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นิพนธ์ต้นฉบับ (Original article)
วิทยาศาสตร์การโค้ช (Sports Coaching Science)

ผลของความสูงและจำนวนของรั้วต่อกลศาสตร์การกระโดด

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อศึกษาผลของความสูงและจำนวนของรั้วในการกระโดดข้ามรั้วต่อระยะเวลาสัมผัสพื้น (CT), แรงปฏิกิริยาแนวดิ่งสูงสุด (p-VGRF), อัตราการเกิดแรงในช่วง Eccentric (E-RFD), ความตึงของขา (LS), ค่าความต่างของความยาวขาแนวดิ่ง (ΔL) และค่าเฉลี่ยคลื่นไฟฟ้ากล้ามเนื้อ (AEMG) ในนักกีฬามหาวิทยาลัยเพศชายจำนวน 14 คน (อายุ 20.7 ± 1.7 ปี, น้ำหนัก 65.5 ± 4.5 กก., ส่วนสูง 173.6 ± 3.9 ซม.) เข้าร่วมงานวิจัยในครั้งนี้ด้วยความสมัครใจ โดยทำการทดสอบกระโดดข้ามรั้วสองขาคู่ 15 ครั้งต่อเนื่อง (3 รอบ) ที่ความสูงของรั้ว 100% และ 140% Countermovement jump (CMJ) ตามลำดับการสุ่ม แต่ละรอบของการกระโดดจะต้องกระโดดข้ามรั้ว 5 รั้ว ที่มีระยะห่างระหว่างรั้ว 1 เมตร ความสูงของรั้วแต่ละคนคำนวนจากความสูงที่ได้จากการกระโดด CMJ ที่สูงสุด (100% CMJ) แผ่นวัดแรง (Kistler, Switzerland) 2 แผ่นจะถูกวางไว้ระหว่างรั้วที่ 2-3 และรั้วที่ 3-4 และติดเครื่องวัดคลื่นไฟฟ้ากล้ามเนื้อไว้ที่กล้ามเนื้อ Rectus Femoris (RF) และ Vastus Lateralis (VL) และข้อมูลของคลื่นไฟฟ้ากล้ามเนื้อได้รับการวิเคราะห์ทั้งช่วงของ Eccentric (EC) และ Concentric (CON) ค่ากลศาสตร์การกระโดดและคลื่นไฟฟ้ากล้ามเนื้อได้รับการวิเคราะห์เป็น 3 รอบ (รอบที่ 1 = รั้วที่ 1-5, รอบที่ 2 = รั้วที่ 6-10, และรอบที่ 3 = รั้วที่ 11-15) ผลการวิจัยแสดงให้เห็นว่าที่ความสูงของรั้ว 140% CMJ มีค่าความตึงของขา (LS) น้อยกว่า, ค่าความต่างของความยาวขาแนวดิ่ง (ΔL) สูงกว่าและค่าเฉลี่ยของคลื่นไฟฟ้ากล้ามเนื้อช่วง Eccentric ของทั้งกล้ามเนื้อ RF และ VL สูงกว่าที่ความสูงของรั้ว 100% CMJ ในรอบที่ 3 ของการกระโดดอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) นอกจากนี้ในการกระโดดที่ความสูงของรั้ว 140% CMJ มีค่าเฉลี่ยของคลื่นไฟฟ้ากล้ามเนื้อช่วง Concentric เฉพาะที่กล้ามเนื้อ VL สูงกว่าที่ความสูงของรั้ว 100% CMJ ในรอบที่ 2 และ 3 ของการกระโดดอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ค่าความต่างของความยาวขาแนวดิ่ง (ΔL) ในรอบที่ 2 ของการกระโดดสูงกว่ารอบที่ 1 อย่างมีนัยสำคัญทางสถิติทั้งที่ความสูงของรั้ว 100% และ 140% CMJ ($p<0.05$) แต่เฉพาะที่ความสูงของรั้ว 140% CMJ เท่านั้นที่พบว่าความต่างของ ΔL ในรอบที่ 3 ของการกระโดดสูงกว่ารอบที่ 1 อย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ผลจากการวิจัยสรุปได้ว่าการกระโดดข้ามรั้วที่ความสูงของรั้ว 140% CMJ มีการกระตุ้นการทำงานของกล้ามเนื้อมากกว่า ในขณะที่มีค่าความตึงของขา (LS) ที่ต่ำกว่าเมื่อมีการเพิ่มจำนวนของการกระโดดข้ามรั้ว ดังนั้นในการศึกษาครั้งนี้จึงแนะนำการกระโดดข้ามรั้วที่ความสูงของรั้ว 140% CMJ (~50 ซม.) จำนวน 5-10 ครั้งต่อเนื่อง ซึ่งน่าจะเป็นความสูงและจำนวนครั้งที่เหมาะสมสำหรับนักกีฬามหาวิทยาลัย

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คำสำคัญ: กระโดดข้ามรั้ว, จำนวนของรั้ว, วงจรเหยียดตัวออก-หดตัวสั้นเข้า, ระยะเวลาสัมผัสพื้น

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นิพนธ์ต้นฉบับ (Original article)
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EFFECTS OF HEIGHTS AND NUMBER OF JUMP ON JUMPING MECHANICS

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ABSTRACT

The objective of the present study was to investigate the effects of hurdle heights (100% and 140% CMJ height) and number of jumps on contact time (CT), peak vertical ground reaction force (p-VGRF), eccentric rate of force development (E-RFD), leg stiffness (LS), vertical displacement of leg (ΔL), and average electromyography (AEMG). Fourteen healthy male university athletes (aged: 20.7 ± 1.7 years, body weight: 65.5 ± 4.5 kg, height: 173.6 ± 3.9 cm) were volunteered to participate in this study. Subjects were asked to perform 15 continuously repeated hurdle jumpings (3 series) at 100% or 140% CMJ heights in a randomized order. Each series consisted of 5 hurdle jumps and each hurdle was placed 1 meter apart. The hurdle height for each subject was computed from the individual maximal CMJ height (100% CMJ). Two force platforms were placed between the 2nd – 3rd and the 3rd – 4th hurdles. Electromyography was measured from rectus femoris (RF) and vastus lateralis (VL), and the data were analysed from both eccentric (EC) and concentric (CON) phases. Jumping mechanic and EMG variables were analysed from three series of jumps (the 1st series = 1-5 jumps, the 2nd = 6-10 jumps, and the 3rd = 11-15 jumps). The results showed that 140% CMJ height had lower LS, higher ΔL, and higher AEMG of RF and VL in EC phase than 100% CMJ height in the 3rd series ($p<0.05$). Additionally, AEMG of VL in the CON phase of 140% CMJ height was higher than that of the 100% CMJ height during the 2nd and 3rd series of jumps ($p<0.05$). ΔL of the 2nd series was greater than that of the 1st series ($p<0.05$) both 100% and 140% CMJ heights, but the greater ΔL of the 3rd series compared to the 1st series was only observed in 140% CMJ height ($p<0.05$). In conclusion, hurdle jump at 140% CMJ height stimulated greater muscle activity but LS was lower with progressively increase number of jump. Therefore, it was suggested that the repeated hurdle jump at 140% CMJ height (~ 50 cm) and for 5-10 jumps was likely the optimal height and number of jumps for male university athletes.

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Keywords: Hurdle jump, Number of hurdle, Stretch shortening cycle, Contact time

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INTRODUCTION

Speed, agility, quickness, and power are the important performance in sports that require explosive movement.[1, 2] Plyometric is a type of training program commonly used for developing explosive power.[2-5] The characteristics of plyometric can be explained using stretch-shortening cycle (SSC) model, which muscles are stretched (eccentric contraction) and rapidly followed by concentric contraction.[6]

Hurdle jumping is one type of plyometric training which has been used for athletic training in various sports such as soccer, volleyball, handball, basketball, gymnastics, track and field, and etc. A wide range of hurdle heights between 30-110 cm and a number of hurdles between 4-12 hurdles have been used.[2-5, 7, 8] These may be due to the variations of fitness level and sports-specific training program for each group of subjects or athletes. Importantly, it has been known that jump exercises that have short contact time (CT), high rate of force development (RFD), and high ground reaction forces are more useful for power development [9-12] and mimic explosive activities in sports.[11] The different hurdle heights can influence jump mechanics differently such as excessively hurdle height (160% CMJ height) can negatively affect jump mechanics by increased CT and leg stiffness (LS), but decreased RFD.[9, 13] Hurdle heights between 100-140% of maximal CMJ height have been suggested to be the optimal heights for bilateral hurdle jump training concerning to the fast contact time similar to explosive activities in sports[9,13]. However, no known study has investigated the effects of hurdle height and the number of continuous hurdle jumps. It has been shown in the previous study that 45 seconds of continuous hurdle jump (hurdle height = 65 cm) with an average number of 36-47 jumps had changed jump mechanics in volleyball players, i.e. increased CT, decreased GRF, and increased average electromyography when compared to the initial jumps. Since, the changes began after 12 – 18 jumps, fatigue was suggested to be a likely responsible factor.[14] It must be noted that the number of repeated hurdle jumps used was too high and is uncommon for plyometric exercise or training

Therefore, the optimal number of hurdle jumps in a set of training at specific hurdle height is important regarding to increasing training efficiency.[6] However, the effects of hurdle heights and number of continuously repeated hurdle jumps on jumping mechanics and muscle activity have not been investigated. The present study aimed to investigate the effects of hurdle height and number of jumps on jump mechanic variables (CT, p-VGRF, E-RFD, LS, ΔL) and muscle activity (electromyography) of knee extension muscles. The hypothesis of this study was the difference of hurdle heights and number of repeated hurdle jumps could affect the jumping mechanics and muscle activities differently.

METHODS

Experimental Approach to the Problem

Subjects were assigned to two experimental trials (100% and 140% CMJ height) in a randomized order. Baseline measurements (1st visit) and the experimental trials (2nd visit) were conducted at the same time of day to avoid circadian effect and each visit was separated about 3-5 days. All subjects maintained their normal intake of food and fluids; abstained from alcohol, caffeine, and vigorous exercise for 24 hours; had eaten meal at least 2 hours before testing. Subjects were given verbal encouragement during testing to ensure their maximal effort.

Subjects

Fourteen healthy male university athletes (age between 18 to 25 years old) were from the university sports clubs and trained during pre-season for the university games. Subjects were free from any musculoskeletal injuries and not taking certain medication that would affect muscle activity. All had experiences in strengthening and plyometric trainings at least 6 months before participating in the study. All procedures were approved by Mahidol University Institutional Review Board (2014/028.1302). Subjects were signed the informed consent after receiving both a verbal and a written explanation for the experimental protocol, risks, and benefits of the study. General physical characteristics of subjects are shown in the Table1.

Table 1. General physical characteristics

Parameters	Mean ± SD (n=14)
Age (years)	20.7 ± 1.7
Body weight (kg)	65.5 ± 4.5
Height (cm)	173.6 ± 3.9
Resting HR (beats/min)	69 ± 8.7
Experience in that sports (years)	6.9 ± 5.4
Percentage of body fat (%)	12.8 ± 4.9
CMJ height (cm)	35.1 ± 4.5

Testing Schedule

At first visit (baseline measurement), %body fat, CMJ height, and isokinetic test of knee and ankle joints were measured. Additionally subjects were familiarized with hurdle jumping before participating in the experimental testing. At the second visit, subjects were asked to perform two experimental trials of the hurdle jumps: 1) 100% CMJ height and 2) 140% CMJ heights.

Baseline testing

%Body fat. Skinfold thickness was measured from 4 sites on thigh, triceps, abdominal, and suprailiac skinfolds and calculated for %body fat using Jackson and Pollock's equation.[15]

Countermovement Jump (CMJ). CMJ height was determined using flight time method. Before testing, subjects were asked to warm up by cycling (10 min at free load) followed by 5 reps of single submaximal countermovement jump with 1 minute resting between jumps. Subjects began the CMJ at upright position by standing on force platform (Kistler, Switzerland) before performing downward movement to a knee angle of ~ 90° and quickly pushed off. During the CMJ, subjects were asked to place their hands on their waist and jumped as high as possible. Two CMJs were tested with one minute rest was allowed between the jumps, and the best trial was used to analyse. The force platform was connected to a BTS computer and jumping height was calculated using BTS SMART Motion analyzer software (BTS SMART DX5000). The BTS SMART Motion analyzer was also used to measure and analysed. Jump height of CMJ was calculated as follows.[9]

$$h = (9.81 * t_f * t_f) / 8$$

when h is jump height (m); 9.81 is gravitational acceleration ($m \cdot s^{-2}$); t_f is flight time (s)

Isokinetic Test. Muscles peak torques of knee extension, knee flexion, ankle plantar flexion, and ankle dorsiflexion were measured using the Isokinetic dynamometer (LIDO Active MJ, USA) (Con/Con mode). Angular velocity was set at 120 degrees per second. Subjects performed 5 submaximal contractions during warm up of each testing position and 1 minute rest was allowed to avoid fatigue before testing. Then, subjects performed 2 sets of 5 maximal contractions with 1 minute resting between sets. H/Q ratio was calculated as peak torque ratio of hamstring muscles (knee flexion) per peak torque of the quadriceps muscles (knee extension).

Experimental testing

Hurdle jumps test

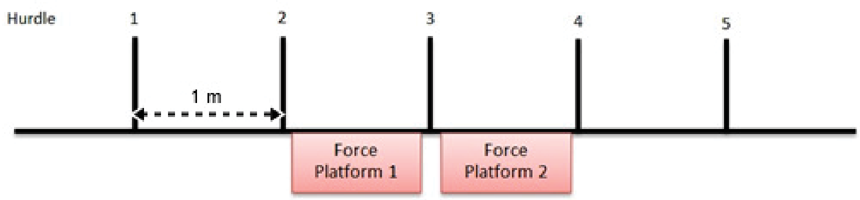

Figure1. Hurdles jumps setting.

Five hurdles were placed with 1 m apart between each hurdle as depicted in Figure 1. Between the 2nd - 3rd and the 3rd – 4th hurdles, two force platforms were placed. Bipolar surface electrodes were placed on RF and VL muscles which the signals were linked to the EMG wireless device (BTS FREEEMG 300). Reflective marker was attached to the greater trochanter on the dominant leg. All devices were synchronized by the BTS smart analyzer software (3-D Motion Analysis) with sampling rate of force platforms set at 1600 Hz, BTS at 200 f/s for cameras, and at 1,000 Hz for EMG wireless devices. Kinematic data and VGRF were filtered at 15 Hz using a low-pass Butterworth filter. EMG data was filtered between 10-500 Hz using band-pass Butterworth filter and the data from EC and CON phases were analysed for average root mean square (AEMG).

Before starting the hurdle jump testing, subjects performed 3 sets of 5 submaximal hopping jumps and 2 sets of submaximal 5 hurdle jumps. Then, subjects were performed bilateral hurdle jump over hurdle at 100% and 140% CMJ heights with a randomized order. Each testing consisted of 2 sets of 15 repeated hurdle jumps divided to three series. After finishing jumps over the 5^{th} hurdles (1^{st} series), subjects turned around (180°) and jumped over the same hurdles row until finishing 3 series. Subjects were encouraged to jump as fast as possible during jump with both feet landing. Contact time is the period during the feet contact force platform. VGRF is the peak vertical GRF in contact phase. E-RFD was defined as the peak of VGRF divided by the time from initial feet contact to peak VGRF. LS was calculated from the peak VGRF divided by vertical displacement of leg length.

Statistical Analysis

All data were analysed used SPSS version 17.0 software. Subject characteristics and muscle peak torques data were shown as Mean ± SD. Jump mechanic and EMG variables were shown as Mean ± SEM. Shapiro-Wilk test was used to test the normality distribution of the data. If the data were normally distributed, two-way ANOVA, repeated measures were used to determine the significant main effect of hurdle heights, number of jumps, and interaction effect. If, the normality of data distribution was not met, Wilcoxon Signed-Rank test was used to test the differences between hurdle heights with alpha values correction using Bonferroni's correction to control Type I error. Friedman test was used to test the differences among three series of jumps (within group). If the significant effect of number of jumps was observed, post-hoc test was applied to locate pairwise differences. The level of statistical significance was set at p-value less than 0.05.

RESULTS

No significant effects of hurdle heights and number of hurdle jumps on CT, VGRF, and E-RFD were found. There was significant main effect of hurdle heights on LS and there were significant differences of hurdle heights on ΔL and AEMG. LS of the 140% CMJ height at 3^{rd} series was lower ($F_{(2,26)} = 1.9$, $p = 0.17$), but ΔL ($Z = -2.92$, $p = 0.003$), and AEMG of RF ($t(13) = 3.99$, $p = 0.002$) and VL ($Z = -2.6$, $p = 0.009$) in EC phase were higher than those of 100% CMJ height ($p<0.05$). Additionally, at the 2^{nd} ($Z = -2.54$, $p = 0.011$) and 3^{rd} ($Z = -2.67$, $p = 0.008$) series of jump, 140% CMJ height had higher AEMG in the CON phase of VL compared to that of 100% CMJ height ($p<0.05$). There was no significant interaction effect on LS. Significant main effect of number of jumps was observed at 100% CMJ height with the 2^{nd}series (6-10 jumps) had greater ΔL than the 1^{st}series (1-5 jumps) ($p<0.05$). In addition, the 2^{nd} and 3^{rd} series of jump had greater ΔL than that of the 1^{st} series ($p<0.05$) with testing at 140% CMJ heights. No significant main effects of the number of jumps on the other variables were observed.

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Table 2. Mean ± SD Isokinetic peak torques and H/Q ratio

Variables	(Left)	(Right)
Isokinetic peak torque		
Ankle plantarflexors (N.m)	81.9 ± 13.3	77.8 ± 15.5
Ankle dorsiflexors (N.m)	23.7 ± 4.1	25.8 ± 6.4
Knee extensors (N.m)	177.3 ± 17.6	180.7 ± 17.5
Knee flexors (N.m)	107.4 ± 20.2	117.4 ± 23.8
H_{con}/Q_{con} ratio	0.61 ± 0.10	0.65 ± 0.11

Values are mean ± SD (n=14)

Table 3. Jump mechanics parameters between hurdle heights and series of jumps. Data were presented as Mean (SEM).

Jump Mechanics	Hurdle Height and Series of Jumps					
	100% CMJ			140% CMJ		
	1st	2nd	3rd	1st	2nd	3rd
CT (ms)	211 (14)	214 (9)	205 (9)	206 (12)	237 (13)	228 (13)
VGRF (N)	3,379 (172)	3,627 (128)	3,721 (210)	3,630 (174)	3,626 (216)	3,403 (174)
E-RFD (N/s)	36,726 (3,148)	36,841 (2,586)	39,304 (3,866)	38,536 (2,921)	37,576 (3,096)	34,964 (2,574)
LS (N/m)	21.6 (1.7)	20.2 (1.5)	23.0 (2.4)	20.2 (1.5)	18.6 (1.7)	16.7 (1.4) *
ΔL (cm)	16.6 (0.8)	19.0 (0.9) #	17.9 (0.8)	17.8 (0.8)	21.2 (0.9) #	20.9 (0.8) *#

* Significant difference compared with 100% CMJ hurdle height at the same series of jumps ($p<0.05$)

Significant difference compared with the 1st series of jump at the same hurdle height ($p<0.05$)

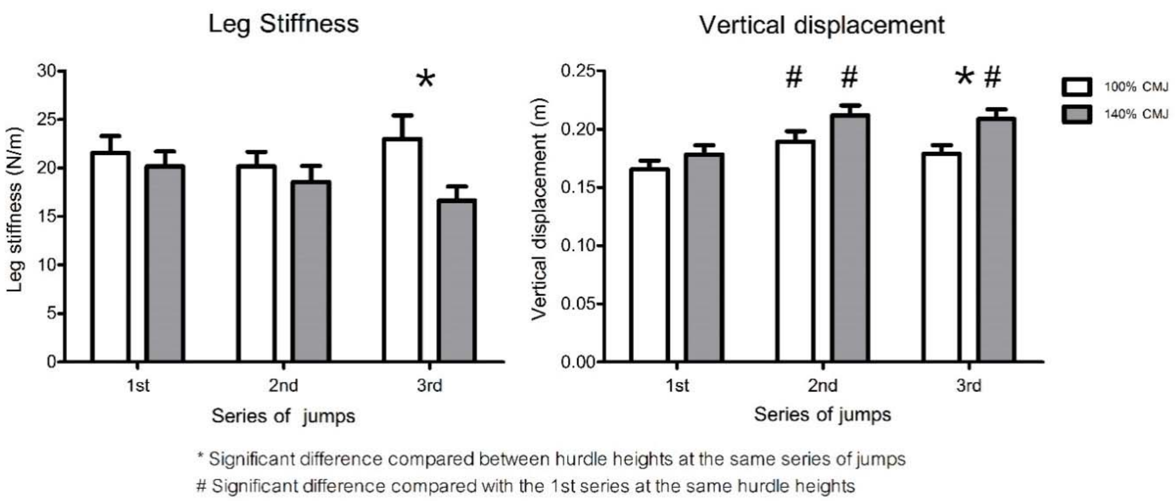

Figure2. Leg stiffness and vertical displacement (ΔL)

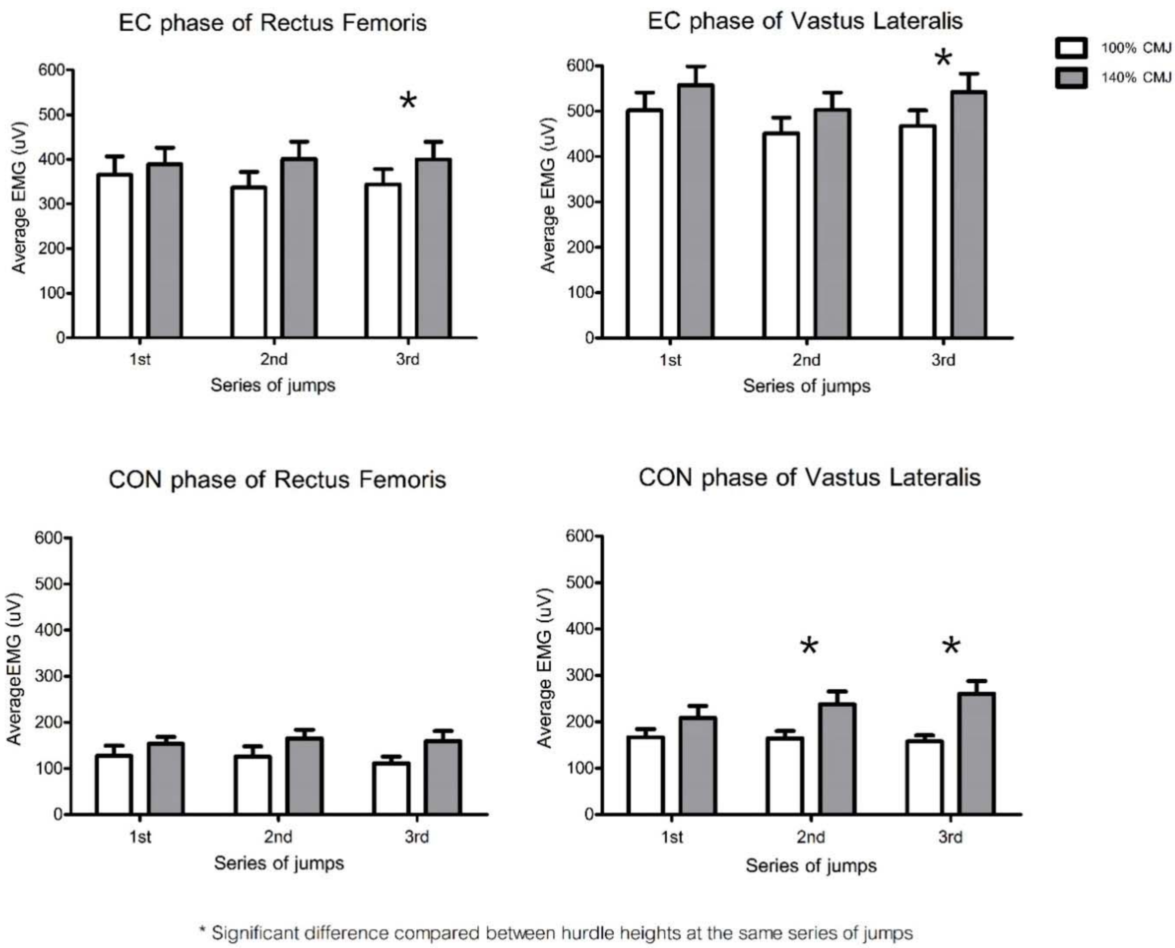

Figure3. EMG activity of rectus femoris and vastus lateralis both EC and CON phases

DISCUSSION

Main findings of the present study were at higher hurdle jump height, a greater knee extensor muscles were recruited. However, this was compromised by the decrease of leg stiffness, especially when progressively increase the number of continuous jumps to greater than approximately 10 hurdles.

CT of the repeated jump at 100% and 140% CMJ height in the present study were ranged between 205-237 ms and classified as fast CT[9], although these values were a little higher compared to other sport skills and jumps in the previous studies e.g. three of the first steps for running (CT = 200, 180, and 160 ms, respectively)[9] ; high jumping (CT ~ 170 – 200 ms)[8] ; bilateral hurdle jumps of adolescent soccer players (CT~180 ms)[13] Fast CT or short stretch shortening cycle has positive effects for the explosive power.[9,16] However, on the other hand, too short CT can decrease the impulse force and distance travelling during the contact.[17]

Vertical ground reaction force (VGRF) of 100% and 140% CMJ height in the present study were ranged from 3,300-3,700 N or approximately 5-6 time of body weight. VGRF values seen in the present study were consistent to those previously reported (5.4 – 6.5 BW) at the same relative levels of hurdle heights.[9,10,13] Effect of hurdle height on VGRF was also similar to the previous studies[9,13] that tested using a lower number of continuously repeated jumps (5 jumps). However, VGRF of 140% CMJ height tended to be lower than 100% CMJ height at the 3rd series. The changes of jump mechanics especially a decrease of VGRF in the previous study when subjects performed continuous jumping for 45 s (approximately 36 jumps) at 65 cm hurdle height has been reported.[14]

The E-RFD was another factor used to determine quality of plyometric intensity in the training programs. Increased time to peak force will compromise the RFD.[11] This variable is also important for fast controlling of balance and preventing risk of fall at landing phase.[18] No statistically significant main effects of height and number of jumps on E-RFD found in the present study and this was similar to the previous studies.[9,13] However, when increasing hurdle heights to about 160% CMJ height, E-RFD was decreased.[9] E-RFD of 100% and 140% CMJ heights (~35,000-39,000 N/s) were similar to those of Cappa and Behm, 2011 (36,000-41,000 N/s) at the same hurdle heights[9], but lower than that reported by Pinthong, et al., 2015 (48,000-52,000 N/s) which studied in younger athletes.[13] The differences may be resulted from the longer CT compared to the previous study and this may affect time to peak force and, then, lead to a lower E-RFD.[11,19]

LS in the present study was similar to the previously reported during 100 m run of Usain Bolt (21 kN/m)[17] but 2-3 folds lower compared to the previous studies (44-54 kN/m)[9,13] testing at the same relative hurdle height. Besides the age difference, a longer distance between each hurdle in the present study compared to the previous study (1 m *Vs* 0.5-0.6 m) may also be the causing factor of the differences values of LS between the present study and the previous studies. Children have lower knee flexion, lower hip flexion, and shorter time to peak force than adults[19] and higher LS has been reported.[13] Additionally, greater distance between the hurdle may lead to a longer CT possibly causing a lower LS.[9,20] It has been shown that LS was decreased when running to exhaustion.[21] Generally, greater LS allows greater storage and release of elastic energy to increase the force motion.[22] However, too high LS has been related to increased risk of bone injuries. High LS can decrease the absorption of the individuals leading to increasing impact force in EC phase and stress to the lower extremities.[20,23] Whereas, too low LS can affect to a longer CT resulting from the greater angle of lower extremities joints deflection.[23] Moreover, LS which is too low may increase soft tissues injury.[24] Therefore, LS should be optimized for more efficient movement (elastic energy) and reducing risk of injuries.

ΔL is an important factor that can influence LS and the pattern of ΔL changes was in accordance with LS in the present study. The increasing height of the landing has been shown to induce larger angle changes of knee and ankle joints during ground contact phase for impact force absorption.[22,25] This may lead to an increase in ΔL, and lower LS observed in 140% compared with 100% CMJ heights at the 3rd series seen in the present study. In addition to, we found a statistically significant effect of the number of jumps on ΔL.

The increasing of ΔL with progressively increased the number of jumps may indicate the changes of jump pattern. It has been shown that individuals can control LS by controlling the joints angle, and CT.[20] Therefore, adapting the joint angle and CT during the repeated jumps may be attributed to the changes of ΔL and/or leg stiffness observed .However, significant change of LS has not been found with the progressively increase number of jumps in the present study.

During the jumps, AEMG both RF and VL muscles of EC phase was higher than CON phase and this was similar to the previous study.[10] Muscle activity at this phase was important for breaking the velocity of the body at the landing phase[20] and optimizing the stored elastic energy that utilize in the CON phase of the SSC during jumping.[26] In this study, 140% CMJ height had higher AEMG than 100% CMJ height and the difference was observed at the last series of jumps (3^{rd} series ~ 11-15 jumps) in EC phase of both RF and VL muscles, and at the 2^{nd} and 3^{rd} (6-15 jumps) in CON phase of VL muscle. However, the number of jumps had no effect on the AEMG of both RF and VL muscles. EMG of knee extensor muscles that increased after continuous jumping over 65 cm hurdle height (about 24 jumps) has been shown the previous study.[14] Fatigue following the repetitive jumps may decrease mechanical energy transfer from eccentric to concentric contraction. Therefore, EMG activity was increased to maintain continuous hurdle jumping at the same hurdle heights. EMG activity in the present study that did not change significantly with the progressive number of jumps may due to the lower hurdle height and lower number of jumps than the previous studies that focused on the effect of fatigue on jump mechanics.

PRACTICAL APPLICATION

Understanding the effect of hurdle height and number of continuing hurdles jumping on jump mechanics and muscle activity are of important for optimizing the jump exercises in plyometric training program that appropriate for individual performance and sports-specific. This study suggested that 140% CMJ height and 5-10 continuous bilateral hurdle jumps were likely the optimal height and number for a set of plyometric training program. Coaches and athletes can apply these findings to design training program regarding to recommended height and number of hurdle jumps of the present study and in combination to the guideline for volume of jumps or plyometric exercises[27] i.e. the volume for the beginner ~ 80-100 jumps/session, intermediate ~ 100-120 jumps/ session, and advanced ~ 120-140 jumps/ session.

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