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Kinematic Motion Analysis of the Lower Limb in Performing the Box Jump Sport at Three Different Heights

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Abstract:
In this study, we evaluated how jumping at different heights (called box jump sport), influences lower limb joint kinematics.Thirteen male athletes who had been doing CrossFit for at least 5 years performed box jumps at three heights (45cm, 60cm, and 75cm). 3D-kinematic analysis used a Vicon motion analysis system with the 6-camera system to record kinematics data at 120Hz. To compare the values obtained from box jump at three heights, the one-way analysis of variance (ANOVA) was used.During landing, the ankle joint showed more dorsiflexion at higher box heights (23.9±3.3, 20.1±4.2, and 19.2±3.6 degrees for 75cm, 60cm, and 45cm, respectively; p = 0.035). Within the knee joint, at the first measured peak, flexion increased with increasing height (98.2±11.7, 99.9±8.7, and 117.4±6.1 degrees for 45cm, 60cm, and 75cm, respectively; p = 0.001). Within the hip joint, at the first measured peak, flexion showed an increase with increasing box height (71.4±5.2, 74.7±7.2, and 82.1±1.5 degrees for 45cm, 60cm, and 75cm, respectively; p = 0.001). In general, the results showed that with the increase in the box height in box jump sports, the angles of the lower limb joints (the ankle, the knee, and the hip) increase in the sagittal and frontal planes.
***Keywords**: Kinematics, Lower Extremity Joints, Range of Motion**,** Box Jump, Sport.*

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I. Introduction

Jumping is present in most sports such as gymnastics, football, volleyball, and basketball. The goal of jumping in these sports is to reach the maximum jump height to achieve success. In addition, the maximum jump height parameter is used to monitor and check the performance of athletes [21]. Jumping has different tests that are used to determine the physical fitness of athletes. These tests include countermovement jump (CMJ), squat jump (SJ), drop jump (DJ), and box jump (BJ). Where SJ is the jump from the squat position, CMJ is a movement downward from a standing position to a squat position and then jump, DJ is the jump from a height on the ground and jumping again, and BJ is the jump from the ground on the box.

So far, most studies have focused on the differences between SJ and CMJ in achieving maximal height [19,18,4]. Maximum jump height after landing and force values recorded by the force plate has been investigated in research related to DJ [5,15]. One of the most popular exercises for various sports that involve jumping is the box jump [1,11,2]. Recently, the impact of box jumping in CrossFit sports has been noticed in investigating heart rate change and muscle fatigue [6,13,16]. CrossFit is a new method in physical fitness training, which includes the implementation of various exercises such as plyometric, and types of jumping, which are applied at high intensity. CrossFit aims to increase flexibility, muscle strength, agility, and endurance [4,15,23].

The difference between the present study with the previous studies is the kinematic analysis of the jumping of professional CrossFit athletes on boxes with different heights. Therefore, considering the importance of jumping in various sports and the effect of lower limb joints on jumping, the purpose of this research was to investigate the kinematics and range of motion of the lower limb joints in box jumping at three heights.

II. Materials and Methods

Participants

In this study, 13 male athletes, aged between 20 and 25 years, who had done CrossFit for at least 5 years were selected. The demographic characteristics of these athletes were: Age) 24.30±2.05 years, Height) 172.84±5.55 centimeters, and Weight) 78.93±4.93 kilograms. For this research, the inclusion criteria for subjects were: male, aged between 20-25 years, more than 5 years of professional experience in CrossFit, no injury in the last year, and no lower body surgery. If the subjects did not include any of them, they were excluded from the study. In this research, protocols followed guidelines stated in the Declaration of Helsinki. Also, the study was approved by the Institutional Review Board of Islamic Azad University. All participants provided written informed consent before entering the study.

Study design

In this study, participants performed box jumps at 3 heights (45, 60, and 75 centimeters) in the Motion Analysis Laboratory. Before the collection of the experimental data, each subject was warmed-up for 10 minutes. To do the box jump, subjects stand in front of the box with legs-apart (shoulder-width). After which, participants bend into a quarter-squat, swing their arms from back to forward and initiate a jump from the ground, and land on the box. Each participant was asked to perform a jump three times with a one-minute interval between each jump, a mean of which was considered that individual's final scores. This was done to minimize any bias as opposed to a single measurement. Kinematic parameters of lower limbs (changes in angles of ankle, knee, and hip) were examined in frontal and sagittal planes associated with take-off, landing, and during the jump.

Figure 1. Box jump. A) Marker set, B) Start of the jump C) during the jump, D) Landing on the box.

To record the kinematic parameters, 16 passive reflective spherical markers with a diameter of 14mm were installed on the subjects' lower bodies. These points were: anterior superior iliac spine, posterior superior iliac spine, lateral thigh, lateral epicondyle of the knee, lateral tibia, lateral malleolus, calcaneus, and second metatarsal head (Figure 1). They were then asked to perform box jumps in front of motion analysis cameras. A Vicon 3D motion analysis system (Oxford Metrics Ltd., Oxford, UK) with a 6-camera system was used to record kinematic data at a frequency of 120Hz. Data were collected from the time the heel separated from the ground until the first contact of the heel with the surface on the box. The maximum angle of the hip, knee, and ankle joints were the biomechanical parameters we extracted.

Statistical analysis

In this study, each participant's right leg was considered the research subject. The results are presented as mean±standard deviation (SD). The Shapiro-Wilk normality test was conducted to confirm the normal distribution of biomechanical parameters. The one-way analysis of variance (ANOVA) was used to determine statistically significant differences between the means of selected biomechanical data. A p-value of less than 0.05 was considered statistically significant. All statistical analysis was performed using the SPSS software version 28.0.0.

III. Results

The changes in the dorsi-plantar flexion and the inversion-eversion angles of the ankle are shown in Figures 2A and 2B during CrossFit jump sport at three different heights (H_1=45cm(solid-line), H_2=60cm(dotted-line), H_3=75cm(dashed-line)) and the results are given in Table 1.

Within the ankle joint, no significant difference was observed in the maximum plantar-flexion angle (P=0.129) and maximum dorsiflexion angle (p=0.833) in the 3 different positions. Also, there was no significant difference in dorsi-plantar flexion angle at take-off time (P=0.092). However, during landing, the ankle joint showed more flexion at higher box heights (23.9±3.3, 20.1±4.2, and 19.2±3.6 degrees for 75cm, 60cm, and 45cm, respectively; p=0.035). Regarding the inversion-eversion angles, no significant difference was found at take-off time and maximum inversion angle (p=0.092 and p=0.833 respectively).

Table 1. Dorsi-Plantar flexion and Inversion-Eversion of the ankle in box jump sport at three heights

		Heights			
Measurement-point	**Angle(deg)**	**45cm**	**60cm**	**75cm**	**P-value**
Take-Off	Df/Pf	-6.8±6.2	-14.2±6.4	-8.6±6.5	0.096
Max-Pf		-8.7±7.4	-17.1±6.6	-11.8±7.8	0.129
Max-Df		27.2±2.1	26.2±2.9	26.9±3.6	0.833
Landing		19.2±3.6	20.1±4.2	23.9±3.3	0.035
Take-Off	Inv/Eve	-6.5±2.5	-6.8±2.5	-7.3±1.4	0.092
Max-Inv		-0.9±2.1	-1.7±2.4	-2.5±1.2	0.010
Landing		-2.3±1.4	-3.6±2.9	-4.4±2.1	0.037

Df/Pf: Dorsi-Plantar flexion, Inv/Eve: Inversion-Eversion.

During the maximum inversion-eversion, the ankle joint showed higher eversion with increasing height (-0.9±2.1, -1.7±2.4, and -2.5±1.2 degrees for 45cm, 60cm, and 75cm, respectively; p=0.010). Furthermore, during landing, ankle joint eversion increased with increasing height (-2.3±1.4, -3.6±2.9, and -4.4±2.1 degrees for 45cm, 60cm, and 75cm, respectively; p=0.037).

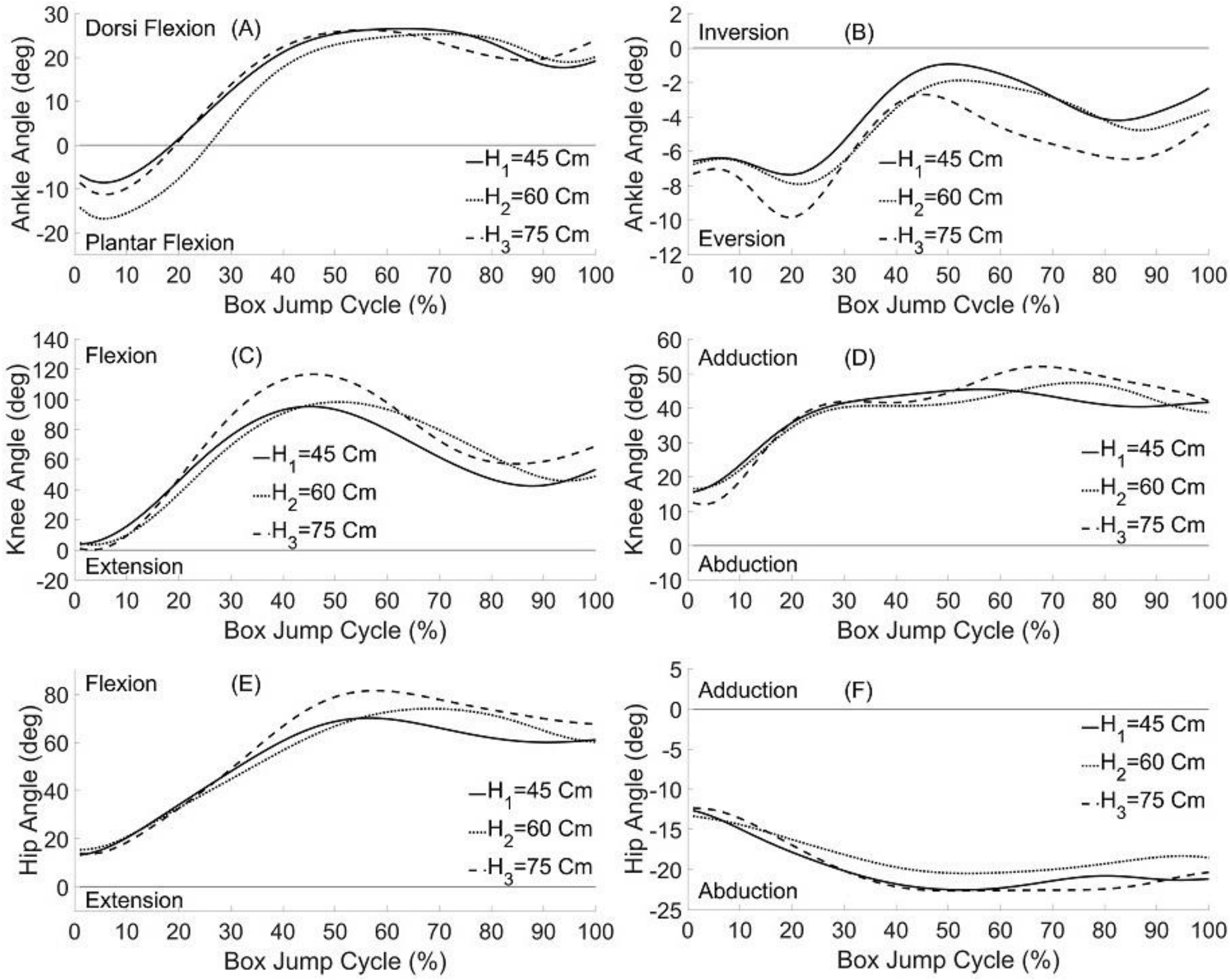

Figure 2. Lower limb angles during box jump sport at three heights (H_1=45cm (solid-line), H_2=60cm (dotted-line), H_3=75cm (dashed-line)). A) Ankle angle in the Sagittal plane, B) Ankle angle in the Frontal plane,C) Knee angle in the Sagittal plane, D) Knee angle in the Frontal plane,E) Hip angle in the Sagittal plane, F) Hip angle in the Frontal plane.

The results of the changes in the knee angles (flexion-extension and abduction-adduction) during CrossFit jump sport at three different heights (H_1=45cm(solid-line), H_2=60cm(dotted-line), H_3=75cm(dashed-line)) are shown in Figures 2C and 2D.

Kinematic changes of the knee joint for the three measurement heights of the plyometric box are reported in Table 2. Within the knee joint, at the first measured peak, flexion increased with increasing height (98.2±11.7, 99.9±8.7, and 117.4±6.1 degrees for 45cm, 60cm, and 75cm, respectively; p=0.001). At the second measured peak, flexion increased with increasing height (38.9±5.7, 43.9±7.4, and 55.2±7.1 degrees for 45cm, 60cm, and 75cm, respectively; p=0.001). Moreover, abduction also showed an increase with increasing height (46.6±2.1, 48.3±1.2, and 52.5±2.4 degrees for 45cm, 60cm, and 75cm, respectively; p=0.001). During landing at the knee joint, at the maximum height (75cm) the joint showed higher flexion compared to shorter heights (68.9±9.9 vs. 49.1±9.1 and 53.5±6.7 degrees for the 60cm and 45cm, respectively; p=0.001).

Table 2. Flexion-Extension and Abduction-Adduction of the knee in box jump sport at three heights

		Heights			
Measurement-point	**Angle(deg)**	**45cm**	**60cm**	**75cm**	**P-value**
Take-Off	Fl/Ex	3.7±5.9	4.6±4.1	0.9±4.2	0.108
	Abd/Add	15.6±4.4	16.6±5.7	12.4±3.8	0.066
1st Peak	Fl/Ex	98.2±11.7	99.9±8.7	117.4±6.1	0.001

	Abd/Add	42.7±1.3	40.8±1.5	42.2±2.9	0.119
2nd Peak	Fl/Ex	38.9±5.7	43.9±7.4	55.2±7.1	0.001
	Abd/Add	46.6±2.1	48.3±1.2	52.5±2.4	0.001
Landing	Fl/Ex	53.5±6.7	49.1±9.1	68.9±9.9	0.001
	Abd/Add	41.6±1.8	38.7±6.1	41.9±6.9	0.295

Fl/Ex: Flexion-Extension, Abd/Add: Abduction-Adduction.

In addition to the changes in the ankle and knee angles, the changes in the hip joint in the sagittal and frontal plane during CrossFit jump sport at three different heights (H_1=45cm(solid-line), H_2=60cm(dotted-line), H_3=75cm(dashed-line)) are shown in Figures 2E and 2F.

Within the hip joint, at the first measured peak, flexion showed an increase with increasing box height (71.4±5.2, 74.7±7.2, and 82.1±1.5 degrees for 45cm, 60cm, and 75cm, respectively; p=0.001). Moreover, during landing at the maximum measured height (75cm), the hip joint showed higher flexion compared to other measured heights (67.6±6.5 vs. 60.1±6.7 and 60.1±8.6 degrees for 60cm and 45cm, respectively; p=0.013). Changes in the kinematics of the hip joint are shown in Table 3.

Table 3.Flexion-Extension and Abduction-Adduction of the hip in box jump sport at three heights

		Heights			
Measurement-point	**Angle(deg)**	**45cm**	**60cm**	**75cm**	**P-value**
Take-Off	Fl/Ex	13.2±3.5	15.4±4.1	13.8±2.1	0.195
	Abd/Add	-12.6±4.7	-13.3±5.2	-12.4±5.3	0.910
1st Peak	Fl/Ex	71.4±5.2	74.7±7.2	82.1±1.5	0.001
	Abd/Add	-23.3±3.4	-20.8±4.2	-23.5±3.8	0.280
Landing	Fl/Ex	61.1±6.7	60.1±8.6	67.6±6.5	0.013
	Abd/Add	-21.2±3.7	-18.5±4.1	-20.3±3.9	0.407

Fl/Ex: Flexion-Extension, Abd/Add: Abduction-Adduction.

IV. Discussion

The purpose of this study was to investigate the changes in the angles of the ankle, knee, and hip joints among male professional CrossFit athletes in the sagittal and frontal planes in box jump at three heights of 45, 60, and 75 centimeters. The kinematic parameters of the joints were examined at the maximum joint angle during the jump, at the start, and at the time of landing on the box. The reason for using professional male athletes was to achieve higher jump heights [17,22] and to avoid the risk of joint injury compared to female athletes [22].

The results showed that the dorsiflexion angle of the ankle increased during landing when changing the height of the box from 45cm to 60cm and 45cm to 75cm respectively, 4.6% and 24%. We found that by increasing the height of the box from 45cm to 75cm, a significant increase in the maximum ankle inversion occurred in the middle of the movement and during landing. This may be because the increase in height is associated with a further increase in knee flexion. After all, the knee goes outwards, and adduction increases. Significant changes in the maximum knee flexion occurred with an increase in the box height. The maximum angle of the knee flexion at a height of 75cm was 19.2 degrees higher than the 45cm height (19.5%) and 17.5 degrees higher than the 60cm height (17.5%).

Furthermore, knee flexion during landing increased by 28.8% with increasing the height of the box by 30cm. The maximum knee adduction at three different heights increased from 46.6 to 48.3 and 52.2 degrees, by about 8.6% and 12.7%, respectively. Moreover, the maximum hip flexion at a height of 75cm increased by 9.9% and 14.9% (compared to the 45cm and 60cm heights, respectively). The hip flexion in the 75cm height in the landing, was 10.6% more compared to the 45cm position and 12.5% compared to the 60cm position. Also, no significant difference was observed in any of the angles of the joints of the lower limbs at take-off.

In this study, arm movements were used to achieve higher-height jumps. Grimshaw et al. Showed that rotating the arms forward and upwards has a great effect on the upward movement of the body and will increase the jump height by 10% to 20% [22,10]. Furthermore, they used arm rotation to jump higher [22].

Pauli et al. Showed that at the beginning of the jump, a greater angle at the hip and knee joint produces more force in the muscles, resulting in a higher jump [18]. In this study, no research was done on muscle strength. As the height of the boxes increased, the maximum flexion angle of the knee and hip also increased significantly, this seems to be due to the greater contraction of the muscles to contract the lower torso. Several researchers have suggested that the effect of pelvic flexion is greater than that of the knee muscles in jumping [3,7]. The results showed that the increase in knee flexion occurs simultaneously with the increase in hip flexion, which is consistent with the results of the study by Clansey[8]. There was also an increase in the maximum knee adduction, which seems to have occurred to maintain balance and to further contract the lower extremity muscles in the middle phase of the jump.

During the landing on the box, significant changes occurred in the knee and hip flexion, and ankle dorsiflexion with an increase in the height of the box. This may have also occurred to maintain balance at the time of contact with the box. By repeating this exercise (box jump) and using different sizes in the height of the boxes, it is possible to increase the flexibility of the knee, hip, and ankle joints.

The goal of past research has been to achieve maximum jumping height. As it turned out, the effect of the countermovement jump was more than the squat jump [19,18,4]. Also, jumping from higher drop heights in the drop jump led to more coordination of the lower limb, bilaterally symmetrical during landing, longer ground contact times, and reaching a higher height in the taking-off again [20,5,15]. Until now, most of the research in the field of CrossFit sport has been about the effect of various continuous or interval training, especially box jumping on physical fitness. Scotty et al. concluded that heart rate changes were greater in continuous training than in interval training [6]. It was found in research by Jordan that muscle fatigue in consecutive box jumps affects the ability of the lower limbs and the production of the necessary forces for jumping [13]. In a different study, it was found that intense CrossFit exercises (weighted front squat, box jumps, and double-under) affect increasing the thickness of the patellar and Achilles tendons [9]. The difference between the present study and the above research was the investigation of the changes in the Lower Extremity Joints angles during jumping on boxes with variable heights.

To develop this method, the number of the boxes can be increased and their number and height can be personalized based on the physical condition and the height of each individual, moreover, specific exercises can be considered for everyone to increase physical fitness. With these exercises, the coordination between the agonist and antagonist muscles can be increased and a higher number of muscles can be contracted simultaneously [14,12]. For more comprehensive research, it is recommended to use a force plate for ground reaction forces and electromyography to record electrical activity and generate muscle force at different heights.

V. Conclusion

The research results showed that with the height of the boxes increased, the angles of the ankle, knee, and hip joints increased in the frontal and sagittal anatomical planes. Therefore, it can be concluded that different jump heights affect the kinematics of the lower limbs. In addition, by designing boxes with different heights for athletes, we can provide various training programs to strengthen the muscles and flexibility of the joints of the lower limbs.

Ethical Considerations

Acknowledgment: The authors would like to thank the participants for their cooperation in the study.
Authors' contributions: FK, NK, MA, PA, HT; study design. DD, FA; data gathering. FK, MA, NK, MS, PA, HT; data interpretation and manuscript preparation. All authors have approved the final manuscript.
Conflict of interests: Authors have no competing interest to declare.
Compliance with ethical guidelines: Study protocols followed guidelines stated in the Declaration of Helsinki and were approved by the Institutional Review Board of Islamic Azad University.
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Informed Consent: Written and informed consent was obtained from the participants before entering the study.

References

[1]. AF KJF, Stieg JL, Tran TT, AF LEB, AF JWC, AF DAJ (2011) Effects of depth jump vs. box jump warm-ups on vertical jump in collegiate vs. club female volleyball players. Med Sport 15:103-106
[2]. Aksović N, Berić D, Kocić M, Jakovljević S, Milanović F (2020) Plyometric training and sprint abilities of young basketball players. Facta Universitatis Series: Physical Education and Sport:539-548
[3]. Aragón-Vargas LF, Gross MMJJoaB (1997) Kinesiological factors in vertical jump performance: differences among individuals. 13:24-44

[4]. Azreh R, Oskouei AH, Shirazi SAE (2020) Effects of Short-term Plyometric Training on Countermovement Vertical Jump Height and Kinematics of Take-Off. Thrita 9
[5]. Beardt BS, McCollum MR, Hinshaw TJ, Layer JS, Wilson MA, Zhu Q, Dai B (2018) Lower-extremity kinematics differed between a controlled drop-jump and volleyball-takeoffs. J Appl Biomech 34:327-335
[6]. Butcher SK, Judd TB, Benko CR, Horvey KJ, Pshyk AD (2015) Relative intensity of two types of CrossFit exercise: Acute circuit and high-intensity interval exercise. Journal of Fitness Research 4:3-15
[7]. Charoenpanicha N, Boonsinsukhb R, Sirisupc S, Saengsirisuwana VJA (2013) Principal component analysis identifies major muscles recruited during elite vertical jump. 22:20-29
[8]. Clansey A, Lees A Changes in lower limb joint range of motion on countermovement vertical jumping. In: ISBS-Conference Proceedings Archive, 2010.
[9]. Fisker F, Kildegaard S, Thygesen M, Grosen K, Pfeiffer-Jensen M (2017) Acute tendon changes in intense CrossFit workout: an observational cohort study. Scand J Med Sci Sports 27:1258-1262
[10]. Grimshaw P, Fowler N, Lees A, Burden A (2007) Instant notes in sport and exercise biomechanics. Taylor & Francis,
[11]. Gross M, Hemund K, Vogt M (2014) High intensity training and energy production during 90-second box jump in junior alpine skiers. The Journal of Strength & Conditioning Research 28:1581-1587
[12]. Hrženjak M, Trajković N, Krističević TJA (2016) Effects of plyometric training on selected kinematic parameters in female Volleyball players. 16:16.13-11.52
[13]. Jordan B (2019) Vertical jump height as an indicator of lower-extremity muscular fatigue in recreational Crossfit athletes.
[14]. LaChance PJS, Conditioning (1995) Plyometric exercise. 17:16-16
[15]. Lim YY, Sterzing T, Teo CJ, Alonzo R, Pan JW, Teng PS, Kong PW (2020) Between-limb asymmetry in kinetic and temporal characteristics during bilateral plyometric drop jumps from different heights. J Sports Sci 38:1605-1614
[16]. Maia NM, Kassiano W, Assumpção CO, Andrade A, Fernandes RJ, De Jesus K, Simim MA, Medeiros AI (2019) Neuromuscular and autonomic responses during a CrossFit (r) competition: a case study. Trends Sport Sci 26:165-170
[17]. McMahon JJ, Rej SJ, Comfort P (2017) Sex differences in countermovement jump phase characteristics. Sports 5:8
[18]. Pauli CA, Keller M, Ammann F, Hübner K, Lindorfer J, Taylor WR, Lorenzetti S (2016) Kinematics and kinetics of squats, drop jumps and imitation jumps of ski jumpers. J Strength Cond Res 30:643
[19]. Shu Y, Sun D, Hu QL, Zhang Y, Li JS, Gu YD Lower limb kinetics and kinematics during two different jumping methods. In: Journal of Biomimetics, Biomaterials and Biomedical Engineering, 2015. Trans Tech Publ, pp 29-35
[20]. Taube W, Leukel C, Lauber B, Gollhofer A (2012) The drop height determines neuromuscular adaptations and changes in jump performance in stretch-shortening cycle training. Scand J Med Sci Sports 22:671-683
[21]. Umberger BR (1998) Mechanics of the vertical jump and two-joint muscles: implications for training. Strength and conditioning 20:70-74
[22]. Utama E, Tinduh D, Pawana IPA, Utomo DN (2018) Relationship for Knee Angle, Hip Angle and Peak Ground Reaction Force With Vertical Jump Performance at Volleyball Athlete in Surabaya.
[23]. Zahedi M, Daneshjoo A, Sahebozamani M, Sadeghi-Gogheri M (2018) Comparison of the effects of hopping and box jump training on the proprioception in males with anterior cruciate ligament reconstruction. The Scientific Journal of Rehabilitation Medicine 7:1-9