Lower extremity stiffness during hopping in different frequencies

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Abstract

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The purpose of the study was to determine leg stiffness and low extremity joint stiffness over different frequency ranges during hopping in place. Eighteen healthy male subjects participated in this study. Single-leg hopping was performed in three different frequencies (2.0 Hz, 2.5 Hz, and the frequency preferred by each subject). Kinematic data were obtained using the 3-D motion capture system (VICON Motion Systems Ltd, UK) synchronized with two AMTI force plates (AMTI, USA). EMG activities were recorded from six leg muscles using DELSYS(Trigno Wireless System, USA). The subjects were asked to hop twelve times. The maximum GRF was found in the middle of the stance phase during the maximum leg compression. Leg stiffness was determined as the ratio of the peak ground reaction force(GRF) and the center of mass(COM) displacement to the maximum leg compression, and the joint stiffness was calculated as the ratio of the joint moment to the joint angular displacement. During landing phase, both ankle joint angular displacement and peak ankle joint moment were relatively larger than those of the knee joint in three frequencies. Ankle joint power was larger than that of knee joint in three frequencies. During landing phase, mean EMG activities except for BF were decreased with an increase hopping frequencies. Knee joint stiffness was larger than that of ankle in three hopping frequencies. But knee joint stiffness was no significant difference with an increase hopping frequencies. Ankle joint stiffness and leg stiffness increased with an increase of hopping frequency. Leg stiffness had an approximately linear relationship with ankle joint stiffness.

***Key Words*:** Hopping, 3D Motion Analysis, Leg stiffness, Joint stiffness

1. Introduction

Hopping is similar to vertical jumping in place, but different from vertical jumping[1]: Hopping is to minimize the time to complete the course and vertical jumping is to touch the highest point in participant's maximum effort. A small correlation exists between hopping and vertical jumping. There are many hopping methods[2], but single-leg hopping represents an activity of higher demands on the knee than walking and jogging or other hopping methods[3]. Therefore, single-legged hopping might provide more information about dynamic activities.

Legs exhibit spring-like characteristics during jumping, and a spring-mass model, as shown in Figure 1, is frequently used to represent the hopping[4]. This model, consisting of a spring attached to a point mass, describes mechanical parameters characterizing human hopping. Supporting the body mass, the leg spring is in compression and then in tension during ground contact phase. The stiffness of the leg spring represents the average stiffness of the overall musculoskeletal system during ground contact phase. It was defined as the ratio of the maximum ground reaction force to the maximum leg compression during ground contact phase[5]. Leg stiffness influences the mechanics and kinematics of the body's interaction. For example, large leg stiffness leads to a shorter ground contact time and a smaller vertical displacement of the body's center of mass during the ground contact phase.

Hobara et al. [6] studied the difference between preferred contact time(PCT) and short contact time(SCT) with increase in leg stiffness during hopping. Even with the same hopping frequency, SCT condition was characterized by larger leg stiffness than PCT condition. In addition, they also performed a quantitative EMG analysis and compared the PCT and SCT conditions. Their study showed that leg stiffness primarily correlated with a change in ankle joint stiffness and muscle activities of gastrocnemius (GCM), soleus(SOL) and tibialis anterior(TA).

Joint stiffness was defined as the ratio of maximal joint moment to maximum joint angular displacement[7]. Understanding the lower extremity joint stiffness is important for evaluation of sports performance and injury prevention[8]. In particular, sports scientists and biomechanical engineers are interested in the role of joint stiffness. While some stiffness may be necessary for performance, either too little or too much stiffness results in the risk of musculoskeletal injury. Increased leg stiffness is associated with reduced lower extremity excursion and increased loading rates and shock to the lower extremity. Recent studies showed that athletes might be able to alter their lower extremity stiffness to reduce the incidence of injury [9, 10].

Leg stiffness was compared between age-matched males and females during hopping. The women's stiffness reduced during hopping than that of the men. Pauda et al. [11] compared the leg stiffness of men and women, and reported that the leg stiffness became greater with increased body mass. Another study showed that the knee joint stiffness significantly increased, and muscle activity of TA and GCM decreased with an increase of the hopping intensity [12].

The purpose of our study was to identify lower extremity stiffness, EMG activity over a range of hopping frequencies. We hypothesized that ankle stiffness increased with an increase in hopping frequency due to changes in muscle activities of GCM and SOL.

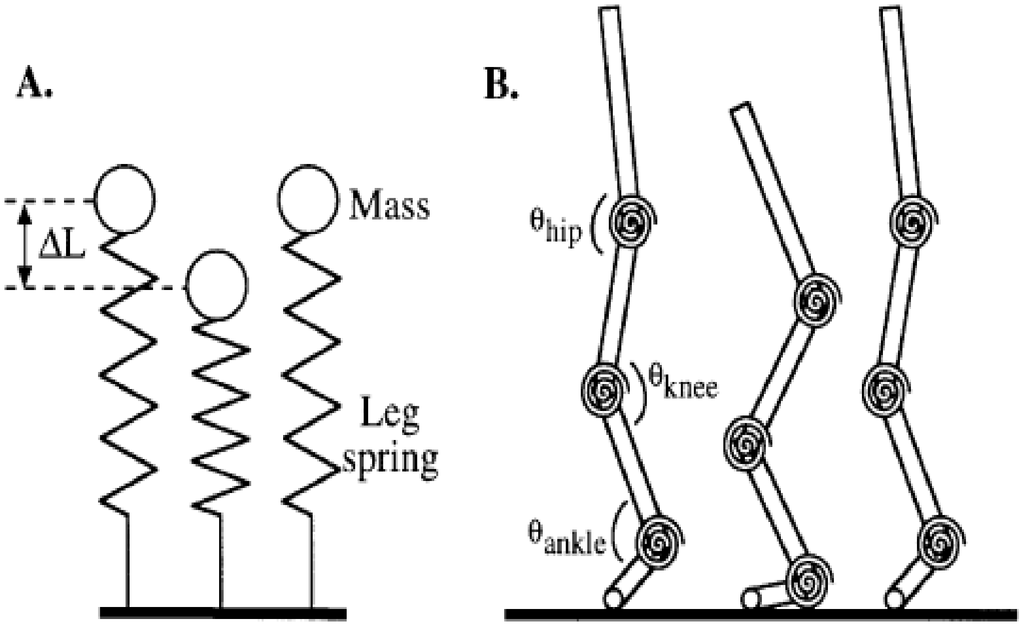


Figure 1. (A) Spring-mass model used for hopping in place. This model represents the stiffness of the all musculoskeletal system (B) The multi-jointed model used for hopping in place, which links the stiffness of the individual joints. The model is shown at the ground contact phase[4]

2. Methods

2.1 Participants

Eighteen healthy male subjects with no neuromuscular disorders of functional limitations in their legs participated in the study. They had no experience of surgery in their lower extremities. Their physical characteristics: (23.63 ± 2.00 years, 70.68 ± 8.75 kg, and 176 ± 3.83 cm), they provided the written consents for the study. They were recruited from students of Yonsei University.

2.2 Experimental design

The subjects were instructed to maintain an upright position of the upper body and to hold their hands on their hips. Then, they were asked to hop in place with their bare foot. Hopping was performed on two AMTI force plates. They performed repetitive one-legged hopping. Since different contact time instructions might affect the stiffness during hopping at a given hopping frequency, they were asked to hop with as short a contact time as possible. Before the data collection, every subject practiced at each frequency as much time as needed. For every subject, we set the hopping frequency at (2.0 Hz. 2.5 Hz, and the frequency preferred by each subject) in random order, with a 3-min resting period between every performance. We measured electromyographic activity (EMG) from biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), tibialis anteriors (TA), gastrocnemius (GCM), and soleus (SOL) muscles of the right leg. We carefully checked electrode placement to minimize EMG crosstalk between muscles.

2.3 Data analysis

Six consecutive hops from the 3rd to the 8th of the 12 hops were used for the analysis. Kinematic and kinetic data were obtained using the 3-D motion capture system (VICON Motion Systems Ltd., UK) synchronized with two AMTI force plates(Figure 2). Totally 37 reflective markers were placed on the subject's anatomical points based on plug-in-gait marker set(Figure 3). During the ground contact phase, based on the spring mass model, leg stiffness(K_{leg}) was calculated as the ratio of peak vertical GRF(F_{peak}) to the maximum vertical displacement(ΔL) of the center of mass(COM) during ground contact (eq. (1)). Based on the torsional spring model, joint stiffness(K_{joint}) was calculated by dividing the peak joint moment(M_{joint}) by the joint angular displacement($/\Delta\theta_{joint}$) (eq. (2)). Leg and joint stiffness were normalized by the subject's body mass. EMG activities were recorded from six leg muscles using DELSYS (Trigno Wireless System, USA). The obtained EMG data was full wave rectified, and then averaged, synchronizing the records to the instant of ground contact. We performed linear envelopes of EMG data using a high- pass filter (cut-off frequency 6Hz). We analyzed EMG recording from 100ms before ground contact to 100ms before the next contact.

$$K_{leg} = F_{peak} / \Delta L \qquad \text{eq. (1)}$$

$$K_{joint} = \Delta M_{joint} / \Delta \theta_{joint} \qquad \text{eq. (2)}$$

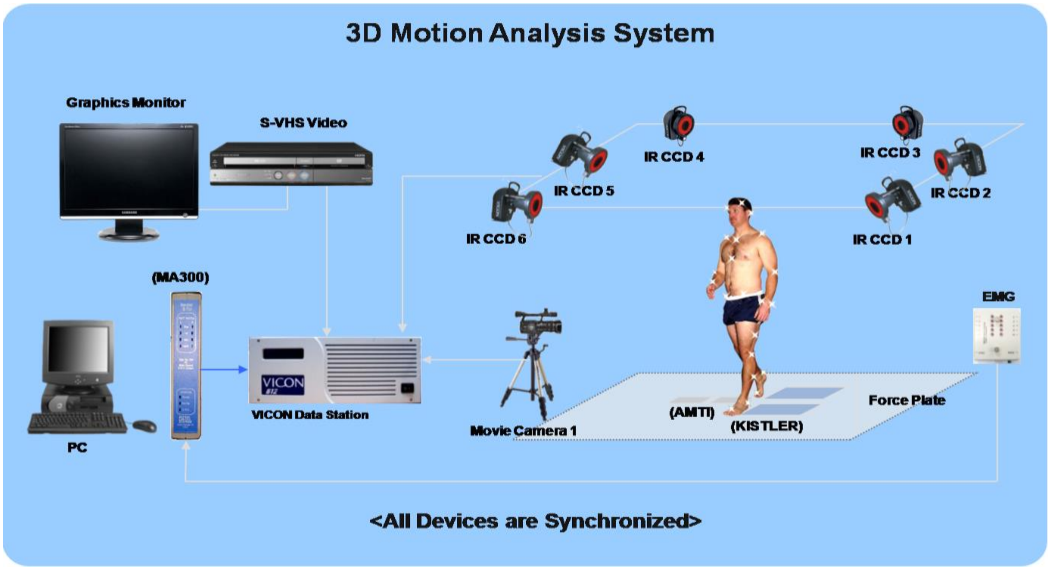


Figure 2. 3D Motion capture system for the study

Figure 3. Reflective marker set for the motion analysis

2.4 Statistics

SPSS for Windows software (2000 Apache Software Foundation, USA) was used for the statistical analysis. Tukey's post hoc multiple comparison test was performed to determine significant differences among the three frequencies (2.0 Hz, 2.5 Hz, and the frequency preferred by each subject). Statistical significance was set at $p<0.05$. All data is presented as mean value ± standard deviation.

3. Results

3.1 Kinetic and kinematic data

Contact time and flight time under three hopping conditions are shown in Table 1. Contact time was the shortest in 2.5 Hz, followed by 2 Hz and then pref. Hz. Flight time was the shortened significantly in pref. Hz, compared with 2 Hz. Point of landing and landing off was delayed in 2.5Hz or the preferred frequency, compared with 2Hz.

Table 1. Contact time and flight time

	2Hz	**Pref. Hz**	**2.5Hz**
Contact time(ms)	347.2(21.1)	315.4(15.0)^{1}	310.5(37.8)^{1,2}
Flight time(ms)	160.3(18.2)	124.9(17.5)^{1}	122.7(23.1)
Landing time(%)	20.6(0.8)	23.6(3.2)^{1}	25.6(2.3)^{1,2}
Landing off time(%)	91.6(5.0)	94.7(3.90)^{1}	95.6(5.3)

Each value is mean(SD)

^{1}*A significant difference($p<0.05$) from 2Hz*

^{2}*A significant difference($p<0.05$) from pref. Hz*

In 2Hz, ankle joint was dorsiflexed and ankle joint plantarflexion moment increased until 35% point after landing(Figure 4A and Figure 4C). Thus, energy was absorbed in the ankle joint during this period(Figure 4E). Then, until landing off point, ankle joint was plantarflexd and plantarflexion moment decreased. Thus energy generation was found during this period. Knee joint also was flexed and knee extension moment increased until 35% point after landing(Figure 4B and Figure 4D). Thus, energy absorption was found during this period(Figure 4F). Then, until landing off point, knee joint was in extension, knee extension moment decreased, and energy generation was found. Kinetic and kinematic records of ankle and knee joint showed similar patterns during the entire hopping cycle in 2.5Hz and pref. Hz(Figure 5 and Figure 6).

Mean kinematic and kinetic data are shown in Table 2. In pre-landing phase, mean values of ankle and knee angle increased with increases in hopping frequency. In landing phase, all mean data in 2Hz was smaller than those of 2.5Hz. In landing off phase, mean values of ankle and knee angle increased with an increase with hopping frequency. In 2.5Hz, mean power of knee joint was significantly smaller than that of 2Hz during landing phase. It means that knee joint’s work decreased with increases in hopping frequency. Also, mean ankle joint power was also larger than that of 2Hz, but there was no significant difference.

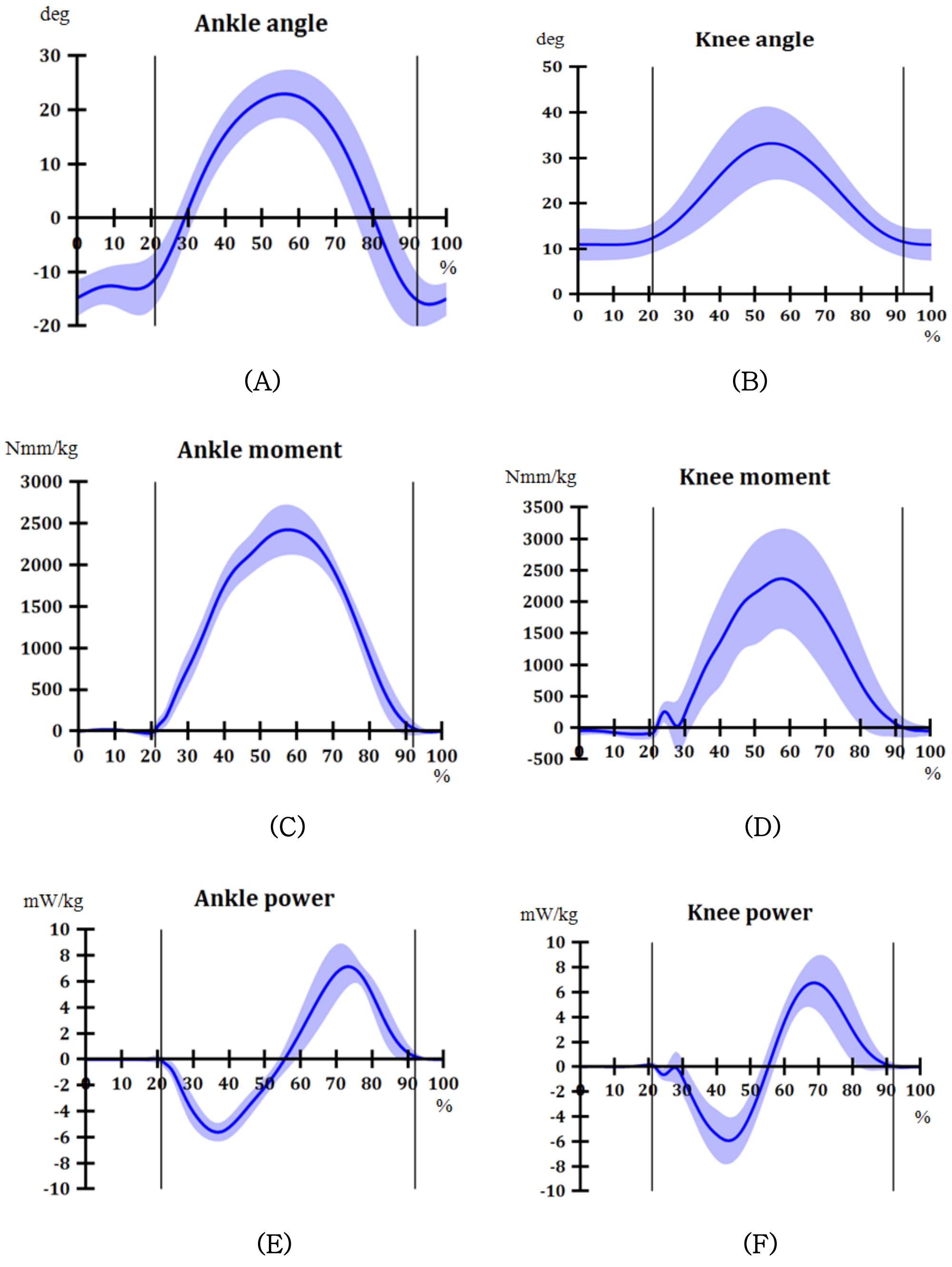


Figure 4. Kinetic and kinematic data at 2Hz

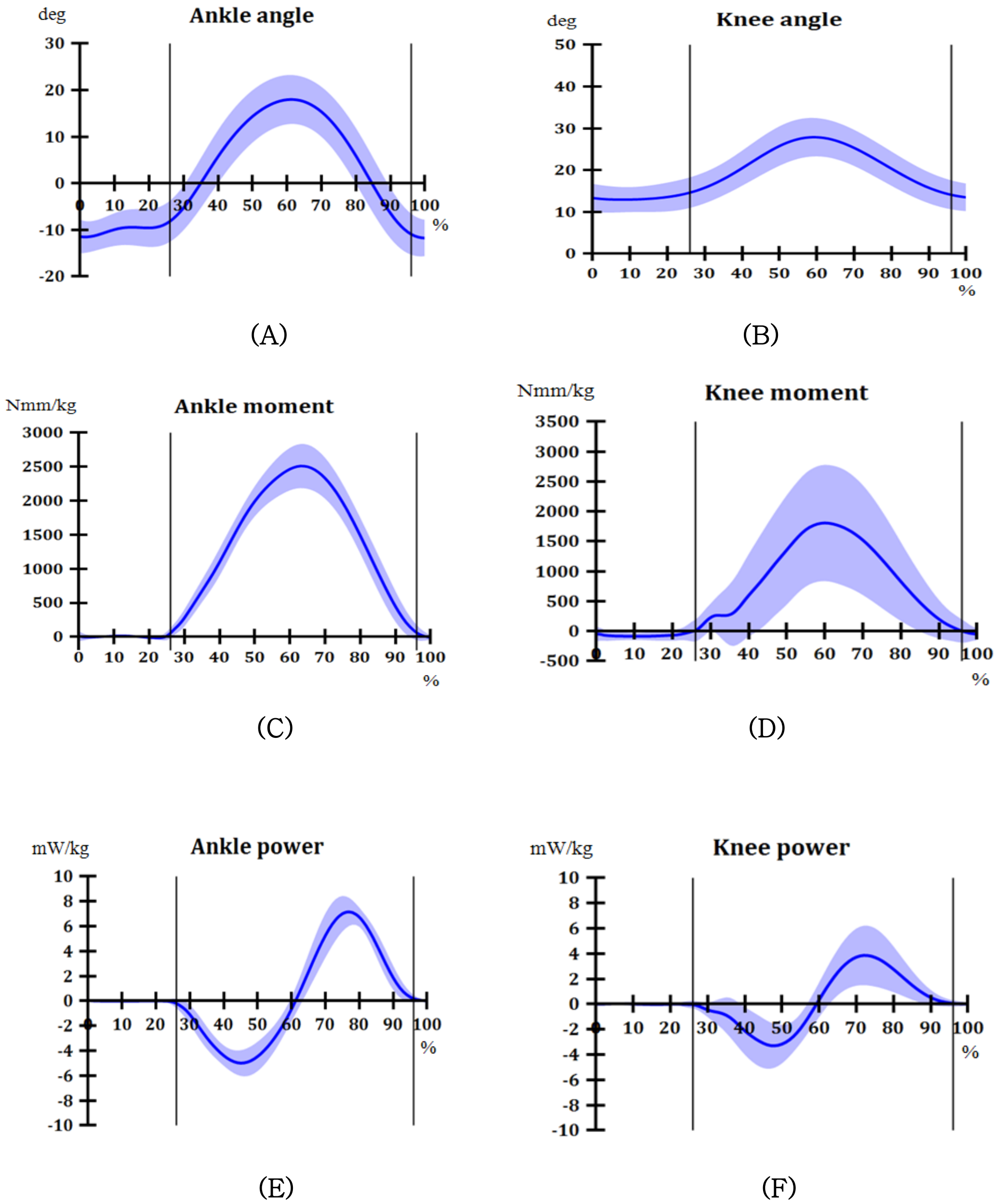


Figure.5. Kinetic and kinematic data at 2.5Hz

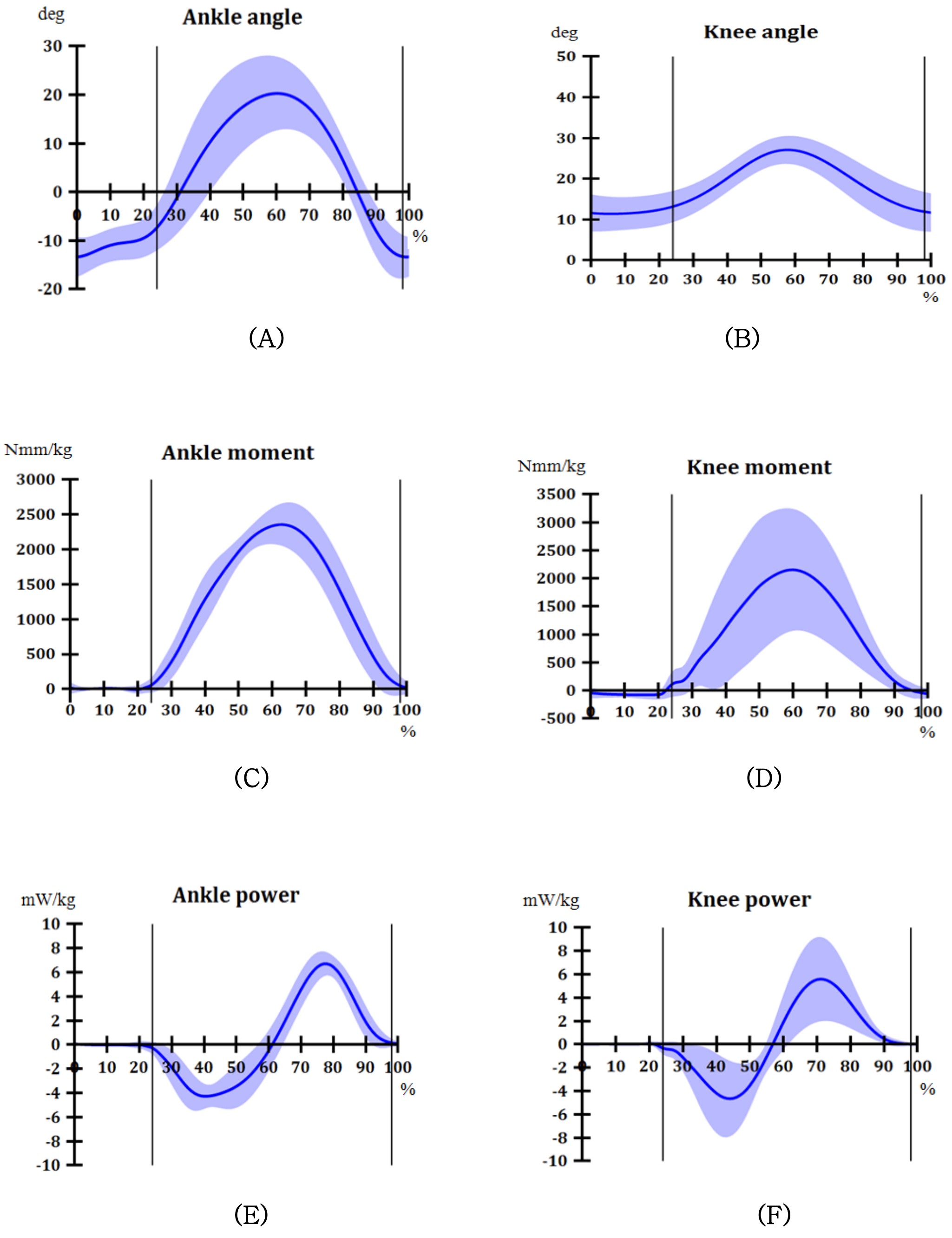


Figure.6.Kinetic and kinematic data at pref. Hz

Table 2. Mean joint angle, moment and power during hopping

	2Hz	Pref. Hz	2.5Hz
Pre-landing			
Ankle angle (deg)	-13.1(0.7)	-10.9(1.5)[1]	-10.0(0.9)[1]
Knee angle (deg)	11.1(0.3)	11.8(0.5)	13.3(0.4)[1]
Landing			
Ankle angle (deg)	9.0(12.2)	7.8(10.2)	6.7(9.3)
Ankle moment (Nmm/kg)	1422.0(821.0)	1358.4(786.1)[1]	1440.6(823.4)[2]
Ankle power (mW/kg)	0.4(4.2)	0.4(3.7)	0.5(4.1)
Knee angle (deg)	23.3(7.3)	20.0(5.0)[1]	21.6(4.6)
Knee moment (Nmm/kg)	1228.3(838.6)	1133.9(747.7)	923.1(613.4)[1]
Knee power (mW/kg)	0.4(4.0)	0.4(3.3)	0.3(2.3)[1]
Landing off			
Ankle angle (deg)	-15.6(0.4)	-13.3(0.0)[1]	-11.4(0.3)[1,2]
Knee angle (deg)	11.1(0.2)	11.8(0.1)	13.8(0.2)[1,2]

Each value is mean(SD)

[1]A significant difference($p<0.05$) from 2Hz

[2]A significant difference($p<0.05$) from 2.5Hz

3.2 Leg stiffness during hopping

The average preference Hz of all subjects was determined to be 2.41±0.05Hz. The peak GRF showed no significant differences among three frequencies, as shown in Table 3. COM displacement in 2Hz hopping was significantly larger than that of 2.5Hz. In preference Hz, it was ranged between values of 2Hz and 2.5Hz. The leg stiffness significantly increased with increased hopping frequencies.

Table 3. Leg stiffness

	2Hz	**pref. Hz**	**2.5Hz**
Leg stiffness(KN/kg/m)	0.161(0.028)	0.225(0.033)[1]	0.235(0.026)[1]
Peak GRF(N/Kg)	26.243(3.969)	26.243(3.869)	26.394(2.481)
COM displacement(m)	0.164(0.012)	0.117(0.008)[1]	0.113(0.011)[1]

Each value is mean(SD)

[1] A significant difference($p<0.05$) from 2.0Hz

[2] A significant difference($p<0.05$) from 2.5Hz

3.3 Joint stiffness during hopping

Knee joint stiffness was larger than ankle joint stiffness in all frequencies, as shown in Table 4. Ankle joint stiffness significantly increased with increases in hopping frequency. Knee stiffness also increased with hopping frequencies, but there was no significant difference. At 2Hz, ankle joint angular displacement was significantly larger than that of 2.5Hz, but peak ankle joint moment showed no significant difference. Knee joint angular displacement and peak knee joint moment was significantly smaller than those of 2.5Hz. For pref. Hz, all kinetic and kinematic data except for joint power was value between 2Hz and 2.5Hz. Peak knee joint power significantly decreased than that of ankle joint with increases in hopping frequency.

Table 4. Joint stiffness

	2Hz	**pref. Hz**	**2.5Hz**
Knee stiffness (Nm/kg/deg)	0.108(0.060)	0.114(0.056)	0.114(0.078)
Ankle stiffness (Nm/kg/deg)	0.059(0.011)	0.076(0.027)[1]	0.079(0.017)[1]
Peak knee moment (Nm/kg)	2.447(0.725)	2.129(0.975)	1.866(0.784)[1,2]
Peak ankle moment (Nm/kg)	2.509(0.371)	2.465(0.292)	2.597(0.292)[2]
Knee angular displacement(deg)	26.022(6.914)	19.172(4.682)[1]	18.529(5.385)[1]
Ankle angular displacement(deg)	43.237(6.000)	36.556(8.606)[1]	34.112(6.486)[1]
Peak knee power (mW/kg)	7.527(2.090)	5.612(3.281)[1]	4.396(2.035)[1,2]
Peak ankle power (mW/kg)	8.459(2.027)	7.484(1.321)[1]	8.256(1.615)[2]

Each value is mean(SD)

[1] *A significant difference($p<0.05$) from 2.0Hz*

[2] *A significant difference($p<0.05$) from 2.5Hz*

3.4 Relationship between leg and ankle joint stiffness

In order to determine the relationship between leg stiffness and joint stiffness, all data based on every hop was used. As shown in (Figure 7-9), leg stiffness was approximately proportional to ankle joint stiffness. Its slope was the largest in pref. Hz, but the smallest in 2.5 Hz.

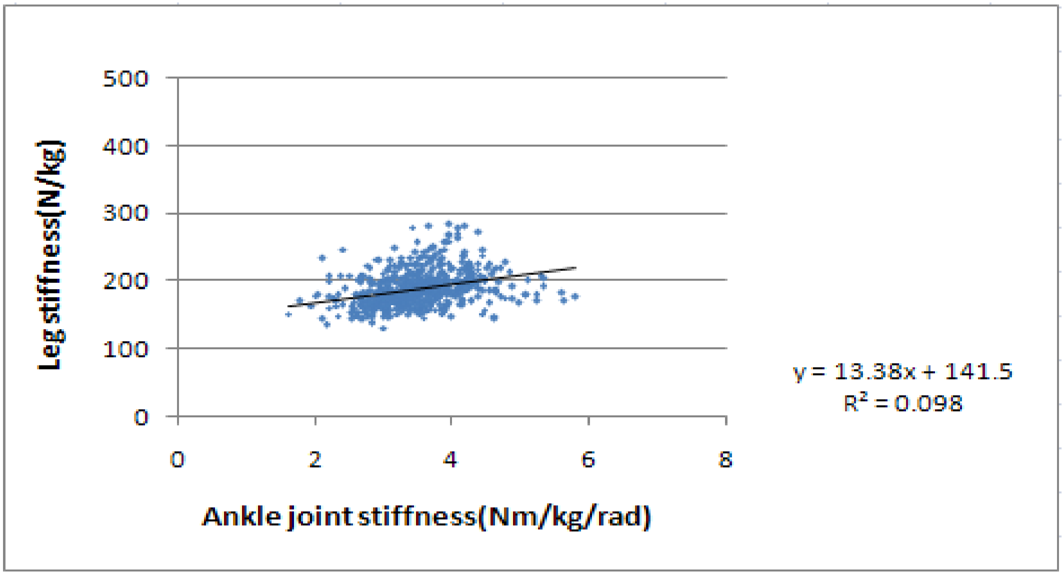


Figure 7. Relationship of leg stiffness and ankle stiffness at 2Hz

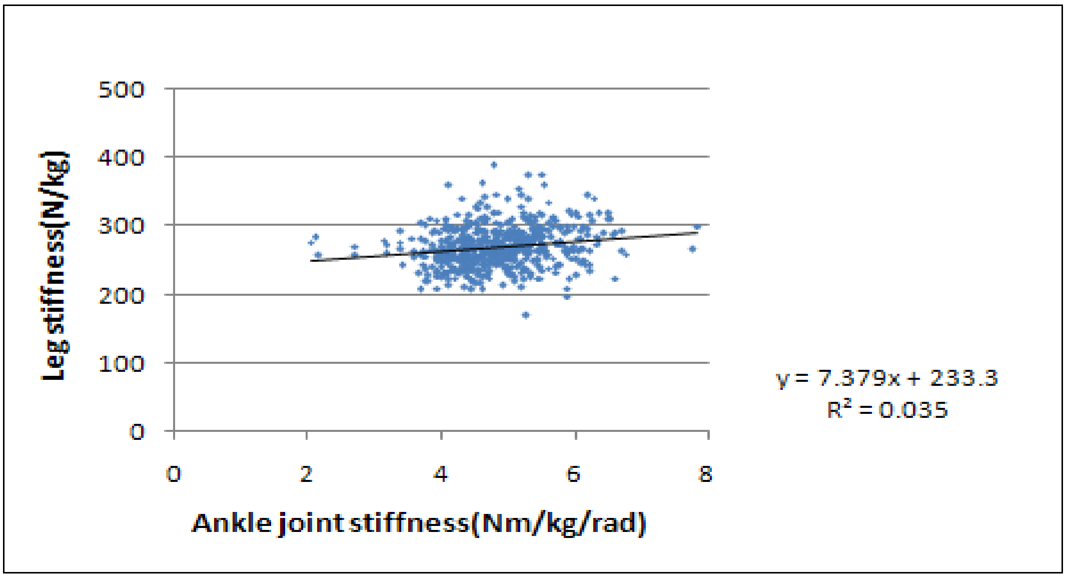


Figure 8. Relationship of leg stiffness and ankle stiffness at 2.5Hz

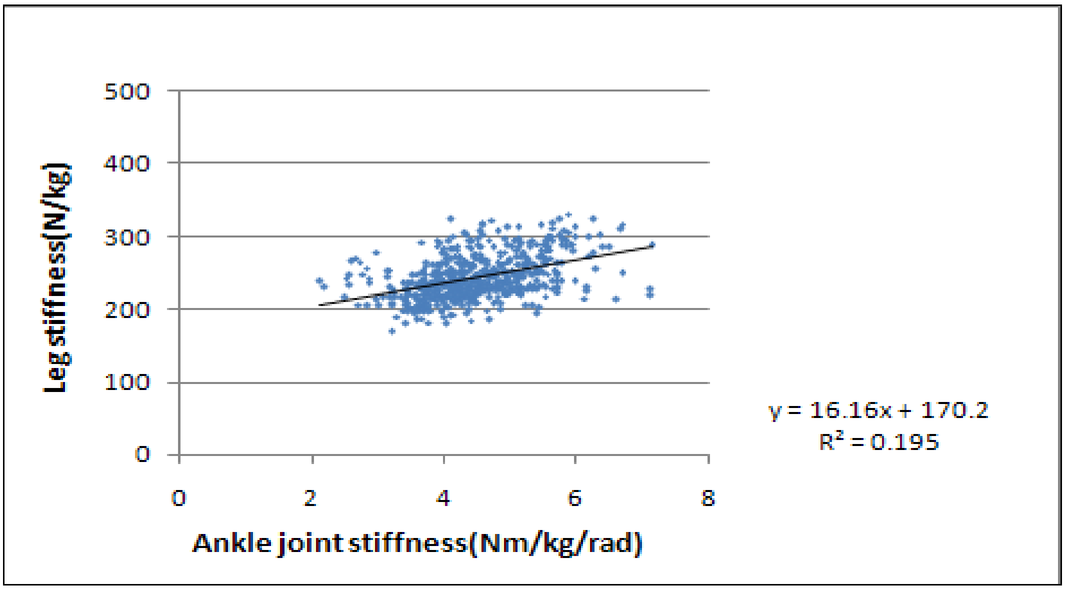


Figure 9. Relationship of leg stiffness and ankle stiffness at pref. Hz

3.5 EMG records according to different frequencies

3.5.1 EMG pattern at 2Hz

Figure 10 represents EMG records of six major lower limb muscles at 2Hz hopping. In the figure, the left vertical line represents the landing point and the right vertical line is the landing off point. X axis is the time, represented by the hopping cycle in 100%. In TA muscle, there was a preparatory contraction during pre-landing period, and a low activity during the ground contact phase(Figure 10A). Then, there was a small peak just after landing off. Muscle activities of GCM and SOL increased after ground contact(Figure 10C, 10E). Muscle activities of GCM and SOL decreased at 30~40% point after ground contact. Then, at 40~60% point after ground contact, they increased again. After then, it continually decreased. Muscle activities of RF and VL increased from 20% point to 50% point after ground contact(Figure 10B, 10D). After then, it continually decreased. BF muscle showed low activities for entire hopping cycle(Figure 10F).

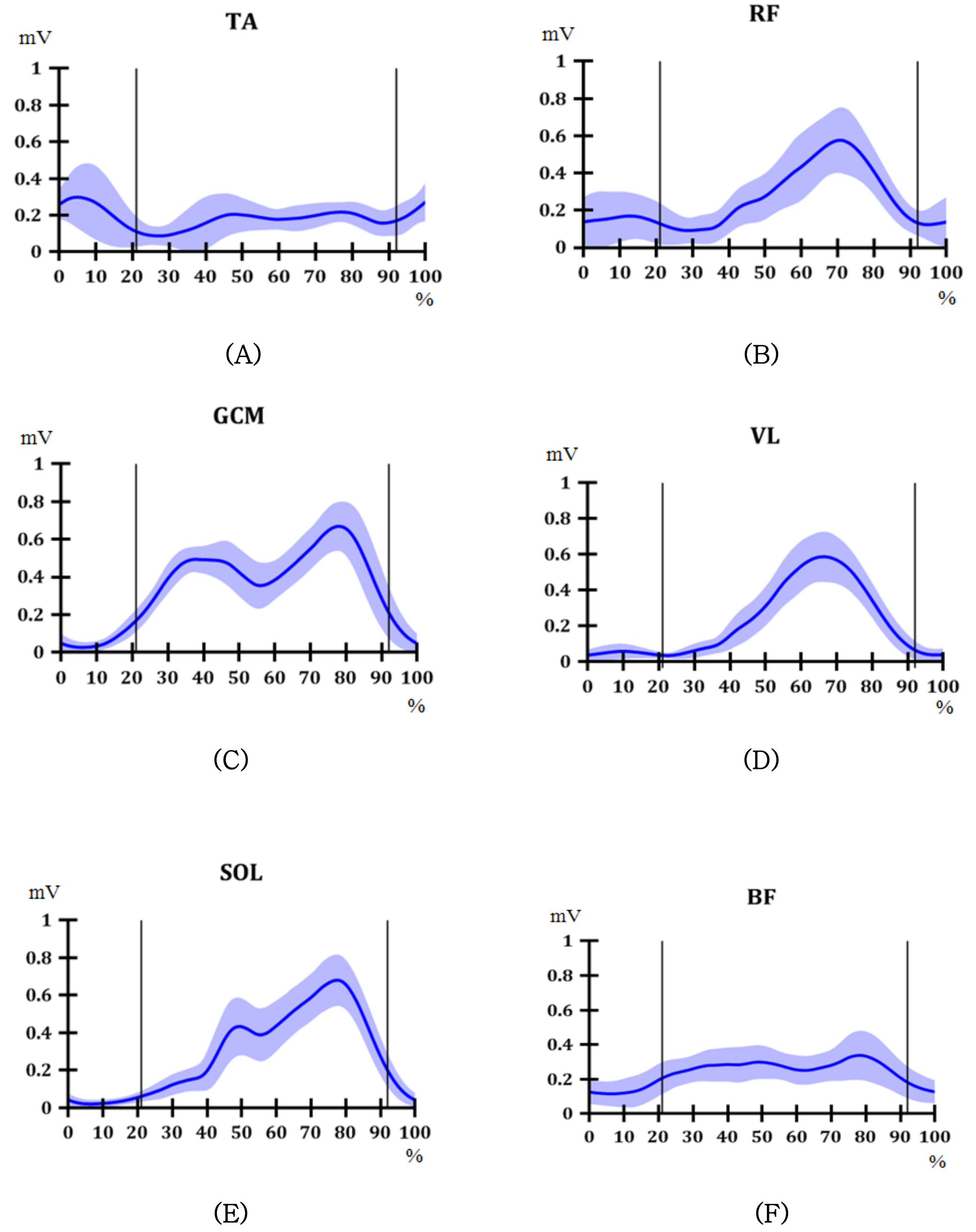


Figure.10. EMG records in 2Hz hopping

Mean EMG records from subjects are shown in Table 5. EMG activation began about 100ms before the landing, and finished about 100ms before the next landing. Except for TA and BF, all muscles showed similar activation patterns during the entire hopping cycle for three frequencies. In pre-landing phase, TA and BF muscle activities significantly decreased with increases in hopping frequency. In landing phase, BF muscle activities in 2Hz were only smaller than those in the other frequencies. In all hopping frequencies, large EMG bursts occurred after ground contact for GCM, SOL and RF, VL. This tendency corresponded well with all hopping frequencies. Except for BF, all muscle activities decreased more with an increase in hopping frequency. In 2.5Hz and pref. Hz, mean EMG of TA was significantly larger than that of 2Hz during pre-landing phase and mean EMG of GCM, and SOL were significantly smaller than that of 2Hz during the landing. During landing off phase, all muscle activities except for TA decreased.

Table 5. Mean EMG records

	2Hz	Pref. Hz	2.5Hz
Pre-landing			
Tibialis anterior(mV)	0.24 (0.06)	0.37(0.07)[1]	0.36(0.10)[1]
Gastrocnemius(mV)	0.06 (0.04)	0.07(0.02)	0.05(0.03)[2]
Soleus(mV)	0.03 (0.01)	0.05(0.02)[1]	0.04(0.03)[1]
Rectus femoris(mV)	0.15 (0.01)	0.15(0.02)	0.08(0.01)[1,2]
Vastus lateralis(mV)	0.05(0.01)	0.03(0.01)[1]	0.03(0.01)[1]
Biceps femoris(mV)	0.14(0.02)	0.18(0.01)[1]	0.18(0.02)[1]
Landing			
Tibialis anterior(mV)	0.17(0.04)	0.15(0.03)	0.12(0.03)[1,2]
Gastrocnemius(mV)	0.45(0.12)	0.43(0.11)	0.39(0.09)[1,2]
Soleus(mV)	0.38(0.19)	0.37(0.17)	0.33(0.15)[1,2]
Rectus femoris(mV)	0.30(0.17)	0.26(0.12)[1]	0.20(0.11)[1,2]
Vastus lateralis(mV)	0.29(0.20)	0.22(0.16)[1]	0.18(0.11)[1,2]
Biceps femoris(mV)	0.28(0.03)	0.29(0.06)	0.29(0.06)
Landing off			
Tibialis anterior(mV)	0.22(0.04)	0.22(0.04)	0.20(0.04)
Gastrocnemius(mV)	0.11(0.06)	0.12(0.02)	0.15(0.03)[1]
Soleus(mV)	0.11(0.06)	0.12(0.02)	0.13(0.03)
Rectus femoris(mV)	0.13(0.00)	0.15(0.00)	0.10(0.00)[2]
Vastus lateralis(mV)	0.05(0.01)	0.03(0.00)[1]	0.03(0.01)[1]
Biceps femoris(mV)	0.15(0.02)	0.18(0.00)	0.18(0.01)

Each value is mean(SD)

[1]*A significant difference($p<0.05$) from 2Hz*

[2]*A significant difference($p<0.05$) from 2.5Hz*

3.5.2 EMG pattern at 2.5Hz

In 2.5Hz, the preparatory contraction of TA muscle was more largely peaked than that of 2Hz during pre-landing phase(Figure 11A). But TA showed low activities during ground contact phase. Then, there was a small peak just after landing off. Muscle activities of GCM and SOL increased after ground contact(Figure 11C, 11E). From 35% point to 45% point after ground contact, muscle activities of GCM and SOL decreased. Then, at 55% point after ground contact, they increased again. After then, it continually decreased. Muscle activities of RF and VL increased from 15% point to 45% point after ground contact(Figure 11B, 11D). After then, it continually decreased. BF muscle showed low activity for entire phase(Figure 11F).

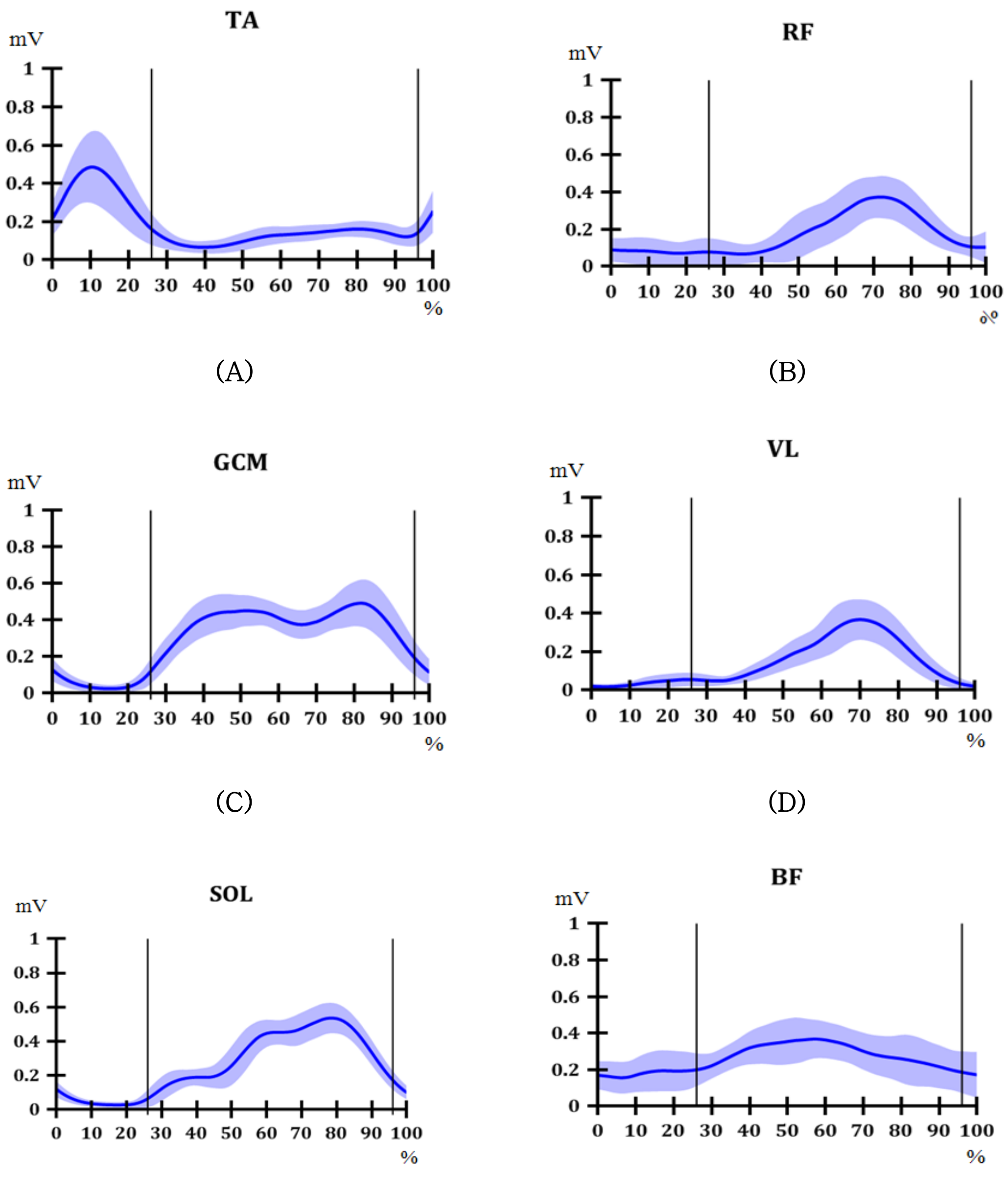
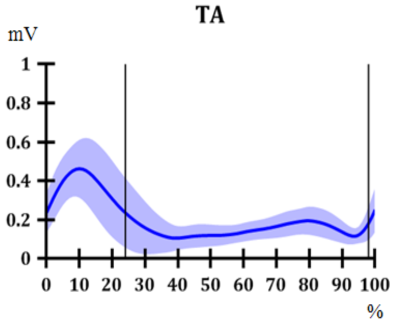


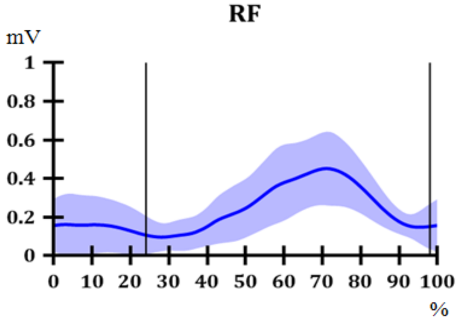
Figure 11. EMG records in 2.5Hz hopping

3.5.3 EMG pattern at pref. Hz

In Pref. Hz, the preparatory contraction of TA muscle was similar to that of 2.5Hz during pre-landing phase(Figure 12A). TA showed low activities during ground contact phase. Then, there was a small peak just after landing off. Muscle activities of GCM and SOL increased until 25% point after ground contact(Figure 12C, 12E). From 25% point to 35% point after ground contact, muscle activities of GCM and SOL decreased. Then, from 35% point to 55% point after ground contact, it increased again. After then, it continually decreased. Muscle activities of RF and VL increased from 15% point to 45% point after ground contact(Figure 12B, 12D). After then, it continually decreased. BF muscle showed low activities for entire phase(Figure 12F).



(A)



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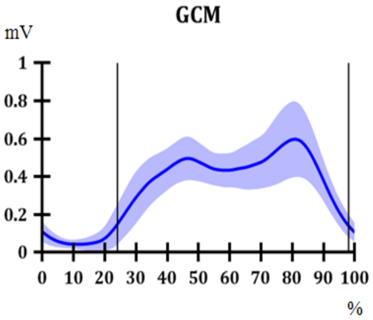

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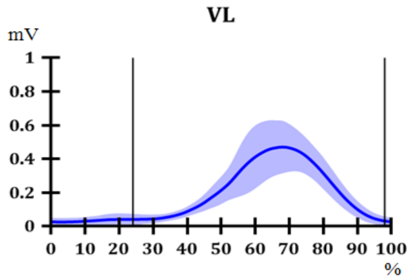

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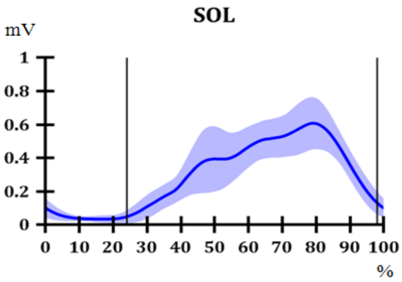
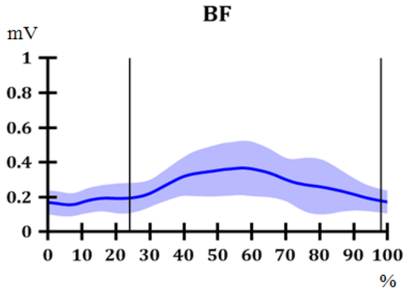


(E)



(F)

Figure 12. EMG records in pref. Hz hopping

4. Discussion

We found that the leg stiffness significantly increased with an increase in hopping frequency. Our results are in good agreement with Hobara et al's study[13], even though their study revealed statistically significant difference between 1.5Hz and 3.0Hz, not between 2.1Hz and 3.0Hz. We also demonstrated that the ankle joint stiffness significantly increased with an increase in hopping frequency. Knee joint stiffness increased with an increase in hopping frequency but with no significant difference. However, their study reported that the knee joint stiffness showed significant difference between 1.5Hz and 3.0Hz but the ankle joint stiffness did not. Hobara et al. [14] reported the relatively larger knee joint moment than that of the ankle joint. However, our study showed the opposite results in three frequencies, even though both their study and ours showed that the ankle joint angle was larger than the knee joint angle. One of the reasons would be due to the fact that their study used the maximal hopping but we performed preferred hopping.

Farley et al. [15] performed both the preferred hopping and the maximal hopping. Both peak moment and angular displacement of the ankle joint were larger than those of knee, and the ankle joint stiffness was larger than the knee joint stiffness in preferred hopping. The ankle joint plays a more important role in preferred hopping than that of the knee joint. In this sense, their results are in good agreement with ours.

Hobara et al. [16] reported that the major determinant of leg stiffness switches from the knee joint stiffness to the ankle joint stiffness with increases in hopping frequency. In our study, leg stiffness was approximately proportional to the ankle joint stiffness. This was in good agreement with their results which was performed in hopping with 2.2Hz and 3.0Hz frequencies.

We analyzed EMG activities of TA, GCM, SOL, RF, VL, and BF. Poulsen et al.[17] reported that there was a preparatory contraction in TA muscle in pre-landing phase and low activities during landing phase. TA muscle activities from ground contact to landing off are were considered to include voluntary activation by supraspinal command and stretch reflex[18-19]. These results are in good agreement with ours. Also, in our study, EMG activities except for BF were significantly higher in the 2 Hz than in 2.5 Hz during landing. Moritani et al. [20] reported that MG and SOL muscle activations significantly increased with decreased frequencies. This means that muscle activation levels play minor role for adjusting the leg stiffness for a range of frequencies.

There are many studies about single-leg hopping of patients with anterior cruciate ligament reconstruction. Oberlander et al. [21] reported that knee joint moment decreased in ACL deficient patients. They reported partially transfer their joint moment output from the knee to ankle and hip joints, increase the risk of loss of balance in ACL reconstruction patients. Thomee et al. [22] reported that there was significant difference in knee joint power ACL reconstruction group and normal group. Also, Robertson et al. [23] reported 12% increase of knee joint stiffness for 6 month post-reconstruction patients, because knee angular displacement decreased.

There was a study about age-related muscle activation and joint stiffness regulation in repetitive hopping[24]. They showed that the ankle joint stiffness of the elderly group was significantly smaller than that of young group, because the elderly group showed more dorsiflexion than the young group. Elderly group' Knee joint angle also more flexed than that of young group. But knee joint stiffness was no significant difference. They also showed that EMG activities of GCM, SOL and TA the elderly group was smaller than those in the normal group for preferred hopping. Our results were in good agreement with the young group's results.

If we additional study about hopping of ACL patients group or elderly group, we can compare present results with them.

5. Conclusion

In the present study, leg stiffness and lower extremity joint stiffness were determined in different hopping frequencies using the 3-D motion analysis. From the present study, the following conclusions can be made:

(1) Mean joint angles of ankle and knee significantly decreased with an increase in hopping frequency during landing. Mean knee joint extension moment also significantly decreased with increases in hopping frequency during landing. In 2Hz, mean power of ankle joint was larger than that of 2.5Hz. But mean power of knee joint was significantly decreased.

(2) Both ankle joint angular displacement and peak ankle joint moment were relatively larger than those of the knee joint in three different frequencies. Ankle joint power was larger than that of knee joint in three frequencies.

(3) Leg stiffness and ankle joint stiffness significantly increased with an increase hopping frequencies. Leg stiffness had an approximately linear relationship with ankle joint stiffness in three frequencies

(4) Knee joint stiffness was larger than that of ankle in three hopping frequencies. But knee joint stiffness was no significant difference with an increase hopping frequencies

(5) During landing phase, mean EMG activities of all muscles except BF decreased with an increase in hopping frequency. In three hopping frequencies, large EMG bursts occurred after ground contact for the GCM, SOL, RF, and VL. This tendency corresponded with all three frequencies. These results mean that muscle activation levels play minor role for adjusting the leg stiffness.

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Abstract (in Korean)

호핑 주파수의 변화에 따른

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이정주

본 연구의 목적은 제자리에서 호핑을 하였을 때, 호핑 주파수에 따라 변화하는 다리 강성도와 하지 관절 강성도를 분석하는 것이다.

18 명의 근골격계 질환이 없는 20 대의 건강한 피험자들이 연구에 참여하였다. 2Hz, 2.5Hz, 선호(2.41±0.05) Hz 의 세가지 주파수에서 한발 호핑을 실시하였다. 2 개의 힘측정판 위에서 호핑 동작을 실시하였으며, 삼차원 동작분석시스템을 이용하여 데이터를 획득하였다. 오른쪽 다리에 전경골근, 내측비복근, 가자미근, 대퇴직근, 외측광근, 대퇴이두근 등 6 개의 근전도 전극을 부착하여 실험하였고 데이터를 획득하였다. 피험자들은 각각 12 번의 호핑을 실시하였고, 그 과정을 5 회 반복하였으며, 가운데 6 번의 홉을 데이터로 사용하였다. 착지 구간의 데이터를 분석하였으며, 다리가 최대로 굽혀질 때, 최대 수직 지면반발력과 체중심의 수직 위치 변화량을 측정하였다. 다리 강성도는 최대 수직 지면반발력을 체중심의 수직위치 변화량으로 나누어

계산하였으며, 하지관절 강성도는 각 관절 모멘트의 최대값에서 각도의 위치 변화값을 나누어 계산하였다.

모든 주파수에서 무릎관절 강성도는 발목관절 강성도보다 높았지만, 주파수가 증가함에 따라 무릎관절 강성도는 유의한 차이를 보이지 않았고, 발목관절 강성도는 유의하게 증가하였다. 다리 강성도와 발목관절 강성도는 대략적으로 비례하였으며, 대퇴이두근을 제외한 5 개의 근육에서 평균 근활성도는 작아졌다.

핵심 되는 말: 호핑, 3 차원 동작 분석, 다리 강성도, 관절 강성도