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THE EFFECTS OF DIFFERENT VERTICAL JUMP HEIGHT ON ELECTROMYOGRAPHIC, KINEMATIC AND KINETIC VARIABLES

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Abstract
Countermovement jump (CMJ) is an element of many sports techniques and has an important role in the overall performance, both when performed at maximal and submaximal intensity. This paper aims to investigate changes in biomechanical and neuromuscular variables that are responsible for controlling different submaximal intensities of the CMJ. 8 healthy and uninjured volleyball players from the first league of the Republic of Serbia, average age 21.9 ± 1.9 years, average body height 191.6 ± 9.2 cm, average body weight 83.1 ± 7.1 kg were included in the study. Subjects performed CMJ at three different jump heights (approximately 65%, 80%, and 95% of the maximal height). For the analysis of electromyographic data, the value of root mean square analysis was used separately for the amortization phase and the jump phase, for the following muscles: m. gluteus maximus (GlutM), m. rectus femoris (RF), m. biceps femoris (BF), m. vastus lateralis (VL), m. tibialis anterior (TA) and m. gastrocnemius medialis (GastM). Kinematic and kinetic variables were monitored: vertical center of mass displacement in the amortization phase [m], the center of mass height at take-off point [m], jump height [m], jump speed [m/s], angular displacement in the ankle, knee and hip joint [rad], maximal vertical ground reaction force [N/kg], vertical stiffness [kN/m/kg], the torque of the ankle, knee and hip joint [Nm/kg]. The change in jump height (65, 80 and 95%) did not have a significant effect on the change in activation for most muscles ($p \geq 0.05$), except for GastM where a tendency towards increase was observed ($p=0.066$). During jump phase, the activation of VL, BF, GlutM, TA muscles significantly increased compared to the amortization phase ($p \leq 0.05$). The torque in the hip joint increased significantly with increasing jump height ($65<80=95\%$) ($p=0.028$). During amortization phase, the values of vertical center of mass displacement increased significantly between each jump height ($65<80<95\%$) ($p \leq 0.05$), while the values of vertical stiffness decreased with increasing jump height, where significant differences were observed between 80% and 95% of maximal jump height ($65=80<95\%$) ($p=0.012$). Angular displacements in the knee and hip joint increased significantly with increasing jump height ($65<80<95\%$) ($p \leq 0.05$) while no changes in angular displacement in the ankle joint were observed ($p \geq 0.05$). The results of the research show that the increase in the jump height is related to an increase in the amortization phase, due to an increase in angular displacements in the knee and hip joint, as well as an increase in torque of the hip joint.

Key wordls: MUSCLE ACTIVATION / VERTICAL STIFFNESS / TORQUE

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INTRODUCTION

Almost all sports require efficient movement of the athlete, as one of the main factors for achieving successful performance outcomes. Sports techniques consist of natural (walking, running, jumping, and throwing) and derived forms of movement (e.g. forehand and backhand in tennis, jump shot in basketball, somersault in gymnastics). Two-legged vertical jump with amortization phase (countermovement jump – CMJ) is one of the very important factors on which depends athletes performance in some sports (basketball, volleyball). In addition, CMJ is a simple, practical and very reliable indicator of the lower extremities strength (Holmberg, 2010). It can be characterized as a widely applicable, multi-joint exercise, which requires high level of neuromuscular engagement. It is used in training programs and testing of many professional and recreational athletes. CMJ performance can be associated with speed and maximal power, but most often is characterized as explosive movement, i.e. the ability of explosive power, which arises as a result of maximal force production in the shortest possible time (Van Zandwijk et al., 2000). Exercises with weights, rubber band, chains, kettlebells (e.g. squats, lunges with additional load etc.) can be used to develop jump height, but more specific methods are more efficient, such as performing various forms of jumps themselves (Holcomb et al., 1990; Gehri et al., 1998).

The coordination pattern of the maximal jump is very similar among individual athletes and it is achieved with the goal to optimize neuromuscular control and to achieve the optimal solution or strategy for maximal performance. The submaximal jump differs from the maximal one in many variables (Van Zandwijk et al., 2000). By adjusting individual variables, such as production of muscle force, duration of movement, movement speed, the overall intensity etc., the height of the jump can be optimized. Submaximal jumps, unlike maximal ones, can theoretically have an infinite number of possible solutions. One of the previous researches showed that there is a difference in relative timing between the two mentioned jump intensities. This indicates that neuromuscular control during submaximal jumps is influenced by changes in the motor pattern itself (van Zandwijk et al., 2000).

Progressive increase in jump height shows an increase in the amortization phase and rotation of the proximal segments (Vanrenterghem et al., 2004; Lees et al., 2004; Mrdakovic et al., 2018), so the usage of kinetic potential energy would be more efficient, as well as the association with negative and positive performed mechanical work in the ankle, knee and hip joint (Kipp et al., 2020). It was revealed that the progressive increase in jump height is associated with the tendency to increase the forward trunk inclination at the beginning of the take-off (Vanrenterghem et al., 2004; Lees et al., 2004; Mrdakovic et al., 2018) and it was most often monitored through increased torque in the knee and hip joint, but not in the ankle joint (Ford et al., 2005; Vanrenterghem et al., 2008). The contribution of the ankle depends on the intensity, so the contribution of the ankle and plantar flexors in the total performed work has the highest value of 78% at 25% of the maximal jump intensity and this contribution decreases with increasing jump height (Vanrenterghem et al., 2004; Zajac et al., 1984). Namely, due to the horizontal orientation of the feet, they are the only ones that can generate the ground reaction force during the take-off phase (Zajac et al., 1984). When trying to maximally reduce the vertical stiffness of the jump, i.e. to consciously perform the jump from the amortization in a deep squat, it has been shown that the performed work, maximal torque and maximal activation of the extensors in the hip joint are significantly higher (Wade et al., 2020). The increase in the jump height from submaximal to maximal intensity is accompanied by increased activation of *m. biceps femoris* in the early stages of the take-off phase, by reduction of *m. quadriceps femoris* activation in the later stages of the take-off (Lees et al., 2004; Salles et al., 2011), as well as by increase of the integrated electromyographic (EMG) signal of *m. triceps surae* when an additional external load is used (Wade et al., 2019). Also, the role of two-joint muscles (*m. rectus femoris* and *m. biceps femoris*) was emphasized, which have a significant role in the control of jumping at different heights (van Zandwijk et al., 2000; Lees et al., 2004).

The purpose of this study is to examine the mechanisms responsible for controlling the intensity of CMJ. The aim of this research is to determine which neuromuscular, kinematic and kinetic variables change with the change in the intensity of the CMJ. The first hypothesis of this research is that the change in the jump height will affect the mechanics of the knee and hip joints, expressed through angular displacements and manifested torques, while the mechanics of the ankle joint will remain insensitive to the change in the jump height. The second hypothesis is that an increase in the jump height will increase amortization phase and reduce vertical stiffness. The third hypothesis of this study is that the muscle activation will increase with increasing jump height, in most of the monitored leg muscles.

METHODS

The subjects

The subjects consisted of 8 volleyball players from the first league of the Republic of Serbia, average age 21.9 ± 1.9 years, average body height 191.6 ± 9.2 cm, average body weight 83.1 ± 7.1 kg. Subjects did not have any injuries in the last year. Each subject voluntary signed a consent form for the participation in this experiment. Also, the subjects were familiar with the testing protocol in advance and had at least eight years of active experience in volleyball.

Testing protocol

The research was conducted in two days. On the first day, after an introductory warm-up consisted of 10 minutes of cycling, active stretching, jumping in place and performing CMJ, the subjects were informed with the main movement tasks. After a three-day rest, the acquisition of electromyographic, kinematic and kinetic variables was done during the main testing day. After introductory warm-up, which was the same as the one on the first day, electrodes for electromyographic analysis and markers for kinematic analysis were placed on the dominant leg of the subjects. Surface electrodes were placed on seven muscles: *m. gluteus maximus* (GlutM), *m. rectus femoris* (RF), *m. biceps femoris* (BF), *m. vastus lateralis* (VL), *m. tibialis anterior* (TA) and *m. gastrocnemius medialis* (GastM). Eight retroreflective markers were placed on the dominant side of the subjects, at the following figurative points: fifth metatarsal phalanx, heel, ankle joint, knee joint, hip joint, shoulder joint, elbow joint, wrist joint, sternoclavicular joint and head.

Subjects jumped at three different jump heights, which were approximately 65%, 80% and 95% of the maximal jump height. Maximal jump heights were measured based on the maximal vertical center of mass displacement (normalized to the upright posture of the subjects) and the control marker that was placed above the upper edge of the ear shell, in line with the eye socket. Indication of the desired jump height was conducted by visual signal, in the box form (20 cm wide, 10 cm long and 2 cm high), which was open on the one side toward the athlete, and had LED lightbulbs on the other side. The box was placed in horizontal plane in relation to the ground, and with the help of a sliding mechanism, it was possible to adjust its height. The task was to achieve a certain jump height by reaching the horizontal plane of the box and visually spotting the light markers on the back of the box. With a linear laser, the Bosch PCL20 device, which was located behind the subject, the experimenter controlled their jump height. The successfully performed task involved cutting the laser beam with the upper edge of the ear shell (Figure 1). Five successful jumps were required for each jump height. A total of seven jumps were performed, and two of them in which the jump height was not adequately hit were removed in the post-processing procedure. An average of five jumps was taken for further analysis. The pause between jumps performed at the same heights was about 30 seconds, and the pause between heights was about 60 seconds.

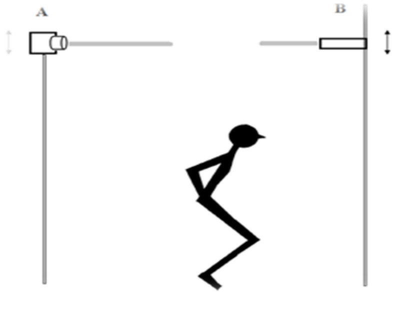


Figure 1. Experimental setting and method for submaximal jump height controll.

The sample of variables and the method of their measurement

For the EMG data analysis, root mean square (RMS) analysis was used for each muscle separately in the amortization phase and in the take-off phase. RMS values were normalized in relation to the maximal value of RMS achieved during maximal vertical jump and are expressed as a percentage value in relation to it (where 1 means 100%). The kinematic and kinetic variables were as follows: vertical center of mass displacement in the amortization phase [m], the center of mass height at take-off point [m], jump height [m], jump speed [m/s], angular displacement in the ankle, knee and hip joint [rad], maximal vertical ground reaction force [N/kg], vertical stiffness [kN/m/kg], the torque of the ankle, knee and hip joint [Nm/kg]. Vertical stiffness was calculated according to the spring-mass model, as a quotient of the achieved maximal ground reaction force and vertical center of mass displacement in the amortization phase (Blickhan, 1989; Farley & Morgenroth, 1999). The joint torques were determined using the model of interconnected rigid segments, then the anthropo-morphological characteristics of the segments and on the principles of inverse dynamics (Winter, 1990). All values of kinetic variables were normalized according to the subject's body weight.

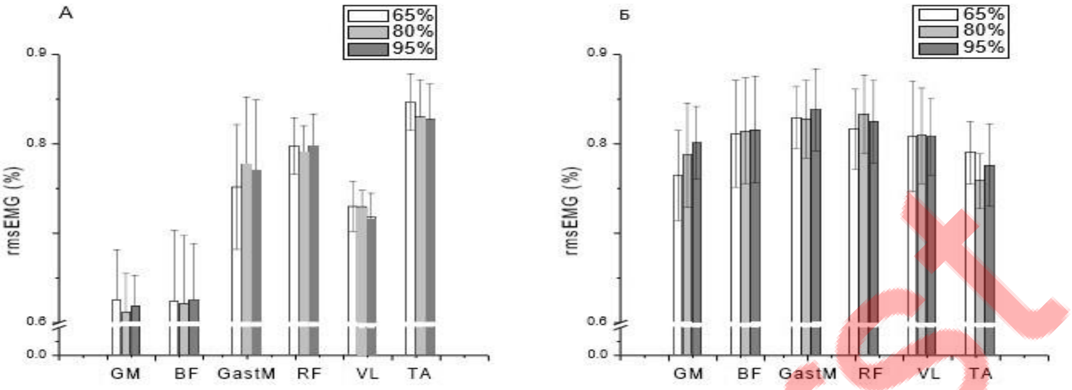
For EMG analysis, it was used Myomonitor IV telemetry apparatus (DelSys Inc. Boston, MA, USA) with individual differential silver-chloride electrodes (DE-2.1), with a sensor contact of 2 silver plates (10 mm long and 1 mm wide) and the with the contact surface of 10 mm. The frequency of signal sampling was set to 2000 Hz. The raw EMG signal was first filtered by a band-pass filter in the range of 10 to 750 Hz, and then a linear increment was formed using a low-pass filter at 10 Hz. The AMTI tensiometric platform (60x120) was used for measurement of ground reaction force and torque in orthogonal directions, at a recording frequency of 2000 Hz, with an amplifier of x4000 and with band-pass filtering of 10-1050 Hz. Kinematic variables were monitored using Qualysis infrared cameras (ProReflex MCU 240) that recorded retroreflective markers with a diameter of 32 mm, with a frequency of signal sampling of 240 Hz.

Statistical data processing

The results of descriptive analysis (mean values and standard deviations) for all studied variables are presented graphically, while the results of analysis of variance with repeated measurements (df, F, p, post-hoc) are presented in the tables. For the purpose of examining the influence of jump height (65%, 80% and 95% of maximal jump height) and jump phase (amortization phase and take-off phase) on EMG variables, two-way analysis of variance with repeated measurements (ANOVA) was used. For the purpose of examining the influence of the jump height (65%, 80% and 95% of the maximal jump height) on the kinematic and kinetic variables, a one-way analysis of variance with repeated measurements (ANOVA) was used. For each group of variables, the assumption of sphericity of the results was first determined using the Mauchly’s test. If the assumption was not satisfied, i.e. if Mauchly’s test values showed p-values less than 0.05, Greenhouse-Geisser correction for df and F-values was used. If the ANOVA statistical analysis determined a significant influence of one of the factors and if that factor had more than two different levels, post-hoc analyzes were done in order to determine the differences between different levels within one factor using Bonferroni post-hoc analysis or t-test for independent samples with Holm-Bonferroni correction. All statistical analyzes were performed in the program for data processing – SPSS version no. 17. P-values less than 0.05 were selected to determine the level of statistical significance.

RESULTS

Between different phases (amortization phase and take-off phase) of the CMJ, two-way ANOVA analysis with repeated measurements revealed a significant difference in the root mean square EMG (rmsEMG) variables for the VL, BF, GlutM and TA muscles ($p \leq 0.01$) (table 1, graph 1). During the take-off phase, a higher amount of activation was measured compared to the amortization phase, except for TA, where the trend of change was reversed. The change in jump height (65%, 80% and 95%) did not significantly affect muscle activation, except for GlutM, where a trend towards significant effect was observed (p=0.066). Bonferroni post-hoc analysis for GastM showed a significant difference in the rmsEMG variable between the jump at 65% and 95% of the maximal height (p≤0.01), while there were no significant differences between the other jump intensities. Two-way ANOVA with repeated measurements did not show a significant effect of the interaction of the jump phase and the jump height on the rmsEMG variable.



Graph 1. Average values of rmsEMG (± SD) during the amortization phase (A) and during the take-off phase (B) of countermovement jump performed at different jump heights.

Table 1. Results of two-way ANOVA with repeated measurements (jump phase and jump height) for rmsEMG variables with Bonferroni post-hoc processing, (p≤0.05).

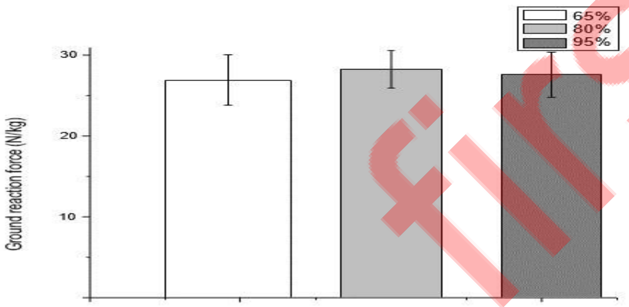
		Jump phase	**Jump height**	**Interaction**
VL	*df;error*	1; 7	2; 14	2; 14
	F	14.925	0.373	0.376
	p	**0.006**	0.696	0.693
	Post-hoc			
RF	*df;error*	1; 7	2; 14	2; 14
	F	3.811	0.157	0.733
	p	0.092	0.856	0.498
	Post-hoc			
BF	*df;error*	1;7	2; 14	2; 14
	F	51.887	0.047	0.033
	p	**0.000**	0.954	0.967
	Post-hoc			
GastM	*df;error*	1; 7	2; 14	2;14
	F	3.151	3.319	1.682
	p	0.119	0.066	0.221
	Post-hoc		c↑	
GlutM	*df;error*	1; 7	2; 14	2; 14
	F	105.883	0.742	3.525
	p	**0.000**	0.494	0.058
	Post-hoc			
TA	*df;error*	1; 7	1.129; 7.906	2; 14
	F	14.201	3.582	0.496
	p	**0.007**	0.093	0.619
	Post-hoc			

Post-hoc (Bonferroni): (a) significant difference between 65% and 80%; (b) a significant difference between 80% and 95%; (c) significant difference between 65% and 95%; symbols (↑) (↓) indicate that the value increases (↑) or decreases (↓) at higher jump heights.

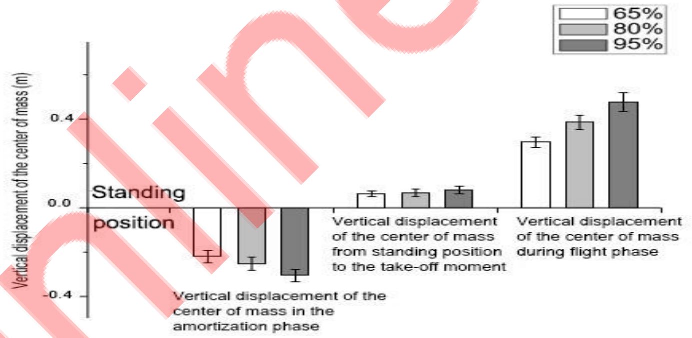
The results show that the jump height, according to ANOVA with repeated measurements, did not affect the variability of the maximal ground reaction force (Table 2, Graph 2). During the amortization phase, the values of the vertical center of mass displacement increased significantly between each jump height (65<80<95%; p≤0.05), while the values of center of mass height at the time of take-off were also significantly higher at 95% of maximal jump, compared to 65% (Table 2, Chart 3). During the flight phase, the values of the vertical center of mass displacement increased significantly with increasing jump height (65<80<95%; $p \leq 0.05$) (Table 2, Graph 3). The values of vertical stiffness decreased with increasing jump height, where significant differences were observed between jump at 80% and 95% of maximal height (65=80<95%; $p \leq 0.05$) (Table 2, Graph 4).

The values of the angular displacement in the ankle joint did not change with the change in the jump height, while the angle in the knee and hip joint changed significantly (Table 2, Graph 6). Post-hoc analysis found that the values of the angular displacement in the hip joint increased significantly between each jump height, while the values in the knee joint at 95% of maximal height were significantly higher than at 65% and 80% (65=80<95%; $p \leq 0.05$).

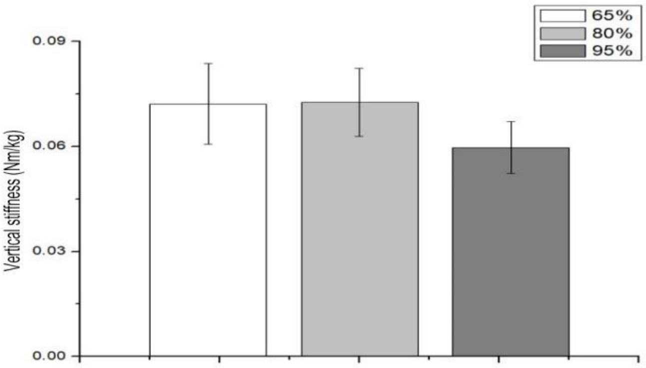
The torque in the hip joint was the only one under the influence of the change in jump height (Table 2, Chart 5). Post-hoc analysis showed that the values of the torque in the hip joint are significantly higher when jumping at heights of 80% and 95% of maximal height, compared to jump heights at 65% (65<80=95%; $p \leq 0.05$).



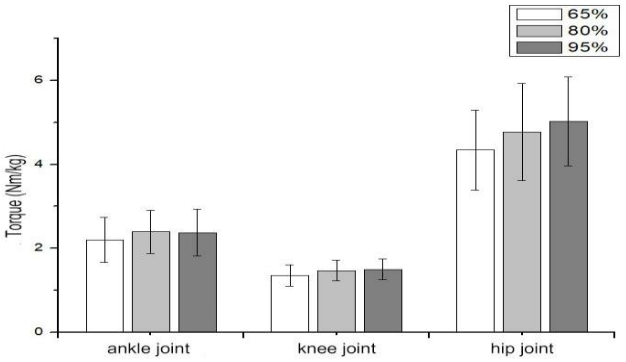
Graph 2. Average values (± SD) of the ground reaction force during countermovement jump performed at different jump heights.



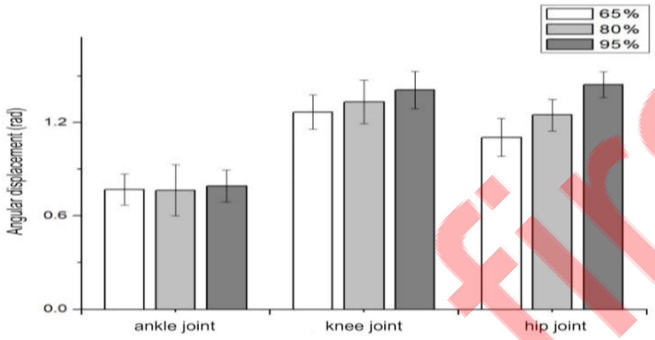
Graph 3. Average values (± SD) of the vertical center of mass displacement during countermovement jump performed at different jump heights.



Graph 4. Average values (± SD) of vertical stiffness during countermovement jump performed at different jump heights.



Graph 5. Average values (± SD) of torque in the ankle, knee and hip joint during countermovement jump performed at different jump heights.



Graph 6. Average values (± SD) of angular displacements in the ankle, knee and hip joint during countermovement jump performed at different jump heights.

Table 2. Results of ANOVA with repeated measurements (jump height) for kinematic and kinetic variables with Bonferroni post-hoc processing. (p≤0.05)

	df;error	*F*	*p*	*Post-hoc*
Maximal ground reaction force	2; 14	1.061	0.372	
Amortization phase	2; 14	34.890	**0.000**	a↑, b↑, c↑
Center of mass height at the take-off	1.213; 8.494	4.888	**0.051**	c↑
Jump height	2; 14	294.225	**0.000**	a↑, b↑, c↑
Jump speed	2; 14	162.142	**0.000**	a↑, b↑, c↑
Angular displacement in the ankle joint	2; 14	0.407	0.673	
Angular displacement in the knee joint	2; 14	14.601	**0.000**	b↑, c↑
Angular displacement in the hip joint	2; 14	32.551	**0.000**	a↑, b↑, c↑
Vertical stiffness	2;14	6.135	**0.012**	b↓, ***c***↓
Ankle joint torque	1.210; 8.470	2.708	0.134	
Knee joint torque	2; 14	1.274	0.310	
Hip joint torque	1.076; 7.530	7.261	**0.028**	a↑, c↑

Post-hoc (Bonferroni): (a) significant difference between 65% and 80%; (b) significant difference between 80% and 95%; (c) significant difference between 65% and 95%; symbols (↑) (↓) indicate that the value increases (↑) or decreases (↓) at higher jump heights.

DISCUSSION

The aim of this study was to determine which neuromuscular and coordination variables of the locomotor system adapt for the purpose of controlling the countermovement jump at different jump heights, based on monitoring changes in electromyographic, kinematic and kinetic variables. Subjects performed jumps at three different jump heights, which were approximately 65%, 80% and 95% of the maximal jump height.

The results showed that the increase of the vertical jump intensity didn't lead to load for each joint proportionally. More precisely, at the ankle and knee joint, torque values slightly increased with increasing jump height, while in the hip joint the torque values increased significantly with increasing jump height (Graph 5). This partly confirmed the first hypothesis of this research. Data from previous research have confirmed the obtained results (Lees et al., 2004), which showed that with increasing jump height there was an increased of the work done by the hip joint. These results confirm the importance of the role of the extensors activity in the hip joint at maximal vertical jump intensities. Based on this information, an adequate vertical jump technique must be accompanied by high-intensity extension in the hip joint and the adequate abilities of these muscles. Given that the mechanics of the knee joint, in the form of manifested torque, was not sensitive to changes in jump height, it cannot be said that the activity of the knee joint is insignificant for the performance of vertical jump because extensor muscles in the knee joint showed a significant change of the level of activation in relation to changed performance conditions (Graph 1 and Table 1). The explanation for this may be the role of the two-joint extensors in the hip joint, which produce hip joint extension but also produce knee joint flexion and thus neutralize the torque of the extensors in the knee joint (Lees et al., 2004).

The vertical center of mass displacement in the amortization phase, as well as from the upright position to the moment of take-off, increased significantly with increasing jump height (Chart 3). In addition, the ground reaction force remained unchanged with the change in the jump height (Graph 2). Increasing the amortization phase, with the aim of increasing the jump height, reduced the vertical stiffness (Chart 4), which is in line with the second hypothesis of this study. According to some authors, jump height control can be explained by the fact that at certain levels of the central nervous system (CNS) there are sets of controlled commands aimed at controlling global performance variables (Auyang et al., 2009). In this way, a person can adapt to the expected and unexpected changes that occurred during the performance of the movement, by stabilizing the kinematics of jumping through inter-articular coordination. The latter confirms the assumption that parts of the locomotor system that function on the basis of the spring-mass model, which have a small number of degrees of freedom, may be variables used by the nervous system to control vertical jump performance (Auyang et al., 2009).

The third hypothesis of this study was not confirmed because the results showed that muscles did not change activation with increasing jump height (Graph 1 and Table 1). The only muscle where there was a tendency towards change under the influence of jump height is GastM (Chart 1 and Table 1). Manifested power production at the ankle has been shown to have three factors: muscle contraction (27%), production of accumulated energy of elastic deformation in connective tissue (53%), and transfer of strength by the knee joint via two-joint muscle (Bobbert et al., 1986). The latter proves that the presence of two-joint muscles shows much greater ankle power compared to engaging only one-joint muscles. Such a mechanism is possible because with extension in the knee joint, GastM elongation occurs. If its length remains constant, extension in the knee joint will cause plantar flexion in the ankle joint, which allows power transfer from the knee joint to the ankle joint. Fine-tuning of two-joint GastM activation is one of the most important factors for successful control of the jump height (van Zandwijk et al., 2000).

As the foot has a horizontal orientation, in contrast to the vertical orientations of the upper leg and lower leg, the last phases of the take-off are performed by angular displacement in the ankle joint. As the angular displacement in the ankle joint did not change with increasing jump height (Chart 6), it is difficult to conclude that the mechanics of the ankle joint are responsible for adjusting the center of mass height at the take-off. With regards to this, high activation of GastM during maximal jumps, compared to submaximal, occurred with the aim of adequate transfer of activities from the knee joint to the ankle joint (Bobbert et al., 1986). In contrast to the angular displacement in the ankle joint, the angular displacement in the knee and hip joint increased significantly with increasing jump height.

The increase in the intensity of VL activation during the concentric phase compared to the eccentric (Graph 1 and Table 1) can be explained by the role of this muscle as the main extensor of the knee joint during the take-off phase. On the other hand, the intensity of RF activation did not change in the take-off phase compared to the amortization phase, but showed a high activation in general (Graph 1 and Table 1). It can be assumed that the activation of RF, a two-joint muscle that work as flexor in the hip and extensor in the knee joint, can't be increased in the take-off phase in comparison with the amortization phase, due to simultaneous extension of the hip and knee joint during the take-off phase. Finally, the intensity of TA activation in the eccentric contraction phase was pronounced in comparison with the concentric phase (Graph 1 and Table 1), which explains its role as an important shock absorber of accumulated kinetic energy during the amortization phase.

The results showed that there was a significant difference in the level of muscle activation of VL, BF, GlutM and TA between the amortization phase and the take-off phase (Chart 1 and Table 1). A significant increase in GlutM and BF activation in the take-off phase highlights the importance of the hip extensor activity during take-off. The proximal-to-distal pattern of vertical jump firstly implies the trunk extension from the lowest point, which has the ability to achieve the highest kinetic energy, and then the rotation of the distal body segments. During the amortization phase, the torso is bent, and in order to neutralize that amount of movement, high activity of the hip extensor muscles is necessary. Based on that, the importance of BF activity is emphasized, as a two-joint muscle that significantly affects the performance of the vertical jump, although there was no significant change in its activation in relation to the increase in jump height (Graph 1 and Table 1).

CONCLUSION

The change in jump height (65, 80 and 95% of maximal height) did not significantly affect the change in muscle activation, except for GastM, where a tendency towards increase was observed. On the other hand, the take-off phase significantly influenced the increase of activation of VL, BF, GlutM and TA, but not in the two-joint muscles – GastM and RF. The increase in jump height significantly affected the increase in torque at the hip joint (65<80=95%). The jump height did not affect the variability of the maximal ground reaction force. During the amortization phase, vertical center of mass displacement values increased significantly between each jump height level (65<80<95%), while vertical stiffness values decreased with increasing jump height, where significant differences were observed between jumps at 80% and 95% of maximal height (65=80<95%). The values of the angular displacement in the ankle joint did not change with the change of the jump height, while the angular displacements in the knee and hip joint increased significantly (65<80<95%).

Detecting the changes on certain neuromuscular, kinematic and kinetic variables during increasing in jump height, movement variables are identified that lead to increased performance, where there is a possibility of performance improvement with certain motor task instructions. Accordingly, instructions to increase the amortization phase and the angular displacement in the knee and hip joint should improve vertical jump performance. Of course, these recommendations must be considered in relation to the athletes muscular ability to overcome the increased torques that occur due to such instructions.

LITERATURE

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