJ-DL (r: 0.71; p<0.005). Our findings are evident of an association between jumping capacity, reactive strength (i.e. RSI) and balance performance, that reinforce the need for differential plyometric training programs aimed at improving balance control in elites wrestlers.

Keywords: Balance, muscle power, relationship, elites athletes

INTRODUCTION

Wrestling is a sport of multdimensional demands which include the need to express explosive power,

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strength, neuromuscular coordination and static and dynamic balance [2]. A previous analysis of junior world champions suggests that strength and power are major contributors to success and tend to differentiate champions from other competitors [24]. These qualities underpin such skills as repetitive pulling and pushing, controlling take downs, and maintaining or resisting the arch position [7].

In athletic activities, movements such as jumping are dependent on leg muscle power, flexibility and

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technique [7]. Also, deficits in muscle strength and power can lead to impaired balance and, therefore, lower performance levels [3, 15, 5, 14]. The cited studies highlight the importance of the interaction between strength, power and balance on performance qualities and, on this basis, the targeting of these through systematic training for wrestling is justified.

Balance is defined as the ability of the centre of the body to remain stable with minimal movement [29]. A balanced state is achieved through the combination of several mechanisms such as muscle coordination and body sensory organisation which are two important components controlled by the central nervous system [11]. Two types of balance, static and dynamic, are mentioned in the literature and various study protocols have been used to assess these. The standing stork test (SST) and the Y-balance Test (YB) are considered the most popular assessments of static and dynamic balance [23] but despite this, there has been minimal analysis of how balance, as measured by these functional tests, relates to sport-specific actions such as hopping and jumping. Booysen et al. [3] demonstrated a significant corelation between YB and countermovement jump (CMJ) in university (n = 27, mean age = 20.7 ± 1.84 years; r= 0.4, p= 0.004) and professional athletes (n = 23, mean age = 23.0 ± 3.08 years; r=0.56, p=0.006). Author's showed moderate association between vertical jumping ability and dynamic balance when using the non-dominant leg. Johnson (2011) [16] observed difference between power-trained and endurance athletes in response to an external perturbations in a bilateral stance. Furthermore, significant relationship were observed between Balance Error Scoring System score test and standing long jump (r = 0.641) and triple hop (r = 0.520–0.636) performance in 22 elite Turkish athletes [5]. Also, Basar et al., [2] demonstrated a strong correlation (r = 0.65) between static balance with maximum ice-skating speed in high school ice hockey players. In contrast, a non-significant association between dynamic balance performed with dominant leg for stance and countermovement jump height was found in both healthy young and middle-aged adults. Author's concluded that theses neuromuscular capabilities are independant of each other and should be developped simultanuesly in order to prevent injuries [21]. Zemkova et al. (2017) [30]demonstrated no significant relationship between postural perturbation and maximum voluntary isometric contraction, peak force, peak rate of force development and peak power during jumping in young adults, the authors concluding that the composition of postural stimuli strongly influenced compensatory response effects on muscle power. Improvement in postural control, jumping height and rate of force development were observed after 4-week balance-training program integrated into high school physical education lessons [9]. Author's also stated that postural instability was a result of a significant impairments in force, power, movement velocity, and range of motion. Consequently, better scores in balance performance was associated with strength performance and this could positively impact trunk stability as well as rate of force development [10], which could, in turn, influence dynamic activities such as jumping and hopping.

For the above reasons, it is important to consider jumping and balance performance together in athletes; however, to our knowledge, no study charachterises the relationship between jumping technique and static and dynamic balance. In light of the points made, this study aims to determine the association between reactive strength, jumping performance and static and dynamic balance parameters in young elite wrestlers.

MATERIAL AND METHOD

Subjects

Descriptive data for the participants can be seen in Table 1. Fourteen high level elite male wrestlers from

Table 1. Descriptive statistics and Reliability of the applied tests for group (n=14)

Variables	M±SD	ICC (95% IC)	SEM
Age (yrs)	17.82±4.60	-	-
Body mass (Kg)	69.49±14.21	-	-
Height (cm)	162.9 ±4.10	-	-
IMC (Kg.m^{-2})	22.79±4.16	-	-
Leg length (cm)	98.71±10.33	-	-
CMJ (cm)	32.46±4.93	0.86 (0.55-0.95)	1.84
DJ (cm)	187.9±59.23	0.93 (0.77-0.97)	4.1
RSI (mm ms^{-1})	1.02±0.24	0.84 (0.50-0.95)	0.09
FJT (m)	10.57±0.53	0.83 (0.47-0.95)	0.21
SLJ (cm)	187.9±59.23	0.95 (0.85-0.98)	2.06
CMJ-DL (cm)	13.1±2.95	0.88 (0.61-0.96)	1.00
DJ-DL (cm)	186.0±22.36	0.90 (0.68-097)	0.06
RSI-DL (mm ms^{-1})	3.61±2.17	0.95 (0.88-0.98)	0.43
SLJ-DL (cm)	186.0±22.36	0.81 (0.39-0.94)	1.02

CMJ – countermovement jump; DJ- drop jump; RSI- strength reactive index; FJT- five jump test; SLJ – standing lateral jump; CMJ-DL – countermovement jump with dominant leg; DJ-DL- drop jump with dominant leg; RSI-DL – strength reactive index with dominant leg; SLJ-DL- standing lateral jump with dominant leg; SEM – Standart Error of Estimate; ICC – intra-class coefficient; CI – confidence interval.

the national team of Tunisia and participated in an Olympic competition (mean age: 17.8±4.6 [years]; body mass: 69.5 ± 14.2 [kg]; body mass index [BMI]: 22.8 ± 4.2 [kg · m⁻²]; Height: 162.9 ± 4.1 [cm]; Leg length: 98.7 ± 10.3 [cm]), volunteered to participate in the study. Participants had a mean training experience of 5 ± 3.79 years and engaged in at least five training sessions and one competition per week. None had been exposed to balance/perturbation training prior to this study. Testing was performed during the pre-season during March and April. The study was conducted according to the Declaration of Helsinki, and all athletes received a clear explanation of the study, including the risks and benefits of participation; written informed consent was obtained from their parents/responsible adults prior to testing, and the athletes themselves agreed to participate in the study.

DESIGN AND PROCEDURES

In addition to body mass (in kg), body height (in cm) and the body mass index (BMI), the testing in this study included indices of static and dynamic balance testing, power testing and reactive strength testing. The testing was done in an indoor center of wrestling. One week before the commencement of the study, all the subjects participated in an orientation session to become familiar with the testing procedures.

With a Static balance protocol (SST) [13] subject stood on the dominant leg with his opposite foot against the inside of the supporting knee with both hands on the hips. Then he raised the heel of his foot from the floor and attempted to maintain balance control for as long as possible. The trial ended if the subject either moved his hands from his hips, the ball of the dominant foot moved from its original position, or if the heel touched the floor. This test was carried out with eyes opened as well as with eyes closed and was timed (seconds) using a stop-watch. The recorded score was the best of three attempts.

With the YB test, and for each trial, subjects placed their hands on their hips and began in a unilateral stance with the most distal aspect of their great toe behind the line on the centre of tape. Distances were then recorded by pushing the target reach indicator in the 3 directions and trials were performed on dominant leg. Throughout, subjects were required to keep the heel of the non-reach leg on the testing platform, maintain balance in a single leg stance, and return the reach foot back to the start prior to attempting the next direction. Also, no visible kicking of the target reach indicator was permitted. Maximal reach distances were recorded to the nearest 0.5 cm marker on the Y-balance kit. Balance performance was calculated as the YBT composite score (MADX [%]), obtained by dividing the sum of the maximal reached distances in the three directions by three times the length of the lower limb (LL; measured from the most distal end of the anterior superior iliac spine to the most distal end of the medial malleolus of each limb), then multiplied by 100: MADX $\% = \{[(A + PM + PL)/(LL \times 3)] \times 100\}$. [22].

Participants also performed vertical jumps: unilateral on the dominant leg (CMJ-DL) and bilateral CMJ. They were instructed to jump as high as possible and verbal encouragement was provided before each trial. All vertical jump tests were performed using an Ergojump system (ErgojumpP apparatus; Globus Italia, Codogne, Italy), which recorded jump height, with a passive rest of 1 min between each repetitions and 3 min between each test.

This five jump Test (FJT) test consisted of five consecutive unilateral strides from the starting position with a leg of the participant's choice. Each stride alternated between legs and the test culminated with a bilateral landing. Performance on the test was measured with a tape measure from the front edge of the subject's feet in the start position to the rear edge of the feet in the finishing position. Test-retest assessment demonstrated high reliability for elites athletes (TEM = 2.3%, ICC = 0.94) [26].

For the standing lateral jump (SLJ) and standing lateral jump on the dominant leg (SLJ-DL), each participant began by standing, either bilaterally (SLJ) or unilaterally on their dominant leg (SLJ-DL), with the foot at the starting line and hands on the hips. Each participant was instructed to sink to a self-selected depth and to jump laterally to the inside as far as possible, landing on two feet for the bilateral jump (SLJ) and one foot for the unilateral jump (SLJ-DL). The distance jumped was measured to the nearest 0.01 m with a tape measure [19].

For strength reactive index (RSI), each participant performed two maximal effort drop jumps (DJ) from box heights of 30 cm with approximately 30 seconds of rest between each trial. RSI (mm/ms) was determined by dividing jump height by contact time [6]. All DJ trials were undertaken bilaterally and unilaterally on the dominant leg (DJ-DL) and were supervised by a certified training practitioner.

STATISTICAL ANALYSIS

All data were verified for normal distribution using the Kolmogorov-Smirnov test and were presented as means and standard deviations (SD). Test retest reliability for the variables was computed using intraclass correlation coefficients. A paired sample t-test was used to determine any significant differences between the scores recorded during the two test trials. The SEM was estimated with the formula: SEM = SDd/√2 [28]. The relationship between measures of balance and muscle power was analysed using Pearson's product–moment correlation coefficient. Associations are reported by their correlation coefficient (r value), level of significance (p value), and the amount of variance explained (r^2-value). Values of r ≥ 0., r ≥ 0. and r ≥ 0.50 correspond to small, medium and large correlations respectively [28]. Further, multiple linear stepwise multiple regression models were calculated to determine the most robust predictors of balance. Coefficients of determination ($R^2 \times 100$) were used to interpret the meaningfulness of the relationships [27]. Analyses were performed using SPSS software statistical package (SPSS Inc., Chicago, IL, version. 18.0), and statistical significance was set at $p<0.05$.

RESULTS

Reliability of all measures

Intraclass correlation coefficients indicated good reliability for all tests. (range: 0.81 to 0.95). Relationships between measures of balance performance and muscle power components.

Associations between the SST, RSI and jump performances are presented in Table 2. Significant positive correlations were observed between the SST and CMJ (r-range: 0.41 to 0.63; p<0.005) as well as CMJ-DL (r-range: 0.58 to 0.64; p<0.005). Significant positive correlations were observed between static balance and FJT (r-range: 0.55; p<0.005), and SLJ and SLJ-DL (r-range: 0.41 to 0.58; p<0.005) [23]. SST and unilateral RSI (r:-0.26; p<0.005). The composite score of the YB test showed no correlation with DJ or DJ-DL (r = range -0.26 to 0.36; p<0.05). However, there were moderate to large positive correlations with CMJ-DL and CMJ (r-range: 0.54 to 0.71; p<0.005) as well as with FJT (r: 0.50; p<0.005) and SLJ-DL (r: 0.71; p<0.005).

Multiple regressions analysis

The multiple regression analysis revealed that RSI and jump components explained 97% (F=2.93; p<0.02) of the variance of balance performance [23]. Furthermore, the single best predictor of SST was the CMJ-DL test with an explained variance of 47% (F=9.28; p<0.005). For the dynamic balance, 50% of the explained variance in YB score was determined by SLJ-DL (F=11.87; p<0.001).

DISCUSSION

The main findings demonstrate a possible relationship between static and dynamic balance and muscle power performance. Medium to large correlations between all measures of static and dynamic balance with RSI and muscle power was observed. The unilateral CMJ was considred as a power indicator of static balance (SST) with the highest proportion of variance explained. In addition, With regard to dynamic balance, the unilateral standing long jump was demostrated the

Table 2. Pearson's moment correlation coefficients between studied variables

Variable	SST (s)			SYB (%)		
	r	p	95% CI	r	p	95% CI
CMJ (cm)	0.63	0.01	0.12 to 0.87	0.54	0.05	-0.01 to 0.84
DJ (cm)	0.41	0.15	-0.17 to 0.78	0.36	0.21	-0.23 to 0.76
RSI (mm ms^{-1})	-0.62	0.02	-0.87 to -0.10	-0.53	0.06	-084 to 0.01
FJT (m)	0.55	0.05	0.00 to 0.84	0.50	0.07	-0.06 to 0.82
SLJ (cm)	0.41	0.15	-0.17 to 0.78	0.36	0.21	-0.23 to 0.76
CMJ-DL (cm)	0.64	0.01	0.14 to 0.88	0.61	0.02	0.10 to 0.87
DJ-DL (cm)	0.58	0.03	0.04 to 0.85	0.71	0.00	0.26 to 0.90
RSI-DL (mm ms^{-1})	-0.26	0.38	-0.71 to 0.33	-0.36	0.22	-0.76 to 0.23
SLJ-DL (cm)	0.58	0.03	0.04 to0.85	0.71	0.00	0.26 to 0.90

best predictor with a highest proportion of variance. Importantly, the CMJ-DL was the single best power predictor with the highest proportion of variance to explain SST.

Previous research examining possible association between muscle power and balance performance have been published [13, 5, 21, 12]. Erkmen et al., (2010) [5]demonstrated significant correlations between triple hop (r = 0.713), standing broad jump (r =0.617), vertical jump (r = 0.596) and Balance Error Scoring System test in elite soccer player. In addition, static balance was correlated with drop jump height (r= -0.44; p<0.002) and power (r= -0.29, p= 0.04) but not with CMJ height with 46 male athletes [7]. Regarding to horizontal jumping abilities, the standing long jump was demonstrated as a best indicator of the standing stork test with the highest proportion of variance (12–47%) in youth athletes [13]. The research appeared so far are in accordance to those obtained in the current study demonstrating significant correlations between static balance and five jump test. However, they contrast with the study of Hamilton (2008) [12] who reported no correlations between soccer players' balance performance, triple jump, and vertical jump distances. Otherwise, the unilateral CMJ as complex movement relies on better coordination and powerful contraction of the knee and hip extensor muscles in order to maximise vertical height [8; 18] wich can enhance performance in static balance by providing an adequate extensor moment. The extensor moment is responsable for controling balance in the static phase during the standing stork test execution and assist in mantaining an individual's centre of mass inside the base of support to finaly controlling postural sway.

Similarly, it has previosuly been shown that elite wrestlers with greater leg power demonstrated better dynamic balance performance. Simek et al. (2008), Granacher et al. (2010) and Myer et al. (2006) [25, 9, 22] all found that balance training increased jump height and that jump training improved balance performance. Therefore, it may be possible to conclude that there exists a meaningful causative relationship between jumping ability and balance. Boosyne et al., (2015) [3] demonstrated that the normalised reach score in the YB test using the non-dominant leg for stance correlated with eccentric strength (r = 0.56, P = 0.006) and jumping ability (r = 0.52, P < 0.0002) of the non-dominant leg knee extensors in professional athletes. The authors concluded that the ability to generate power correlates moderately with dynamic balance on the non-dominant leg in male footballers. It would therefore be expected that there are other relevant factors which could influence dynamic balance, such as jumping technique or neuromuscular coordination.

The relationship between lateral jump performance and dynamic balance could be explained by the similarities in the muscles recruited during the SLJ and YB tests. During the YB test high levels of muscle activation from the knee extensors and hip extensors are necessary [4; 19] to resist the large flexion moments (or torques) as the participant during the reaches distance [4]. Performing certain technical skills or activities with substantial lateral displacement in specific wrestling training, athletes needs to develop greater leg extensor power and must consequently maintain a stable position during these tasks by better controling their body position or center of gravity inside their base of support. Further, whilst being jostled by opponents, wrestlers must adopt a strategies to control the moments or torque demands with maintaining their centre of mass inside the base of support to maintain balance while moving in the lateral plane. Furthermore, the high demand of muscle power during dynamic activities that have been observed in wrestling training and competition [23] may emphasise the need for prescription of a specific bilateral and unilateral plyometric training in order to improve balance.

Our findings are evident of an association between jumping capacity (i.e. CMJ) and reactive strength (i.e. RSI) and balance performance directly supporting the results of previous studies in which investigators identified those qualities as being significantly related to static and dynamic balance [13; 3; 20]. This is mostly explained by the similar physiological underpinnings of jumping, RSI and balance with all three qualities requiring the intensive involvement of the fast twitch muscle fibers [14]. Anderson and Behm, (2005) [1] indicated that power and resistance training can also improve the coordination of synergistic and antagonist muscle activity leading to improved stability. Indeed, RSI is representative of an individual's ability to efficiently switch between eccentric and concentric muscle actions (i.e., to perform plyometric activities). It is known that efficient use of the stretch shortening cycle results in more powerful muscle actions than purely concentric action [17]. The rationale for this finding might be attributed to the high level of power output ine the vertical and lateral plane modifying the center of gravity providing novel challenges to the equilibrium for high level elite wrestlers with which to optimize their strategies to maintain static and dynamic balance, respectively. Since our correlation analysis demonstrates that the two variables vary in the same direction, improved repeated and single jumping abilities in the vertical and lateral planes may enahance static and dynamic balance control.

There are some limitations to this work. The study design was cross sectional and thus causality cannot be assumed. Consequently, longitudinal or intervention studies are waranted. Furthermore, a kinematic assessment of knee joint angles was not conducted. In conclusion, these results suggest that there can be a transfer of effects from balance training to activities involving dynamic lateral movements and vice versa. Consequently, repeated jump activities and lateral plyometric training techniques should be incorporated into the training programmes of elite wrestlers to improve balance capability. Powerful muscle contractions may assist in providing an adequate extensor moment and assist wrestlers in returning to a more stable position whilst balancing. However, numerous other neuromuscular factors contribute to a stable, unilateral stance in male wrestlers. Further studies should quantify additional performance variables related to dynamic balance in wrestlers and should include female participants due to the high number of non-contact injuries to the support leg in that population. Also, controlled intervention studies may further enhance understanding of the factors that commonly contribute to enhanced static and dynamic performance.

In conclusion, fitness programs aimed at improving balance performance in youth wrestlers should incorporate elements of vertical and horizontal movement. This is based on the relationship between power expression capability and balance in this type of athlete. Additionally, special attention should be paid to lateral plyometric training since this quality is related to dynamic balance. Enhanced balance capabilities should prove beneficial to elites wrestlers as they must coordinate technical explosive action being jostled by opponents.

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REFERENCES

1) Anderson K, Behm DG (2005). The impact of instability resistance training on balance and stability. Sports Med: 43-53.
2) Basar S, Duzgun I, Guzel NA, Cicioğlu I, Çelik B (2014). Differences in strength, flexibility and stability in freestyle and Greco-Roman wrestlers. J of back and musculo rehab: 321-330.
3) Booysen MJ, Gradidge PJL, Watson E (2015). The relationships of eccentric strength and power with dynamic balance in male footballers. Sports Sci: 2157-2165.
4) Earl JE, Hertel J (2001). Lower-extremity muscle activation during the Star Excursion Balance Tests. J of Sport Rehab: 93-104.
5) Erkmen N, Taşkin H, Sanioğlu A, Kaplan T, Baştürk D (2010). Relationships between balance and functional performance in football players. Human Kinetics: 21-29.
6) Flanagan EP, Ebben WP, Jensen RL (2008). Reliability of the reactive strength index and time to stabilization during depth jumps. The J of Strength & Cond Res: 1677-1682.
7) Goktepe M, Gunay M, Bezci S, Bayram M, Ozkan A (2016). Correlations between different methods of vertical jump and static balance parameters in athletes. Turkish J of Sport and Exer: 147-152.
8) González-Badillo JJ, Marques MC (2014). Relationship between kinematic factors and countermovement jump height in trained track and field athletes. J of Strength & Cond Res: 3443-3447.
9) Granacher U, Gollhofer A, Kriemler S (2010). Effects of balance training on postural sway, leg extensor strength, and jumping height in adolescents. Res Quart for Ex & Sport: 245-251.
10) Gruber M, Gruber SB, Taube W, Schubert M (2007). Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. J of Strength & Cond Res: 274.
11) Gstöttner M, Neher A, Scholtz A, Millonig M, Lembert S, Raschner C (2007). Balance ability and muscle response of the preferred and nonpreferred leg in soccer players. Motor Control: 218-231.
12) Hamilton, R. T., Shultz, S. J., Schmitz, R. J., & Perrin, D. H. (2008). Triple-hop distance as a valid predictor of lower limb strength and power. *Journal of athletic training*, *43*(2), 144-151.
13) Hammami R, Chaouachi A, Makhlouf I, Granacher U, Behm DG (2016). Associations between balance and muscle strength, power performance in male youth athletes of different maturity status. Ped Ex Sci: 521-534.
14) Heitkamp HC, Horstmann T, Mayer F, Weller J, Dickhuth HH (2001). Balance training in men and women: Effect on knee extensors and flexors. Iso & Ex Sci: 41-44.
15) Hrysomallis C (2001). Balance ability and athletic performance. Sports Med: 221-232.
16) Johnson TK, Woollacott MH. Neuromuscular responses to platform perturbations in power-versus endurance-trained athletes. Percep & motor skills 2011,112(1): 3-20.
17) Komi, P. V. (2003). Stretch-shortening cycle. *Strength and power in sport*, *2*, 184-202.
18) McLellan CP, Lovell DI, Gass GC (2011). The role of rate of force development on vertical jump performance. J of Strength & Cond Res: 379-385.
19) Meylan C, Malatesta D (2009). Effects of in-season plyometric training within soccer practice on explosive actions of young players. J of Strength & Cond Res: 2605-2613.
20) Miyaguchi K, Demura S (2011). Specific factors that influence deciding the takeoff leg during jumping movements. J of Strength

& Cond Res: 2516-2522.

21) Muehlbauer, T., Gollhofer, A., & Granacher, U. (2013). Association of balance, strength, and power measures in young adults. *The Journal of Strength & Conditioning Research*, *27*(3), 582-589.
22) Myer GD, Ford KR, Brent JL, Hewett TE (2006). The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes J of Strength & Cond Res: 345.
23) Plisky P J, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. North Am J of Sports Phy Thera: 92.
24) Sharratt MT, Taylor AW, Song TM (1986). A physiological profile of elite Canadian freestyle wrestlers. Canadian journal of applied sport sciences. J Canad Sci App Sport: 100-105.
25) Šimek S, Milanović D, Jukić I (2008). The effects of proprioceptive training on jumping and agility performance. Kinesiology: Int J of Fond & App Kine: 131-141.
26) Slattery KM, Wallace LK, Murphy AJ, Coutts AJ (2006). Physiological determinants of three-kilometer running performance in experienced triathletes. J of Strength & Cond Res: 47.
27) Thomas JR, Nelson JK, Silverman SJ (2005). Research Methods in Physical Activity. Champaign, IL, 7E, Human Kinetics.
28) Weir JP (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J of Strength & Cond Res: 231.
29) Winter DA, Patla AE, Frank JS (1990). Assessment of balance control in humans. Med Prog Technol: 31-51.
30) Zemková E, Jeleň M, Kováčiková Z, Miklovič P, Svoboda Z, Janura M (2017). Balance Performance During Perturbed Standing Is Not Associated With Muscle Strength and Power in Young Adults. J of Motor Beha: 514-523.