International Journal of Sports Science 2012, 2(4): 36-41
DOI: 10.5923/j.sports.20120204.02

Differences in Muscular Performance between Practitioners and Non Practitioners of Parkour

Paulo Henrique Marchetti[1,2,3,*], Danilo Atanázio Luz Junior[2], Enrico Gori Soares[2], Fernando Henrique Silva[2], Marco Carlos Uchida[3], Luis Felipe Milano Teixeira[3]

[1]Faculty of Physical Education, Methodist University of Piracicaba, Piracicaba, São Paulo, 13400-911, Brazil
[2]Faculty of Physical Education, Young Men Christian Association, Sorocaba, São Paulo, 18010-400, Brazil
[3]Faculty of Physical Education, Department of Biological Sciences and Health, FIEO University, Osasco, São Paulo, 06020-190, Brazil

Abstract The aim of this study was to investigate the strength and power performance of Parkour practitioners and compare to those who do not. Eleven male Parkour practitioners and 12 male physical educators participated in this study and performed: pull-up test, handgrip strength dynamometer test (HSDT), plyometric push-up test, maximal horizontal jump, and maximal bipodal and unipodal countermovement jumps (CMJ). We calculated limb asymmetry for HSDT and CMJs and the bilateral deficit for CMJs. Significant differences were found between groups for the pull-up test (P=0.002), plyometric push-up test (P=0.039), bipodal CMJ (P<0.001), dominant unipodal CMJ (P=0.008), nondominant unipodal CMJ (P<0.001), maximal horizontal jump (P<0.001), and bilateral deficit (P<0.004). The Parkour group presented higher performance than the active group, except for HSDT.

Keywords Bilateral Deficit, Limb Asymmetry, Free Running, Radical Sport, Physical Tests

1. Introduction

Parkour is a leisure practice and a method of navigating the objects and spaces of urban environments[1]. This method was developed in France in the 1980s, and it has been used as a basis for military training since then. This particular technique has been characterized as an intermittent practice of the body's displacement. Practitioners try to overcome barriers in the environment in the most efficient manner, jumping or scaling an obstacle, which is sometimes done with acrobatic skill[2]; these actions are related to preventing energy expenditure, gaining time, and defeating obstacles during combat and rescue[3].

The practice of Parkour as a physical activity is relatively new and not as popular as other sports; therefore, few scientific studies have analyzed specific parameters, such as foot injuries[2] and physical fitness[3]. Additionally, no description about the specific strength and power performance of Parkour practitioners exists. Gaining knowledge about the physical capacities and skills of the Parkour athlete may be relevant to understanding the physiological demands of the activity and, consequently, to improving and developing training routines for this practice. Thus, the aim of the present study was to investigate the strength and power performance of people who practice Parkour. We hypothesized that the Parkour group would have a better performance when compared to the active group.

* Corresponding author:
dr.pmarchetti@gmail.com (Paulo Henrique Marchetti)
Published online at http://journal.sapub.org/sport

2. Material and Methods

2.1. Participants

Eleven male Parkour practitioners (the Parkour group, mean±SD: age, 19±3 years; height, 173±5 cm; weight, 67±7 kg) and 12 male physical educators (the physically active group, mean±SD: age, 21±2 years; height, 177±6 cm; weight, 79±4 kg) participated in this study. Both groups were matched with regard to age and height but not for weight (P=0.002). The Parkour practitioners had trained using only this method for at least three years four to five times a week for at least one hour. The physically active group had an average level of physical activity, and they practiced one occasional physical activity at a recreational level one to two times a week, such as running, soccer, and volleyball. For both groups, the inclusion criteria were as follows: (1) no previous surgery on the upper and lower extremities and (2) no history of injury with residual symptoms (pain, "giving-way" sensations, endurance loss) in the upper and lower limbs within the last year. The participants were informed about the study's aims and the risks of participating in this research before they gave their written informed consent. The study was approved by the Ethics Committee of the School of Physical Education of Jundiaí.

2.2. Procedures

Prior to data collection, the participants were asked which leg they preferred for kicking a ball. The preferred kicking leg was considered the dominant leg[4]. All participants chose the right leg as their dominant limb. Initially, all participants performed a specific warm-up for each test, including brief vertical and horizontal jumps. All the tests were conducted in a single day's session. The participants were asked to perform the following upper and lower limb tests:

Pull-up test: The participants were positioned holding a fixed bar that was 2 m above the floor. They were instructed to keep their elbows extended, their forearms in a pronated position, and their hands closed. The top of the range of motion corresponded to the point when the chin was pulled up to the level of the bar as viewed by the evaluator. The bottom of the range of motion occurred when the elbows were fully extended. All of the participants were instructed to perform the maximal number of complete pull-ups using a self-selected cadence[5, 6]. The pull-up tests were corrected for body mass (rep/kg)[7, 8].

Handgrip strength dynamometer test: The participants stood with their arms positioned on the sides of their bodies. They performed the maximal handgrip force against the dynamometer (Filizola™). Each limb completed three trials with one minute of rest between each. The highest value was adopted for analysis, and the level of asymmetry was calculated using an asymmetry index (AI) between the highest values of the handgrip performance of both upper limbs (right and left). The AI was calculated using absolute values as follows: $AI = 100 * \left| \frac{(V_r - V_l)}{(V_r + V_l)/2} \right|$, where Vr means right and Vl indicates the left limb[9].

Plyometric push-up test: To standardize the test, the participants were in a prone position with their arms held apart at shoulder width (i.e., biacromial distance) with their hands in contact with the jump mat (Ergojump Jump Pro 2.0™) and their trunks held in a rigid and straight position[10]. The participants began in the up position with their elbows fully extended and lowered their bodies toward the ground, flexing their elbows until their upper arms were parallel to the floor's surface[11]. Three maximal push-ups were performed through the full range of motion as quickly as possible, and the goal was that the participants would lose contact with the jumping mat and land with their elbows extended. We recorded the highest value of the three trials. The push-up jump tests were corrected for body mass (cm/kg)[7].

Maximal horizontal jump: The participants stood on the floor with their arms positioned on the sides of their bodies and their hands on their hips. All participants were asked to perform three trials of maximal horizontal displacement, and we used the longest value in our analysis[5]. The maximal horizontal jumps were corrected for body mass (cm/kg)[7].

Maximal bipodal and unipodal countermovement jump: For both bipodal and unipodal countermovement jumps, the participants were instructed to keep standing on the contact jump mat (Ergojump Jump Pro 2.0) with their arms positioned at the sides of their bodies and their hands on their hips[10, 12]. Then, the participants were asked to perform the highest possible countermovement jump while keeping their knees straight during the flight phase. For the unipodal jump (dominant and nondominant limb), the same position was adopted, but only one leg was in contact with the contact mat during both takeoff and landing. We used the highest value of the countermovement jumps. The sequence of the countermovement jumps (bipodal, dominant, and nondominant unipodal) was randomized among the participants. All tests were corrected for body mass (cm/kg)[7]. In addition, we calculated the level of asymmetry and the bilateral deficit. For the asymmetry level, we used an asymmetry index (AI) between the highest values of the unipodal countermovement jump (dominant and nondominant). The AI was calculated using absolute values as follows: $AI = 100 * \left| \frac{(V_r - V_l)}{(V_r + V_l)/2} \right|$ where Vd means dominant and Vnd indicates the nondominant limb[9]. The bilateral deficit was calculated as the difference between the sum of the maximal height of the two unipodal countermovement jumps (dominant and nondominant) and the maximal height of the bipodal countermovement jump divided by the sum of the maximal height of the two unipodal countermovement jumps (dominant and nondominant)[9, 13], $BLD = \frac{UP_d + UP_{nd} - BP}{UP_d + UP_{nd}}$ where UP means unipodal countermovement jump, BP means bipodal countermovement jump, and d and nd indicate the dominant and nondominant limb, respectively.

2.3. Statistical Analyses

Normality of the data were confirmed by the Kolmogorov-Smirnov. Data were expressed by mean ± standard deviation[14]. The comparison between groups was determined by t-tests for independent samples as: pull-up, handgrip strength dynamometry, plyometric push-up jump, horizontal jump, bipodal and unipodal countermovement jumps, lower limb asymmetry and bilateral deficit. An alpha of .05 was used for all statistical tests. Cohen's formula for effect size (ES) was used, and the results were based on the following criteria: >0.07 large effect; 0.69-0.30 moderate effect; ≤0.30 small effect.

3. Results

Table 1. Mean and standard deviation of the maximal values for Pull-Up test, handgrip strength dynamometer test and Plyometric Push-Up test for active and Parkour group.* Statistical differences between groups, *P*<0.05

Group	Pull-Up (Rep/kg)	Handgrip Strength Dynamometry (N)		Plyometric Push-UpTest (cm/kg)
		Right Limb	Left Limb	
Active	0.1±0.05	484±32	475±42	0.11±0.05
Parkour	0.16±0.03*	466±40	461±50	0.19±0.1*
Δ%	37.5%	3.7%	2.9%	42.1%

Table 2. Mean and standard deviation of the countermovement jump (bipodal, unipodal) and horizontal jump of both active and Parkour group. * Statistical differences between groups, *P*<0.05

Group	Bipodal Countermovement Jump (cm/kg)	Unipodal Countermovement Jump (cm/kg)		Horizontal Jump (cm/kg)
		Dominant Leg	Nondominant Leg	
Active	0.46±0.09	0.24±0.06	0.23±0.046	2.57±0.34
Parkour	0.58±0.08	0.31±0.04	0.32±0.05*	3.22±0.24*
Δ%	20%	22%	28%	20%

There were significant differences for weight between groups(P=0.002), therefore, pull-ups and plyometric push-up tests were normalized by this variable. The results of the upper limb tests revealed significant differences between the groups for the pull-up test(P=0.002) and the plyometric push-up test(P=0.039) (ES=0.33 and 0.93, respectively). There was no significant AI difference for the handgrip strength dynamometer test between the groups (mean±SD:1.4±1.8% and 2.4±2.3%, respectively). Table 1 shows the mean and standard deviations of the maximal values for the pull-up test, handgrip strength dynamometer test, and plyometric push-up test for both groups (active and Parkour). Table 2 contains the mean and standard deviations of the maximal values for the countermovement jumps and horizontal jumps for both the active and Parkour groups.

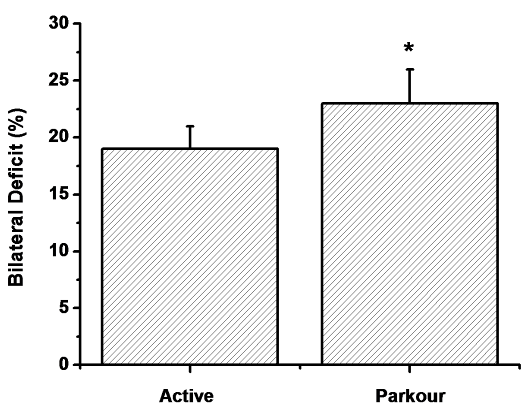

Figure 1. Mean and standard deviation of the bilateral deficit. *Significant differences between groups (*P*=0.004)

The results of the lower limb tests revealed significant differences between the groups for bipodal countermoveme nt (P<0.001), dominant unipodal countermovement(P=0.00 8), nondominant unipodal countermovement(P<0.001), and maximal horizontal jump (P<0.001) (ES=1.50, 1.37, 1.98, and 2.20, respectively) (Table 2).

However, a significant AI difference for countermoveme nt between the groups was found (mean±SD: 4.3±13% and 4.6±10%, respectively). There was significant bilateral deficit difference for countermovement between the groups(P=0.004) (ES=0.97) (Figure 1).

4. Discussion

In this study, we investigated the strength and power performance of Parkour practitioners and non practitioners. Our hypotheses that the Parkour group would have better performance than the active group was supported by this work, with the exception of the handgrip strength dynamometer test. Several functional tests were included in this study that were intended to evaluate participants' physical condition as related to the specific demands of Parkour. These functional tests were classified according to the upper and lower limbs.

During the Parkour routine, the arms are used primarily to overcome obstacles, place the practitioner in certain maneuvers, and grab onto structures; therefore, fast and powerful upper limb movements are very important to the Parkour routine. The push-up can be used either in the assessment of muscle performance or as an exercise to increase the strength of the pectoralis major, anterior deltoid, and triceps brachii. Push-up performance therefore measures the strength and endurance of several upper-extremity and trunk muscles[15], and plyometric push-ups are used in both training and testing protocols[16, 17].

Plyometrics is a nontraditional form of resistance training that emphasizes the loading of muscles during an eccentric muscle action, which is quickly followed by a rebound concentric action[18]. Several researchers have published good reliability values for push-ups in determining upper body muscular function[11, 19-21]; however, no study has analyzed this performance on the maximal plyometric push-up test, especially for Parkour practitioners.

The results of our study showed that the Parkour group exhibited higher performance than the active group for both absolute and corrected body mass values on the plyometric push-up test. The main reason for these results was the specific characteristics of the modality of the upper limbs, which the Parkour group uses frequently to produce propulsion to cross obstacles or to position the body in space.

The other functional test used in this study was the pull-up test, which has been employed as a performance measure to assess physical fitness, muscular strength, and endurance of the shoulder complex[22]. We observed that the Parkour group demonstrated better performance during the pull-up test than the active group in both analyses (approximately 37.5% for absolute values).

LaChance and Hortobagyi[6] evaluated the influence of cadence on maximal performance during different exercises (pull-ups and push-ups). Part of their study assessed the maximal number of repetitions during a single bout of maximal effort exercise of their 75 participants (college-age males), and the results showed that the participants' performance reached 11.2±4.3 maximal repetitions during self-paced cadence. This result corroborated our findings considering the low differences between our groups (active and Parkour). Because the Parkour routine is highly specific, the number of repetitions (muscular endurance) is probably not the most important variable when compared to plyometric or strength conditions.

Parkour requires specific demands of the hands, and isometric handgrip contractions are needed to prevent falling and to provide propulsion of the body during different conditions of the routine[23]. In addition, handgrip strength is an important measure of general health and is regarded as one of the most reliable methods for estimating strength[24]. However, it is important to note that the handgrip dynamometer test does not simulate all of the handgrip positions that are encountered in the Parkour routine.

Regarding our results, we did not verify the differences among the handgrip strength values between the groups or the different sides of the body (right and left upper limbs). These results were partially supported by a previous study[23]. Green and colleagues[23] determined differences in isometric handgrip exercise performance between trained and untrained climbers. They observed that the maximal voluntary contractions for both groups were different, reaching approximately 400 N for untrained and 550 N for trained climbers. The climbers presented higher values of isometric handgrip strength than the Parkour group (> 500 N), showing the specificity of the modality. However, in our study, comparisons of isometric handgrip strength between the groups were similar despite the fact that our active group was composed of active participants.

Other studies have established normal reference values for handgrip strength in healthy adult participants by using isometric handgrip dynamometry to analyze 229 participants[25] and 1122 participants[26]. Their results showed that males normally have a maximal isometric handgrip force around 351 N and 428 N, respectively. The values achieved in our study were higher, which was probably because we analyzed two active groups of participants.

During the Parkour routine, the lower limbs are important to propel the body to jump over obstacles and long distances, to maintain balance, and to decrease lower limb impact during vertical and horizontal landings. Several functional tests were used in this study to analyze lower limb strength and power.

The countermovement jump is a task that involves a stretch shortening cycle to allow the body to store and redirect energy through an eccentric movement that is quickly followed by a concentric movement. Then, the countermovement jump can produce more force and power during the concentric phase of the jump[27]. In the present study, we used three different kinds of countermovement jumps: unipodal (dominant and non dominant lower limb), bipodal vertical countermovement, and horizontal.

Our results showed that the Parkour group presented higher values than the active group for all countermovement jumps, which was probably due to the high demand of different kinds of jumps during the Parkour routine. Only one other study[3] has previously analyzed the countermovement jump (vertical and horizontal jump) in 13 Parkour practitioners. The results of this previous study reported higher values than our study: vertical countermovement jump (55.96 cm vs. 39.5 cm) and horizontal jump (2.53 m vs. 2.17 m). However, this work did not correct the data by body mass.

It has been theorized that a balance in strength should exist between opposing muscles or muscle actions to help avoid injury and enhance performance[11]. Intense unilateral training demands (e.g., unilateral jumps) can produce lower limb asymmetries. Based on the study of Stephens et al.[28], we hypothesized that the Parkour group would present more asymmetries than the active group. However, this hypothesis was not confirmed because both groups presented similar differences in unilateral (dominant and nondominant lower limb) jump performance (less than 5% differences between lower limb power). This result could be explained by a more coordinated pattern of postural stability and better force management of the legs in the Parkour group, the higher physical demands of the activity[29-31], and specific sensorimotor challenges[32].

A bilateral strength deficit is a commonly verified phenomenon that was first described in 1961 by Henry and Smith[36] in which the voluntary maximal strength levels produced during bilateral contractions are lower than those required for unilateral contractions of the same muscles when they are added[13, 33-35], The mechanisms responsible for bilateral deficits are currently unknown partially because it is a nonvisible phenomenon in all experimental conditions[37]. However, many theories related to the deficit of bilateral strength have been proposed, such as the spinal inhibitory reflex[38], reduction of motorneuron excitability[33], inter-hemispheric inhibition[33, 39], influence of postural instability[37, 40], influence of the strength-velocity curve of the active muscles[13, 41, 42], and differences in neuromuscular activity between the unilateral and bilateral contractions [13].

In our study, the Parkour group presented with higher bilateral deficits than the active group. The most likely reason for this is the high level of unilateral jumping stress that results during the Parkour routine. The amount of work produced by one leg in a bilateral jump is lower than that generated by unilateral jumps, which has been confirmed by inverse dynamics analysis[43]; therefore, this asymmetric physical stress may be increasing the power differences between the lower limbs.

This study had some limitations. We assumed self-cadence (velocity), and the data were corrected only by body mass. The kinetic energy of the participants is a function of mass (m) and velocity (v), and the greater velocity of falling results in greater work to decelerate and then accelerate the body during maximal plyometric tests (Energy Kinetic=½ m.v2)[6, 18].

The purpose of this study was to understand the profile of strength and power between practitioners and non-practitioners of Parkour and to increase the understanding of specific characteristics of this modality. To apply these results, more studies will need to be developed regarding the characteristics of this modality (i.e. energy expenditure, landing strategies) to begin to formulate better training sessions that may be incorporated into training programs or periodization. More studies could also evaluate different approaches to improve the performance of Parkour athletes and to decrease the risks of injury.

5. Conclusions

In conclusion, the Parkour group presented with a higher performance ability than the active group in all of the tests except for handgrip strength dynamometry. These results were dependent on the specificity of each task realized during the Parkour routine.

ACKNOWLEDGMENTS

The authors would like to thank all Parkours' participants from Sorocaba and Aylton Figueira Junior, Ph.D. and a special thanks to the Faculty of Physical Education (GNTF-YMCA/Sorocaba) and GEPEFFA-UNIFIEO.

REFERENCES

[1] Bavinton N: *From Obstacle to Opportunity: Parkour, leisure, and the reinterpretation of constraints*. Australian and New Zealand Association for Leisure Studies.: Australia. 2007, p. 391-412.

[2] Miller JR, Domoinv SG: Parkour: a new extreme sport and a case study. J Foot Ankle Surg 2008, 47(1): 63-65.

[3] Leite N, Aguiar Jr RP, Cieslak F, Ishiyama M, Milano GE, and Stefanello JMF: Perfil da aptidão física dos praticantes de Le Parkour. Rev. Bras. Med. Esporte 2011, 17(3): 198-201.

[4] Maulder P, Cronin J: Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. Phys. Ther. Sport 2005, 6(2): 74-82.

[5] Mathews DK: Medida e avaliação física em educação física. 1980, Rio de Janeiro: Interamericana.

[6] LaChance PF, Hortobagyi T: influence of cadence on muscular performance during push-up and pull-up exercises. J. Strength Cond. Res 1994, 8(2): 76-79.

[7] Mayhew JL, Ball TE, Bowen JC: Push-ups as a measure of upper body strength. J. Appl. Sports Sci. Res 1991, 5(1): 16-21.

[8] Youdas JW, Amundson CL, Cicero KS, Hahn JJ, Harezlak DT, Hollman JH: Surface electromyographic activation patterns and elbow joint motion during a pull-up, chin-up, or perfect pullup rotational exercise. J. Strength Cond. Res 2010, 24(12): 3404-3414.

[9] Marchetti PH, Uchida MC: Influence of unilateral fatigue of lower limbs on the bilateral vertical jump. Rev. Bras. Med. Esporte 2011, 17(6): 401-404.

[10] Sale DG: Testing strength and power. Physiological testing of high-performance athlete. 1991, Human Kinetics: Champaign.

[11] Negrete RJ, Hanney WJ, Kolber MJ, Davies GJ, Ansley MK, McBride AB, Overstreet AL: Reliability, minimal detectable change, and normative values for tests of upper extremity function and power. J. Strength Cond. Res 2010, 24(12): 3318-3325.

[12] Marchetti PH, Cesquini F: Validação do tapete de contato na mensuração da altura de salto em jogadores de basquete de elite. Rev. Bras. Ciên. Saúde 2009, 21: 10-15.

[13] Rejc E, Lazzer S, Antonutto G, Isola M, Di Prampero PE: Bilateral deficit and EMG activity during explosive lower limb contractions against different overloads. Eur. J. Appl. Physiol 2010, 108: 157-165.

[14] Marsden CD, Meadows JC, Merton PA: "Muscular wisdom" that minimizes fatigue during prolonged effort in man: peak rates of motoneuron discharge and slowing of discharge during fatigue. Adv. Neurol 1983, 39: 169-211.

[15] Cogley RM, Archambault TA, Fibeger JF, Koverman MM, Youdas JW, Hollman JH: Comparison of muscle activation using various hand positions during the push-up exercise. J. Strength Cond. Res 2005, 19(3): 628-633.

[16] Gouvali MK, Boudolos K: Dynamic and electromyographical analysis in variants of push-up exercise. J. Strength Cond. Res 2005, 19(1): 146-151.

[17] Hrysomallis C, Kidgell D: Effect of heavy dynamic resistive exeercise on acute upper-body power. J. Strength Cond. Res 2001, 15(4): 426-430.

[18] Vossen JF, Kramer JF, Burke DG, Vosses DP: Comparision of dynamic push-up training and plyometric push-up training on upper-body power and strength. J. Strength Cond. Res 2000, 14(3): 248-253.

[19] Romain BS, Matthew MT: Norm referenced and criterion referenced reliability of the push-up and modified pull up. Meas. Phys. Edu. Exerc. Sci 2001, 5: 67-80.

[20] Suni JH, Oja P, Laukkanen RT: Health-related fitness test battery for adults: Aspects of reliability. Arch. Phys. Med. Rehabil 1996, 77: 399-405.

[21] Suprak DN, Dawes J, Stephenson MD: The effect of position on the percentage of body mass supported during traditional and modified push-up variants. J. Strength Cond. Res 2011, 25(2): 497-503.

[22] Pate RR, Burgess ML, Woods JA, Ross JG, Baumgartner T: Validity of field tests of upper body muscular strength. Res. Q. Exerc. Sport 1993, 64: 17-24.

[23] Green JG, Stannard SR: Active recovery strategies and handgrip performance in trained vs. untrained climbers. J. Strength Cond. Res 2010, 24(2): 494-501.

[24] Groslambert A, Nachon M, Rouillon JD: Influence of the age on self-regulation of static grip forces from perceived exertion values. Neurosci. Lett 2002, 325: 52-56.

[25] Luna-Heredia E, Martin-Pena G, Ruiz-Galiana J: Handgrip dynamometry in healthy adults. Clin. Nutr 2005, 24(2): 250-258.

[26] Schlussel MM, dos Anjos LA, de Vasconcellos MT, Kac G: Reference values of handgrip dynamometry of healthy adults: a population-based study. Clin. Nutr 2008, 27(4): 601-607.

[27] Earp JE, Kraemer WJ, Newton RU, Comstock BA, Fragala MS, Dunn-Lewis C, Solomon-Hill G, Penwell ZR, Powell MD, Volek JS, Denegar CR, Hakkinen KA, Maresh CM: Lower-body muscle structure and its role in jump performance during squat, countermovement, and depth drop jumps. J. Strength Cond. Res 2010, 24(3): 722-729.

[28] Stephens II TM, Lawson BR, DeVoe DE, Reiser II RF: Gender and bilateral differences in single-leg countermovement jump performance with comparison to a double-leg jump. J. Appl. Biomech 2007, 23(3): 190-202.

[29] Hugel FM, Cadopi M, Kohler F, Perrin P: Postural control of ballet dancers: a specific use of visual input for artistic purposes. Int. J. Sports Med 1999, 20: 86-92.

[30] Vuillerme N, Danion F, Marin L, Boyadjian A, Prieur JM, Weise I, Nougier V: The effect of expertise in gymnastics on postural control. . Neurosci. Lett 2001, 303: 83-86.

[31] Oliver GD, Di Brezzo R: Functional balance training in collegiate women athletes. J. Strength Cond. Res 2009, 23(7): 2124-2129.

[32] Bressel E, Yonker JC, Kras J, Heath EM: Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. J. Athl. Training 2007, 42(1): 42-46.

[33] Oda S: Motor control for bilateral muscular contractions in humans. Jap. J. Physiol 1997, 47: 487-498.

[34] Owings TM, Grabiner MD: Fatigue effects on the bilateral deficit are speed dependent. Med. Sci. Sports Exerc 1998, 30(8): 1257-1262.

[35] Kuruganti U, Murphy T, Pardy T: Bilateral deficit phenomenon and the role of antagonist muscle activity during maximal isometric knee extensions in young, athletic men. Eur. J. Appl. Physiol 2011, 111: 1533-1539.

[36] Henry FM, Smith LE: Simultaneous vs. separate bilateral muscular contractions in relation to neural overflow theory and neuromotor specificity. Res. Q. Exerc. Sport 1961, 32: 42-47.

[37] Magnus CRA, Farthing JP: Greater bilateral deficit in leg press than in handgrip exercise might be linked to differences in postural stability requirements. Appl.Physiol. Nutr. Metab 2008, 33: 1132-1139.

[38] Ohtsuki T: Decrease in human voluntary isometric arm strength induced by simultaneous bilateral exertion. Behav. Brain Res 1983, 7: 165-178.

[39] Post M, Van Duinen H, Steens A, Renken R, Kuipers B, Maurits N, Zijdewind I: Reduced cortical activity during maximal bilateral contractions of the index finger. . Neuroimage 2007, 35: 16-27.

[40] Herbert RD, Gandevia SC: Muscle activation in unilateral and bilateral efforts assessed by motor nerve and cortical stimulation. J. Appl. Physiol 1996, 70: 306-316.

[41] Bobbert MF, Graaf WW, Jonk JN, Richard Casius LJ: Explanation of the bilateral deficit in human vertical squat jumping. J. Appl. Physiol 2005, 100: 493-499.

[42] Yamauchi J, Mishima C, Nakayama S, Ishii N: Force-velocity, force-power relationships of bilateral and unilateral leg multi-joint movements in young and elderly women. J. Biomech 2009, 42: 2151-2157.

[43] Van Soest AJ, Roebroeck ME, Bobbert MF, Huijing PA, Van Ingen Schenau GJ: A comparison of the one-legged and two-legged countermovement jumps. Med. Sci. Sports Exerc 1985, 17: 635-639.