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EFFECT OF KNEE COMPRESSION ON KINETIC VARIABLES DURING VERTICAL JUMPS

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The purpose of this study was to determine how knee compression affected kinetic variables during vertical jumps. Ten healthy males, age 20s, performed a single maximum vertical jump and a ten-consecutive vertical jump trial without knee compression (control condition) and with knee compression. The collected data of ground reaction force were used to analyse the vertical jump height (VJH), peak active force (PAF), decay rate (DR), peak passive force (PPF), loading rate (LR), and the coefficient of variation (CV). During a maximum vertical jump, knee compression increased the magnitudes of DR, PAF, and VJH by 19.8%, 3.41%, and 4.87%, respectively, compared to those under a control condition. During ten consecutive vertical jumps, PAF and VJH showed statistically significant difference according to the repetition count. Also, the mean and CV of PAF, DR, LR, and VJH over consecutive jumps were higher in magnitude under knee compression condition than under the control condition.

Key words: *knee compression, maximum vertical jump, consecutive vertical jumps, jump height, ground reaction force.*

INTRODUCTION

In athletic competitions and leisure sports, compression garments (e.g., elastic band, tights, shorts and suits) have been widely used among athletes (Fu *et al*., 2012). Early studies on compressive garments focused on increased venous blood flow due to the elastic compression and its prophylactic effect on the formation of venous thrombosis in post-operative patients. Also, the studies revealed that compressive tights and stockings resulted in decreased venous stasis in the lower extremities (Sigel *et al*., 1975; O'Donnell *et al*., 1979; Lawrence and Kakkar, 1980; Schraibman *et al*., 1981) and were effective in decreasing circumference, volume and symptoms in the lower legs of patients with problems (Pierson *et al*., 1983; Onorati *et al*., 2003).

The elastic compression garments which give externally even pressure to particular body places have recently appeared as commercial products (Gladfelter, 2007), and have been suggested to play an effective role in improving athletes' endurance, strength and recovery (Fu *et al.,* 2012). The exercise-related research on compressive garments by Berry and McMurray (1987) found lower blood lactate concentrations after maximal exercise when the stockings were worn during exercise. Doan *et al*. (2003) reported several noteworthy effects for the compression garment. The performance of countermovement vertical jumps was enhanced when wearing compression shorts while the muscle oscillation was decreased during vertical jump landings. The skin temperature increased more and at a faster rate during a warm-up protocol. The hip flexion angle and impact force reduced, although 60 m sprint time was not influenced. Since the elasticity of the garment gives increased extension and flexion torque at the final range of flexion and extension, respectively, compressive garments have been thought to assist hamstrings in controlling the leg at the end of the swing phase in sprinting.

Hijmans *et al.* (2009) conducted research on the effect of foot and ankle compression on joint position sense and balance. Ankle compression in older people was associated with an enhancement of joint position sense towards normal values while the compression deteriorated their balance. The compression in young adults was not influenced on joint position sense or balance.

Previous studies have revealed the benefits of compressive garments contributing to enhanced performance from various points of view. Sports in which compressive garments have become widespread show a tendency for high intensity sports such as soccer heading, hand ball, basketball, track and field, volleyball, rugby and badminton. In such sports, the vertical jump ability and safe landing motion are a critical factor combined with success.

Power is defined as the product of velocity and force and it is closely related to vertical jump ability. Peak power is obtained from the largest instantaneous power of the whole body during movements (Carlock *et al*., 2004). Many studies have investigated how power and jump ability are affected by compressive garments worn during exercises. Kraemer *et al*. (1996) indicated that while single maximal jump power was not enhanced, compression shorts had an effective influence on repetitive vertical jumps by assisting to keep larger mean jumping power.

Wearing compression shorts improved the jump height with an increase of 6.9 mm, although subjects experienced an extra 1 BW of force during landing (Peters *et al*., 2009). Compressive knee wraps produced increased vertical force at the feet and thus contributed to a greater one-repetition maximum squat in competitive lifters (Harman and Frykman, 1990).

During drop jumps, a knee brace improved jump height, increased the maximal knee angle in the phase of ground contact, and decreased the maximal knee angle in the phase of landing (Rebel and Paessler, 2001). The benefits of a knee brace were thought due to the mechanical action, a psychological effect and increased coordination. Ramsey *et al*. (2003) reported that joint stability resulted from proprioceptive feedback rather than the mechanical stabilising effect of a knee brace.

Based on results investigated in the scientific literature, compression appeared to give an improvement in balance and proprioception (Chuang *et al*., 2007; MacRae *et al*., 2011; Hanzlikova, 2016; Sugimoto *et al*., 2016), which were important for improving kinetic variables, especially in case of consecutive vertical jumps. Also, compression tights were able to increase muscle activation because of increasing cutaneous stimulation (Chae and Kang, 2009). Although many studies have demonstrated the benefits of compression garments, some of the positive effects and underlying mechanisms claimed by apparel manufacturers are still unsupported and unconfirmed (Maton *et al*., 2006; Sperlich *et al*., 2010). In sports, gravitational landings after a maximum vertical jump and consecutive vertical jumps under knee compression condition occur concurrently and consecutively. To date, most studies have been limited to analysing either a maximum vertical jump or landing affected by the wearing of compression garments. Although both vertical jump and landing with compression garments worn occur frequently and consecutively in sports and exercises, there has been the lack of available research on the effect of compression garments, which can reveal possible mechanisms contributing to improved performance and injury prevention.

The purpose of this study was to determine quantitatively the effect of knee compression on jump performance and kinetic variables. During a maximum vertical jump and ten consecutive vertical jumps, the kinetic variables associated with jump-landing performance were evaluated under two conditions, a control condition (no knee-compression) and knee-compression condition. This study on the influence of knee compression can provide useful information to athletes in sports.

MATERIALS AND METHODS

Subjects. The group consisted of ten voluntary healthy male participants (age 22.60 ± 1.83 years, height 178.72 ± 3.25 cm, body mass 73.44 ± 11.96 kg) who were free from injury and had no health problem related to performing the task efficiently. In accordance with the policy of the government and University, informed consent was obtained from all subjects after the purpose and procedure of the study were explained to each subject.

Experimental procedure. For every subject, intense exercise was not allowed for at least 12 hours prior to testing and food intake was restricted for two hours prior to testing. Each subject was thoroughly familiarised with test procedures, experimental techniques, and the vertical jump test. Subjects had a brief warm-up period and practiced jumps enough for familiarisation prior to data acquisition. This study employed a test using a single maximum vertical jump and a ten-consecutive vertical jump trial under two conditions: control and knee-compression conditions. The jump test was performed on a force plate (AMTI-OR-7, USA) interfaced to a laptop with customised software (Kwon GRF 2.0, Visol., Korea) to determine ground reaction force (GRF) at 1000 Hz. In the control condition, participants wore their workout shorts without any compression leaving the legs bare for analysis. After finishing a single maximum vertical jump, the subjects had a two-minute rest period followed by one set of ten consecutive vertical jumps. Ten consecutive jumps were performed, one every 3 sec as cued by an auditory signal. The subjects were asked to perform the jump naturally but also to be aware of a mark target attached on a 2.5 m ceiling in order to minimise anterior-posterior and left-right displacement of subject's body centre. In cases when the subject's landing feet were out of the force plate and data acquisition failed, the jump test was performed again. After completing the control condition performance test, the participant rested for 20–30 min and after that, when the participant was ready to conduct the task by checking visually facial change and condition, and depending on his statement, compression was applied at the knees of the participant using an elastic knee support. Then the participant crossed over and completed the other test condition. Although there were various types of compressive garments used by players in the past, covariate analyses revealed that prior experience with the use of compressive garments did not influence the results of experiments. Based on this observation, an elastic, compressive knee support (TROVIS, LT-759) with neoprene fabric was chosen. The knee support had a circular cutout and its padded boundary in the middle front. It was designed to crush the knee to pressure the sled (patellar tendon). Three different sizes (small, medium, large) of knee supports were used and a proper size was chosen for each subject. Both conditions for the performance test were conducted on the same day to avoid day to day variation.

Data processing. Kwon GRF 2.0 software (Visol., Korea) and Excel 2007 software (Microsoft., USA) were used to analyse the GRF data collected during maximum and consecutive vertical jump performance. As seen in Figure 1, the active force generated prior to a vertical jump is distinguished from the passive force generated at landing posterior to jumping. Peak active force is defined as the largest value of the active-reactive force occurred at the instant in which the subject's feet released from the force platform. Peak passive force is obtained from the highest active-reactive force occurred at the touch-down instant in which the subject had contact with the force platform at jump-landing. Figure 2 shows vertical GRF during ten consecutive vertical jumps.

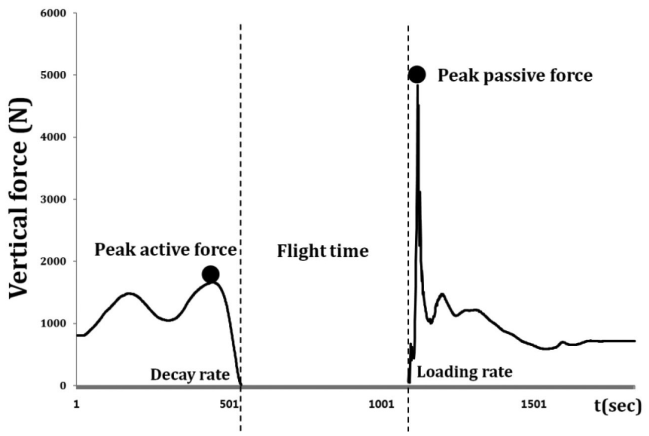

Fig. 1. Detection and definition of selected parameters of the vertical force measured during a maximum vertical jump.

For statistical analysis, the raw vertical GRF (N) data were normalised with respect to the subject's body weight (BW). Under control condition and knee-compression condition, we investigated the alternation of the kinetic variables including the vertical jump height (VJH), peak active force (PAF), peak passive force (PPF), loading rate (LR), decay rate (DR), and the coefficient of variation (CV).

The vertical jump height (VJH) of the centre of mass was calculated by the application of flight time (t_f) to the equation of motion (Bosco *et al.*, 1983) as follows:

$$\mathrm{VJH} = \frac{g \times (t_f)^2}{8}$$

where $g = 9.81\ \mathrm{m \cdot s^{-2}}$ is the gravitational acceleration. In the study, the loading and decay rate were calculated by the average change of force exerted on the body over a certain time period (Munro *et al.*, 1987). The first 50 N of GRF was neglected in the calculation because the position of the subject's foot changed in initial contact with the platform. Loading rate (LR) assessing rise to impact was calculated as

$$\mathrm{LR} = \frac{F_1 - F50}{T_1 - T50}$$

Here F_1 corresponds to the peak passive force occurred at the touch-down instant in which the subject had contact with the force platform at landing, and $F50^+$ denotes the first vertical force value excess to 50 N prior to the generation of the peak passive force. Also, T_1 ($T50^+$) denotes the moment at which F_1 ($F50^+$) occurred. Decay rate (DR) at which the force approaches zero was estimated by

$$\mathrm{DR} = \frac{F50^- - F_2}{T50^- - T_2}$$

Here F_2 corresponds to the peak active force occurred at the take-off during a maximum vertical jump, and $F50^-$ denotes the first vertical force less than 50 N posterior to generation of peak active force. Also, T_2 ($T50^-$) denotes the moment at which P_2 ($F50^-$) occurred. The coefficient of variation (CV) was calculated for kinetic variables.

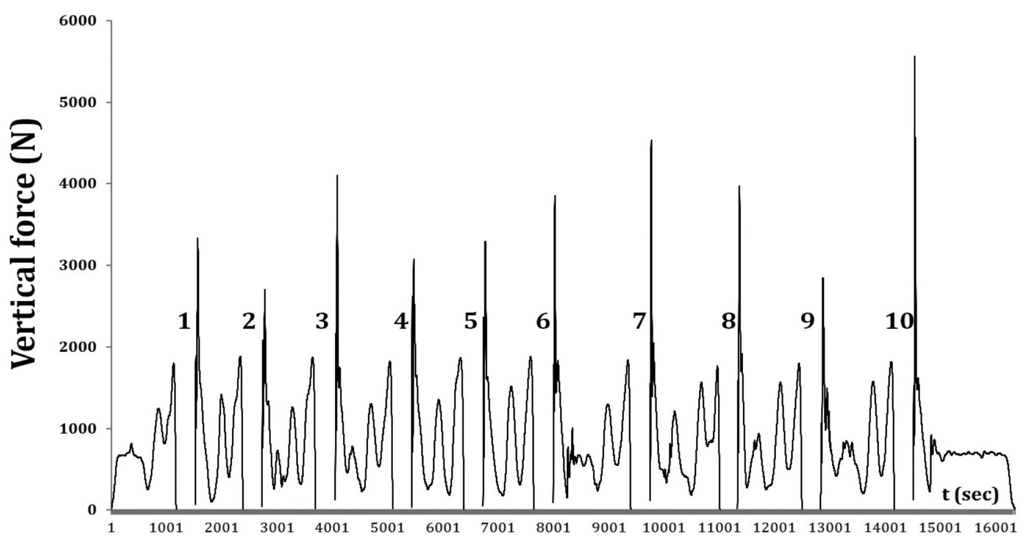

Fig. 2. Vertical force during consecutive vertical jumps.

Table 1

KINETIC VARIABLES DURING A MAXIMUM VERTICAL JUMP

Variables	Conditions		t	p	Δ%
	control condition (CC)	knee-compression condition (KC)			
PAF (N/kg)	2.52 ±0. 30	2.52 ± 0.22	–0.028	0.978	0
DR (N/kg·sec^{-1})	–21.06 ± 8.60	–25.23 ± 5.69	–1.949	0.083	19.80
PPF (N/kg)	5.57 ± 1.56	5.76 ± 1.86	–0.307	0.766	3.41
LR (N/kg·sec^{-1})	103.57 ± 62.09	104.05 ± 55.14	–0.036	0.972	0.46
VJH (m)	0.41 ± 0.06	0.43 ± 0.07	–1.192	0.264	4.87

D% = [(KC-CC)/CC*100]

PASW 18.0 (IBM, USA) was utilised to obtain means (M) and standard deviations (SD) of the kinetic variables. All data are reported as M ±SD unless otherwise noted. Paired t-tests were performed to compare difference between the control and knee-compression condition in maximum and consecutive vertical jump performance. The statistical significance level was set at $\alpha = 0.05$.

RESULTS

Maximum vertical jump. Kinetic variables were analysed when a maximum vertical jump was performed under control and knee-compression conditions. The result of the kinetic variables including PAF, PPF, DR, LR, and VJH are illustrated in Table 1. No significant differences in the kinetic variables were observed between the control and knee-compression condition. However, the magnitude of DR and VJH increased with the knee compression.

Consecutive vertical jumps. Table 2 shows the kinetic variables analysed when a ten-consecutive jump test was conducted under control and knee-compression conditions. During consecutive jumps, no significant difference was shown in the kinetic variables according to the knee compression. However, there was difference in the main effect of the jump repetition in PAF and VJH, showing statistical significance. PAF and VJH showed an increasing trend up to the fifth jump and decreased thereafter. Then these parameters increased again in the tenth jump. The CV of PAF, DR, LF and VJH was higher under the knee-compression condition than those under the control condition.

DISCUSSION

In many sports, vertical jump and landing performance occur often and players' capability to be better able to maintain highest vertical jump performance during repeated consecutive jumping is combined with success in a competition. Compressive garments have been popularised among athletes in power sports to achieve individual goals (Fu *et al*., 2012). Specifically, a compressive knee support can be easily purchased and worn in activities. Recent studies (Prodromos *et al*., 2007; Smith et al., 2013; Sugimoto *et al*., 2016) reported inconclusive evidences on efficiency of mechanical restraints such as ACL braces to prevent injuries. In contrast, promising results on the influence of compression garments have been shown. Elastic knee sleeves improved knee motions with decreased knee adduction angle and peak knee adduction (Schween *et al*., 2015), and silicone web braces reduced knee valgus and internal rotation angles (Hanzlikova *et al*., 2016). Zampporri and Aguinaldo (2017) evaluated the influence of compression tights on knee motion. The use of compression garments resulted in decreased knee valgus angle and hip adduction angle. In this study, changes in the kinetic variables were investigated quantitatively when wearing a knee support.

The result showed statistically no significant differences in kinetic variables between control and knee-compression conditions during maximum vertical jump performance. However, it was noteworthy that the knee compression increased the magnitude of DR, PPF, and VJH by 19.80 %, 3.41%, and 4.87%, respectively, compared to that under the control condition. Similarly, several previous studies (Harman and Frykman 1990; Doan *et al*., 2003; Peters *et al*., 2009) showed that compressive garments and wraps improved jumping height by providing pressure around joints. The wearing of a knee support was suggested to help enhanced maximum vertical jump performance, but it was unclear that the benefit of the knee compression resulted from optimally positioned muscle fibres around knees, and that it was due to the mechanical action, an enhanced coordination and a psychological effect (Rebel and Paessler, 2001; Doan *et al*., 2003). DR was defined as the rate at which the force approaches zero after the peak active force, and determined the toe-off behaviour of a runner following the propulsive phase of running. In the study, DR represented the gradient of the slope from PAF to zero, which was a steep slope up to toe-off. The study examined a subjects' ability to generate a push-off, which was rapidly transferred to the flight phase. Thus, the larger magnitude of DR implied more rapidity of the centre of mass`s upward movement, so it affected the enhanced VJH which resulted in increased PPF during jump-landing.

During the ten-consecutive vertical jump test, there was a difference in the main effect of the jump repetition in PAF and VJH, showing statistical significance. PAF and VJH had increasing trends up to the fifth jump and decreased

Table 2

KINETIC VARIABLES DURING CONSECUTIVE VERTICAL JUMPS

Variables	Conditions	Count of consecutive vertical jumps											Source	*F*	*p*
		1	2	3	4	5	6	7	8	9	10	TA(CV%)			
PAF (N/kg)	CC	2.52 ± 0.37	2.64 ± 0.40	2.55 ± 0.35	2.50 ± 0.37	2.50 ± 0.38	2.43 ± 0.33	2.50 ± 0.37	2.47 ± 0.40	2.44 ± 0.36	2.45 ± 0.36	2.49 ± 0.35 (14.05)	*C*	1.618	0.220
	KC	2.69 ± 0.25	2.80 ± 0.24	2.70 ± 0.23	2.74 ± 0.39	2.76 ± 0.42	2.70 ± 0.33	2.66 ± 0.35	2.54 ± 0.25	2.63 ± 0.25	2.57 ± 0.30	2.67 ± 0.29 (10.86)	*R*	5.237	0.002**
	TA	2.61 ± 0.32	2.72 ± 0.33	2.62 ± 0.30	2.62 ± 0.39	2.63 ± 0.42	2.57 ± 0.35	2.58 ± 0.36	2.50 ± 0.33	2.53 ± 0.32	2.51 ± 0.33	2.58 ± 0.34	*C*×*R*	1.204	0.318
DR ($N/kg \cdot sec^{-1}$)	CC	–24.26 ± .84	–23.45 ± 7.81	–24.00 ± 6.41	–26.12 ± 5.64	–25.11 ± 4.36	–22.29 ± 6.50	–24.15 ± 5.85	–23.15 ± 5.15	–23.86 ± 5.04	–24.68 ± 5.52	–24.10 ± 5.79 (24.05)	*C*	1.601	0.222
	KC	–26.06 ± 4.06	–25.81 ± 7.06	–24.55 ± 3.15	–28.32 ± 2.23	–27.08 ± 1.77	–25.75 ± 3.19	–26.21 ± 3.93	–24.39 ± 5.32	–26.97 ± 3.28	–25.56 ± 4.30	–26.06 ± 4.06 (15.57)	*R*	1.325	0.249
	TA	–25.16 ± 5.55	–24.63 ± 7.35	–24.27 ± 4.92	–27.22 ± 4.32	–26.10 ± 3.39	-24.02 ± 5.29	–25.18 ± 4.96	–23.77 ± 5.13	–25.41 ± 4.44	–25.12 ± 4.84	–25.08 ± 5.08	*C*×*R*	.261	0.916
PPF (N/kg)	CC	5.33 ± 0.85	4.17 ± 0.78	4.58 ± 0.73	4.68 ± 1.21	5.24 ± 1.66	4.05 ± 0.86	4.82 ± 1.01	5.06 ± 1.37	4.96 ± 1.20	5.01 ± 1.56	4.78 ± 1.18 (23.79)	*C*	3.504	0.078
	KC	4.63 ± 0.90	5.57 ± 1.28	5.55 ± 0.86	5.37 ± 1.34	5.41 ± 1.02	4.93 ± 1.11	5.47 ± 1.44	5.85 ± 1.79	5.72 ± 1.42	5.33 ± 1.42	5.38 ± 1.27 (23.60)	*R*	1.369	0.210
	TA	4.98 ± 0.92	4.87 ± 1.26	5.06 ± 0.92	5.02 ± 1.29	5.33 ± 1.35	4.49 ± 1.06	5.14 ± 1.25	5.46 ± 1.60	5.34 ± 1.34	5.17 ± 1.46	5.08 ± 1.46	*C*×*R*	.219	0.219
LR ($N/kg \cdot sec^{-1}$)	CC	74.07 ± 22.46	70.45 ± 29.23	69.63 ± 18.45	84.84 ± 35.49	89.21 ± 34.71	85.13 ± 56.42	94.31 ± 84.23	72.81 ± 24.89	74.36 ± 27.82	89.43 ± 49.37	80.42 ± 41.66 (51.80)	*C*	.034	0.856
	KC	59.48 ± 14.59	75.54 ± 22.53	80.86 ± 20.61	70.67 ± 15.98	82.94 ± 21.70	107.54 ± 33.97	96.10 ± 30.06	83.34 ± 21.06	86.04 ± 25.28	78.28 ± 19.6	82.08 ± 25.46 (31.01)	*R*	2.028	0.120
	TA	66.78 ± 19.89	73.00 ± 25.53	75.25 ± 19.89	77.76 ± 27.76	86.07 ± 28.36	96.34 ± 46.76	95.21 ± 61.56	78.07 ± 23.08	80.20 ± 26.56	83.85 ± 37.0	81.25 ± 34.45	*C*×*R*	.934	0.417
VJH (m)	CC	0.36 ± 0.04	0.36 ± 0.04	0.36 ± 0.05	0.37 ± 0.05	0.36 ± 0.04	0.35 ± 0.04	0.36 ± 0.05	0.35 ± 0.04	0.33 ± 0.04	0.37 ± 0.04	0.36 ± 0.04 (11.11)	*C*	1.304	0.068
	KC	0.39 ± 0.04	0.38 ± 0.05	0.38 ± 0.05	0.39 ± 0.04	0.38 ± 0.03	0.37 ± 0.04	0.37 ± 0.04	0.36 ± 0.04	0.38 ± 0.06	0.38 ± 0.02	0.38 ± 0.04 (10.52)	*R*	2.233	0.022*
	TA	0.37 ± 0.04	0.37 ± 0.04	0.37±0.05	0.38±0.05	0.37±0.03	0.36±0.04	0.36 ± 0.04	0.35 ± 0.04	0.35 ± 0.06	0.37 ± 0.03	0.37 ± 0.04	*C*×*R*	.985	0.455

C, compression, *R*. repetition, *C*×*R*, compression and repetition

thereafter. Therefore, PAF and VJH that occurred prior to highest vertical jump were linked tightly. Vertical jump is strongly associated with explosive muscular strength and contraction of the upper and lower limbs (Aragon-Vargas and Gross, 1997; Markovic *et al.*, 2004) and is applied to assess the explosive characteristics of the lower limbs. Deviation in performance of vertical jumps repeated in a short time period might result in the decrease. Specifically, PAF was not influenced by the knee compression during maximum vertical jump performance while knee compression increased PAF during consecutive jumps due to the rebound of lower body segments. The increasing feature of VJH in the tenth jump of the consecutive jumps was considered to be due to the change of PAF.

Kraemer *et al.* (1996) demonstrated that compression shorts had a significant effect on repetitive vertical jumps by helping to maintain higher mean jumping power, which was similar to the results in the present study. Moreover, mean PAF, DR, LR and VJH over the ten consecutive jumps when wearing the knee compression supports were higher than those under the control condition, and showed significant consistency. PAF, which is the force pushing off for body propulsion prior to jumping, were related with the increased mean magnitude of DR and influenced the improvement of VJH. In contrast, LR is a measure of the rate of stress application to body tissues (Cook *et al.*, 1997). High LR represents poor shock attenuation and high stress applied to the lower extremity in a short time (Hargrave *et al.*, 2003). In the current study, PPF was increased when wearing the knee compression support, although PPF had no difference in CV. Repetitive high-impact forces applied to the musculoskeletal system can lead to injury and decrease performance (Nigg, 1985). An individual's ability to control and absorb the forces during functional and dynamic activities is important to prevent injury (Hargrave *et al.,* 2003).

Thus, more stress can be applied to the lower extremities when wearing a compressive knee support, but it results from the fast preparatory movement to maintain the consistency of VJH. Further studies on the mechanism of the preparatory movement and time interval during consecutive jumps are needed.

CONCLUSION

Knee compression increased VJH during maximum vertical jump performance, and mean vertical height over ten consecutive jumps, showing high consistency. These resulted from the change of DR and were closely linked. During ten consecutive vertical jumps, PAF and VJH showed significant difference according to the repetition count. The mean and CV of PAF, DR, LR, and VJH over the consecutive jumps were higher under the knee-compression condition than those under the control condition. Furthermore, knee compression increased PPF and LR during consecutive jumps, but it was unclear that the increase of PPF and LR was caused by the effect of preparatory movement due to a short interval between consecutive jumps. This study suggests that there are distinct differences in the kinetic characteristics and mechanism between maximum vertical jump and consecutive vertical jumps.

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CEĻGALA KOMPRESIJAS IETEKME UZ KINĒTISKIEM PARAMETRIEM VERTIKĀLO LĒCIENU LAIKĀ

Pētījuma rezultāti ļauj secināt, ka ir būtiska atšķirība gan maksimālo vertikālo lēcienu un secīgo vertikālo lēcienu kinētiskos rādītājos, gan to mehānismā.