POSTURAL STABILITY ASSESSMENT IN ELITE TAEKWONDO ATHLETES: COMPARATIVE STUDY BETWEEN DIFFERENT AGE GROUPS

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Abstract
The main aim of this investigation was to characterize the postural stability profile in elite Croatian male and female Taekwondo athletes. The second aim was to compare postural stability in frontal and sagittal plane in Taekwondo athletes of different age groups. The sample was composed of three groups of Taekwondo athletes. The first group included seniors (N=38; 20.3±2.26 years), the second group included juniors (N=40; 16.6±0.63 years) and the third group included cadets (N=43; 14.625±0.73 years). The following stability parameters were used in the research: Range centre of force X (RCX); Range centre of force Y (RCY); Force (Force); Area of sway (ASWAY); Sway distance (SWAY); Speed of sway (SSWAY). Discriminant analysis showed that all variables significantly contributed to the difference between the groups. The seniors significantly differed from the cadets in all parameters, and the difference was in favour of the seniors (p≤0.05). The results indicate there are differences in oscillations in planes and all groups showed more stability in medio-lateral (m-l) direction. To conclude, postural stability parameters were higher in the senior group when compared with junior and cadet group. The findings depend on trainees' age (seniors>cadets) and may be important for the selection, training design and health care of Taekwondo athletes. To confirm findings, in future research is necessary to verify the hypothesis that taekwondo training can positively impact on postural stability indicators.

Key words: *balance, selection, stabilization.*

Introduction

Taekwondo (TKD) is a martial art that originated from Korea and was used to train combat fighting skills of armies and individual warriors. Since the late 1950s, TKD has been transformed from a traditional combat skill to a modern sport known all over the world. Significant development of TKD as a combat sport started with the foundation of the World Taekwondo Federation (WTF) in 1973 and it became an Olympic sport in 1994 (Markovic, Misigoj-Durakovic & Trninic, 2005). Today, TKD is practiced in two forms. The more traditional form, under the aegis of the ITF, emphasizes combat fighting and various crushing and defensive techniques, whereas a more modern form, under the WTF, has placed emphasis on sport performance and competition (Heller et al., 1998). Good spine stability is particularly important when it is strained during physical activity. Without proper spine stabilization, muscle contraction of the extremities transfers forces proximally and causes spinal movements which put increased stress on the structure of the spine and the surrounding connective tissue. The maintenance and control of balance and posture in a particular position, or during specific movement, are fundamental for physical activity. The somatosensory, vestibular and visual systems, as well as muscle activity, contribute to the maintenance of postural control. This ability is defined as a mechanism for maintaining appropriate relationship between the body segments and between the body and the environment, and to keep the body's centre of mass over the base of support when performing a task (Vander Linden, 1996). The ability to maintain body segments and to be in balance position are crucial elements in the daily training of different athletes. Depending on sport characteristics, postural stability has a role in developing movement and preventing injuries (Oliver & Di Brezzo, 2009). TKD as a sport includes many static positions and dynamic movements and it is characterized by various strikes. Taekwondo is characterized by specific fast, high and spinning kicks and movement structures of the sport are considered to be highly demanding for most muscle groups of athletes (Marković et al., 2005). Based on the competitive activities of athletes, basic model characteristics are obtained which are necessary for successful competitions, but also for the training process in TKD. Postural control during standing is defined as the ability of individuals to maintain their Centre Of Mass (COM) within the limits of the Centre Of Pressure (COP) without having to change the base of support (i.e., take a step or lift feet from surface) (Winter, 1995). Stability and postural control is one of the most important neuromuscular characteristics which are based on trunk muscle strength and balance. The trunk muscles such as pelvic, spinal, and abdominal muscles are called the core muscles. These muscles generate all the power and motility of the human body. Regarding TKD players, strengthening these muscles would improve spinal movement and stability, and greatly help to improve athletic performance (Yoon, Sung, & Park, 2015). Performing fast and coordinated defence and

offence actions is one of most important and determining factors and TKD athletes require muscle power, speed for kicking, and dynamic postural control especially on support leg. Thus all these neuromuscular and postural skills are key elements for great performance in training session and competitions (Jlid et al., 2016). TKD activity appears to speed up the development of postural control (Fong, Fu, & Ng, 2012). Cular et al. (2010) investigated the effect of dominant and non-dominant side of the body in taekwondo performance. The authors determined the effect of motor abilities measured on the left and the right side of the body in performance of basic leg and attack techniques in taekwondo. There are laboratory-based assessment using measures of wide range of postural stability parameters (Collins & De Luca, 1993; Donker, Roerdink, Greven & Beek, 2007), however, centre of pressure (COP) recorded from a footplate is considered the gold standard measure of balance (Haas & Burden, 2000). Previous studies have used different kind of assessment to measure stability in TKD. However, some publications, which can be found in the literature, discuss the issue of postural stability in TKD using footplate parameters.

Several publications, that have appeared in the recent years, have examined the effects of TKD exercise on postural stability, and balance with healthy TKD practitioners (Wojciechowska-Maszkowska, 2012), elderly population (Pons van Dijk, Lenssen, Leffers, Kingma & Lodder, 2013), and young adults (Fong, Fu, & Ng, 2012). Hyun, Kim, & Ryew (Hyun, Kim, & Ryew 2016) used footplate as their latest solution, in order to investigate the effect of fatigue induction on, postural stability, ground reaction force components and vertical jump performance in TKD athletes. Previous research has documented that footplate could be used as a comparing instrument for measuring postural stability in TKD and non-TKD adult group athletes (Fong & Ng, 2012; Rabello et al., 2014). In sport science footplate monitored different parameters as total COP distance, the distance covered in antero-posterior (AP), medio-lateral directions (ML), the maximum oscillation amplitude, frequency of oscillation those directions and the total frequency of oscillation on whole footplate (Nejc et al., 2010). Problem of this study was to investigate postural stability in TKD athletes and the main aim of this study was to characterize the postural stability profile in elite Croatian male and female TKD athletes. The second aim was to compare postural stability in frontal and sagittal plane in TKD athletes of different age groups.

Methods

The sample was composed of three groups of Taekwondo athletes. The first group included seniors (N=38; 20.3±2.26 years), the second group included juniors (N=40; 16.6±0.63 years) and the third group included cadets (N=43; 14.625±0.73 years). All subjects were active athletes that have won medals at national and international competitions. All measurements were carried out in accordance with ethical rules and each subject participating in the measurements was presented with an explanation of the procedure provided for the research and measurement. In the end, participants signed the consent confirming that they were familiar with the purpose and objectives of measurement, measurement protocol and possible risks of measurement and that they voluntarily accepted the measuring process. Prior to the start of the experiment, interviews were held with all the subjects, during which they were informed about the course of the study and possible risks.

Subjects with neurological disorders, disorders of the locomotor system, or disorders of the vestibular or visual systems were excluded from the study. Prior to their participation, all subjects signed a statement of informed consent to participate in the measurements. During testing, every subject was included and there was no dropping out from the research. Postural stability test on laboratory-grade Foot Plate (Footscan, 0.5m Footscan RsSCan Inc. – force plate with software) was used for estimation of the following stability parameters: Range centre of force X (RCX); Range centre of force Y (RCY); Force (Force); Area of sway (ASWAY); Sway distance (SWAY); Speed of sway (SSWAY). Stability was tested during quiet stance on a force plate.

The subjects' task was to maintain a balanced position of the trunk with their hands placed on their hips while their eye focus was directed at a certain point in front of their body. The knees had to be fully extended and throughout the measurement, they had to be active and not in the relaxing position in the joint.

All subject performed each individual task with three trials and each lasting 30 seconds and, the subject had a two-minute break between each trial and a five-minute break each time the foot placement was changed. The sequence of performing the tasks was randomized (Nejc et al., 2010). Standing balance tasks were chosen based on their varying difficulty, good validity and reliability and common use in the existing literature (Springer, Marin, Cyhan, Roberts, & Gill, 2007; Bauer, Groger, Rupprecht & Gassmann, 2008; Li, 2016). The interclass correlation coefficient was excellent (ICC=0.892) for sway parameters and force parameters ICC= 0.980. The data were processed by using the appropriate statistical methods in the software package IBM SPSS 20.0.

For all the analysed variables, the descriptive statistics was performed (minimum, maximum, mean and standard deviation). The normality of results distribution was analyzed using the K-S and Shapiro-Wilk test. Discriminant analysis was used to determine whether there were differences between the groups. T-test was used to determine the differences between different categories of elite male TKD athletes.

Results

Table 1 presents the mean, standard deviation (SD), minimum and maximum values of the parameters obtained during stability tests, and shows statistical significance of Shapiro-Wilk test of normality.

Table 1 Descriptive statistics.

Group		N	Min	Max	Mean	SD	Sig.
Range cof x	Senior	38	3.4	14.2	6.86	2.461	.055
	Junior	40	3.4	15.4	7.72	3.051	.099
	Cadet	43	3.9	19.4	9.88	3.867	.172
Range cof y	Senior	38	3.3	15.1	7.90	3.354	.075
	Junior	40	3.4	15.7	8.67	3.519	.196
	Cadet	43	3.0	24.7	10.82	4.863	.097
Force N	Senior	38	140.1	345.1	219.73	45.673	.200
	Junior	40	134.9	274.1	195.31	35.843	.157
	Cadet	43	84.8	256.3	165.42	45.407	.190
Area of sway	Senior	38	149.9	430.4	323.38	58.081	.189
	Junior	40	183.5	434.0	320.81	55.395	.184
	Cadet	43	215.3	537.7	359.84	75.899	.176
Sway	Senior	38	88.7	155.6	120.12	16.776	.098
	Junior	40	92.8	171.7	126.08	17.885	.120
	Cadet	43	91.6	218.2	144.35	28.308	.168
Speed of Sway	Senior	38	3.0	5.2	4.00	.5595	.116
	Junior	38	3.0	5.2	4.007	.5595	.174
	Cadet	43	3.1	7.3	4.816	.9446	.186

Legend: N - Number of participates; Min – Minimum; Max – Maximum; Mean – Arithmetic mean; SD – Standard deviation; Sig. – Significant differences Shapiro-Wilk test of normality ($p<0.05$).

Table 2 Discriminant analysis.

Variable	WL	F	df1	df2	F1	F2
Range cof x	.859	9.704*	2	118	.426	-.103
Range cof y	.910	5.865*	2	118	.069	.324
Force N	.781	16.560*	2	118	-.655	.555
Area of sway	.925	4.814*	2	118	.039	.910
Sway	.812	13.691*	2	118	.339	-.014
Speed of Sway	.811	13.711*	2	118	FTT	FTT
Test of function					WL	WL
					.651*	.981
Functions at Group Centroids	Senior				-.795	.132
	Junior				-.201	-.193
	Cadet				.890	.063

Legend: WL - Wilks' Lambda value; F – test – univariate test results; df1 - Effect degrees of freedom; df2 - Error degrees of freedom; *- Significant differences ($p<0.05$); F1 – Function 1; F2 – Function 2; FTT - Failing Tolerance Test.

Table 3 Differences between age categories.

Variable	Group	Mean	T	Sig. (2-tailed)
Range cof x	senior/junior	6.86/7.72	-1.372	0.17
	senior/cadet	**6.86/9.88**	**-4.251**	**0.00**
	junior/cadet	**7.72/9.88**	**-2.846**	**0.01**
Range cof y	senior/junior	7.902/8.67	-0.985	0.33
	senior/cadet	**7.90/10.82**	**-3.173**	**0.00**
	junior/cadet	**8.67/10.82**	**-2.320**	**0.02**
Force N	**senior/junior**	**219.73/195.31**	**2.618**	**0.01**
	senior/cadet	**219.73/165.42**	**5.356**	**o.oo**
	junior/cadet	**195.31/165.42**	**3.340**	**0.00**
Area of sway	senior/junior	323.38/320.815	0.199	0.84
	senior/cadet	**323.38/359.84**	**-2.443**	**0.02**
	junior/cadet	**320.81/359.84**	**-2.689**	**0.01**
Sway	senior/junior	120.121/126.08	-1.52	0.13
	senior/cadet	**120.12/144.35**	**-4.749**	**0.00**
	junior/cadet	**126.08/144.35**	**-3.540**	**0.00**
Speed of Sway	senior/junior	4.00/4.207	-1.528	0.13
	senior/cadet	**4.00/4.81**	**-4.754**	**0.00**
	junior/cadet	**4.20/4.81**	**-3.538**	**0.00**

Legend: t – values t-test; Sig. (2-tailed) - significant differences ($p<0.05$).

If the value of the Shapiro-Wilk test is less than 0.05 (Sig. < 0.05), distribution does not deviate from normal distribution, and vice versa. From the results, it can be seen that none of the parameters in all three groups differ significantly from normal distribution. In all parameters seniors have the highest mean values in relation to the juniors and cadets. Based on the discriminant analysis (Table 2), all variables significantly contribute to the difference between the groups in postural stability parameter of standing balance. In the further processing of the data, only parameters that significantly contributed to the difference between the groups were analysed. As follows from the Table 2 shown below, there is one statistical significant discrimination function (F1) which explains 96.3% of the variance. Functions at group centroids clearly indicate that negative values separate Seniors, Juniors from Cadets TKD athletes. In structural analysis, the results show coefficient and function of separate variables in Function 1 (F1) and Function 2 (F2). Table 3 shows the postural stability variables that significantly contribute to the difference between groups, based on discriminant analysis. From the results, it can be seen that the seniors significantly differ from the cadets in all parameters, and the difference is in favour of the seniors. Seniors and juniors differ only in maximal force and the difference is also in favour of the seniors. Juniors and cadets differ in all parameters in favour of the juniors.

Discussion and conclusion

There is some scientific evidence that, muscle endurance, power, strength, agility, and flexibility are very important fitness factors in success in TKD (Cular et al., 2013), but factors that directly affect athletic performance have not yet been precisely investigate and established. The importance of postural stability in martial arts as complex neuromuscular system is well known. However, there is limited empirical evidence to support this and other facts in postural stability of TKD. The main aim of this study was to characterize the postural stability profile in elite Croatian male and female TKD athletes. The second aim was to compare postural stability in frontal and sagittal plane in TKD athletes of different age groups. The major finding was that international level TKD athletes showed high postural stability, good balance, and the postural stability parameters were significantly higher in the senior group when compared with junior and cadet group. We found that the postural stability parameters were significantly higher in the senior group, when compared to the junior and cadet group. The results demonstrate that older and more expert TKD athletes perform better in terms of stability, have more precise standing balance, with minimum oscillations in frontal and sagittal plane. The results indicate there are differences in oscillations in planes and all groups showed more stability in medio-lateral (m-l) direction. The ability to maintenance and control of posture position and balance in static position or during movement, are one of fundamental factors for physical activity (Ageberg et al., 2003). Core stabilization exercises and physical activities are known to strengthen the deep muscles of the human body (Brill, 2002). The results of the present study support the notion that core strength is a determinant of high-level TKD performance. The ability to generate and sustain power output using both concentric and 'stretch-shortening cycle' muscle actions of the lower limbs may be important to support the technical and tactical actions in combat (Bridge et al., 2014). TKD competitors also display moderate to high maximum dynamic strength characteristics of the lower and upper extremities, and moderate endurance properties of the trunk and hip flexor musculature. The dynamic nature of the technical and tactical actions in the sport demand high flexibility of the lower limbs (Bridge et al., 2014; Kim, Kwon, Yenuga & Kwon, 2010; Zare, Letafatkar & Hadadnezhad, 2016).

Whether or not the core has sufficient power that power will be lost especially at the hip muscles if the trunk is unstable and it is because the level of core stability is inadequate so the whole body will supported from other muscles power which leading to the loss of proper body balance (Barr et al., 2005). Previous studies have stated that elite Olympic TKD athletes used kicks to score points around 98% of the time and that large emphasis is placed on lower limb power due to the large amount of explosive leg power needed for kicking (Kazemi, De Ciantis & Rahman, 2013). Accordingly, the importance of trunk muscles in performing lower and upper extremity movements while maintaining spinal stability in sitting or standing positions is obvious (Hodges & Richardson, 1997). In one longitudinal study, Yoon, Sung, & Park (Seo, Lee, Park, Ha & Kim, 2015) found that the core muscles of the TKD athletes were strengthened by the eight weeks of exercise, and measurement of the foot pressure in standing positions indicated that balance was significantly improved. We found that the postural stability parameters were significantly higher in the senior group when compared with junior and cadet group.

The possible main reason could be found in the different training pattern and numbers of hour in training session in different age categories. All mobility and power of human core generate from abdominal, pelvic and spine muscle named as the core muscle (Yoon et al., 2015). In the case of TKD athletes, strengthening these core muscles stability and improves spinal movement, and greatly helps to improve athletic performance. Senior and Junior selection of TKD athletes have more training sessions for improving strength and stability of posture in a way to increase performance. Cadets selection, on the other side, have more techniques training session in periodization. By performing more training hours, TKD athletes improve postural stability and specific strength of abdominal and trunk muscle. Particular attention is paid to basic position in TKD, which involves structural stability of posture in a way to react properly, so senior

athletes have high muscular settings and quality postural stability. As postural control is crucial for TKD practitioners, due to its dynamic kicking nature (Pieter & Heijmans, 2000; Leong, Fu, Ng, & Tsang 2011; Guo, 2013) during training sessions, competitive TKD athletes train static and dynamic balance stability. The dynamic nature of the technical and tactical actions in the sport demand high core abilities and it is important to develop specific postural stability to improve performance. Based on the competitive activities of TKD athletes, basic model characteristics are obtained, which are necessary for successful competitions, but also for the training process in TKD. In the practice routine of elite seniors of TKD, one of the most frequently used skills is roundhouse kick (Falco et al., 2009). Beside these skills, other commonly used techniques include side kick, back kick and spinning kick (Pieter & Heijmans, 2000). In kicking techniques, unilateral stance stability is crucial and is a determining factor of success in competitions (Pieter, 2009). These skills involve pivoting and rotation of the body on one leg as an essential component. Therefore, for TKD athletes, the importance of balance at landing during kicks takes a part of key fitness factors. In Seniors selection, there are more of these activities (Yoon, 2015), therefore, it is reasonable to conclude that elite senior TKD athletes have developed specific balance ability during turning, jumping and stepping so they would not fall and lose points during competitions (Fong, 2012b). Previous research concluded that Balance systems have not fully matured in adolescents of 11 to 14 years old and TKD training can speed up the development of balance in adolescents with training session and competitions (Fong, 2012). Thus, senior TKD athletes have developed balance as the most important 'coordination motor ability' of elite level combat athletes (Sadowski, 2005). These findings could explain the better result of postural stability in senior selection of TKD athletes in the research that has been conducted. Based on these findings, it was concluded that the different patterns of age trends between sexes should be considered by TKD coaches and fitness trainers in the evaluation of neuromuscular fitness of their athletes (Nikolaidis, Busko, Clemente, Tasiopoulos, & Knechtle 2016; Tasiopoulos & Knechtle, 2016). Since only elite competitors were tested, the findings could be of importance for both the selection and training design of TKD athletes. To conclude, the postural stability parameters were significantly higher in the senior group when compared with junior and cadet group. Since stability in competition situations is different from the stability on a stable surface, it is essential to evaluate postural stability when the centre of gravity of the body is effectively arranged to maintain the balance of a relatively heavy weight on a small and narrow base of support. Having in mind that there is a scarcity of research available on the physical characteristics and stability of TKD athletes in relation to age, sex, competition levels and weight categories, this and similar studies are welcome in order to evaluate a more extensive range of fitness and posture components that are pertinent to the sport. To confirm findings, in future research is necessary to verify the hypothesis that taekwondo training can positively impact on postural stability indicators.

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PROCJENA POSTURALNE STABILNOSTI ELITNIH TAEKWONDO SPORTAŠA: USPOREDNO ISTRAŽIVANJE IZMEĐU RAZLIČITIH DOBNIH SKUPINA

Sažetak

Cilj istraživanja je utvrđivanje karakteristika posturalne stabilnosti na uzorku vrhunskih muških i ženskih taekwondo natjecatelja. Sekundarni cilj je usporedba pokazatelja posturalne stabilnost u frontalnoj i sagitalnoj ravni između različitih dobnih skupina. Uzorak ispitanika sastojao se od tri subuzorka: seniori (N=38; 20,3±2,26 godina), juniori (N=40; 16,6±0,63 godina) i kadeti (N=43; 14,625±0,73 godina). Procjenjivani su sljedeći parametri: Raspon centra sila na X osi (RCX); Raspon centra sila na Y osi Y (RCY); Sila (Force); Površina centra težišta (ASWAY); Prijeđeni put centra težišta (SWAY); Brzina centra težišta (SSWAY). Rezultati diskriminativne analize ukazuju na postojanje statistički značajnih razlika između pojedinih uzrasnih kategorija. Seniori se statistički značajno razlikuju od kadeta u svim parametrima posturalne stabilnosti (p≤0,05). Rezultati pokazuju da postoje razlike u oscilaciji težišta i da su sve grupe pokazale veću stabilnost u medialno-lateralnom pravcu. Temeljem dobivenih rezultata možemo zaključiti da su parametri posturalne stabilnosti značajno bolji kod starijih uzrasnih kategorija. Dobiveni rezultati mogu biti od značaja za selekciju i dizajniranjem trenažnog procesa kao i prevenciju povreda taekwondo natjecatelja. Za donošenje kvalitetnijih zaključaka potrebno je u budućim istraživanjima dodatno provjeriti hipotezu da trenažna dob, odnosno vježbanje takewondo-a može pozitivno utjecati na pokazatelje posturalne stabilnosti.

Ključne riječi: *ravnoteža, selekcija, stabilizacija.*

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