MAXIMIZE MUSCLE MECHANICAL OUTPUT DURING THE STRETCH-SHORTENING CYCLE -- THE CONTRIBUTION OF PREACTIVATION AND STRETCH LOAD

A Dissertation

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Abstract

It is well documented that the stretch-shortening cycle (SSC), the most common muscle behavior, enhances muscle mechanical output. Stretch load and muscle preactivation level have been suggested as the two important factors regulating mechanical output. The purpose of this series studies is to systematically examine influences of the preactivation and the stretch load on muscle mechanical output during SSC.

In the First study, a two dimensional lower extremity dynamic model was used to evaluate the influence of the approach on mechanical output. The peak summed power during the push-off phase demonstrated a quadratic trend across heights and appeared to be driven primarily by the ankle joint response. When an approach was used summed peak power was approximately 10% greater, regardless of the number of steps.

In the Second study, we investigated muscle activity of seven major low extremity muscles during drop jumps. The surface EMG activities were full-wave rectified and averaged (aEMG) during the pre-activation (50ms before touchdown), downward and pushoff phases. The results showed that the aEMG of most tested muscles during the preactivation phase and the downward phase increased with more steps of the approach. This increase did not change the antagonist-agonist coactivation ratio, therefore would not attribute to knee joint injury. On the other hand, no aEMG changes were found with different drop heights.

In the Third study, stretch load and preactivation were used as inputs for a muscle model to calculate muscle force, muscle velocity and muscle power. This model quantified how the different preactivation level and stretch load (velocity) affect the muscle mechanical output. Results showed that for low preactivation levels, increasing preactivation level can significantly increase gain in height for all stretch velocities we tested, but increasing stretch velocity may

decrease the gain in height; for high preactivation levels, further increasing preactivation level may not increase gain in height.

Over all, increasing preactivation enhances mechanical output due to increased active state level during SSCs; when preactivation is high, increasing stretch load enhances mechanical output due to increased positive work. Stretch load needs a high preactivation level to maximize the mechanical output.

Chapter 1: Introduction

In our daily locomotion and explosive movements such as throwing, sprinting and jumping, muscles often involve the stretch-shortening cycle (SSC), in which the shortening phase is immediately preceded by an lengthening phase (Komi, 2000; van Ingen Schenau, Bobbert, & deHaan, 1997a). External force (e.g. ground reaction force) or the antagonist muscle force can lengthen the muscle. The combination of eccentric and concentric contractions has a great advantage in muscle performance compared to the isolated concentric action. Isolated muscle experiments (Cavagna, Dusman, & Margaria, 1968; Ettema, Huijing, & Dehaan, 1992) and *in vivo* human dynamic movements (Bosco & Komi, 1979; Bosco, Komi, & Ito, 1981; Cavagna et al., 1968; Komi & Bosco, 1978) have demonstrated that SSC induce greater contractile force and produce greater mechanical work and power output (Komi, 2000).

Several mechanisms have been proposed to enhance performance during SSCs (van Ingen Schenau et al., 1997a; van Ingen Schenau, Bobbert, & deHaan, 1997b). These mechanisms include 1) time available for force development (van Ingen Schenau et al., 1997a); 2) contribution of stretch reflex (Komi & Bosco, 1978); 3) reutilization of elastic energy (Bosco et al., 1981; Komi & Bosco, 1978); and 4) potentiation of the contractile machinery (K.A. Edman, Elzinga, & Noble, 1978; Ettema et al., 1992). No convincing evidence has been presented that any one of these mechanisms can explain the entire mechanical output enhancement (Cronin, McNair, & Marshall, 2001). Also no evidence can completely deny any of these suggested mechanisms. The following is background information about these mechanisms and the influence of stretch load and preactivation.

Background Information

The first mechanism, giving muscles more time to develop force, was explicitly supported by most commentators (D.L. Morgan & Proske, 1997; van Ingen Schenau et al., 1997b; D.A. Winter, 1997). However, this factor can't explain the larger force produced in fast SSCs such as drop jumps (Zatsiorsky, 1997). Van Ingen Schenau and colleagues (van Ingen Schenau et al., 1997a; 1997b) suggested that the time available for force development is the only reliable explanation for enhancement mechanisms. In other words, the force level before muscle shortening is the only key factor for muscle performance enhancement. However other studies showed that this factor cannot be the only key factor. For example, Finni and colleagues (2001) showed that the maximal knee extension torque was significantly higher in the pre-stretch condition than in the pro-isometric condition, although the torque prior to the concentric phase was smaller in the pre-stretch than in the pre-isometric condition.

For stretch reflex contribution, the first key issue is to question whether the reflex occurs because some muscle spindles are found not stretched in some SSCs (van Ingen Schenau et al., 1997a). For these fast movements such as drop jumping, running, and hopping, Komi and Gollhofer (1997)showed substantial evidence that the stretch reflexes contributed to the enhanced performance in the fast SSCs. However, van Ingen Schenau and colleagues (1997b) argued that the mechanical effects of stretch reflex would be too late to provide substantial enhancement.

In the literature, studies on *in situ* contractions as well as on the isolated muscle have suggested the reutilization of elastic energy stored in the series elastic components element (SEC). During the stretching of an active muscle, potential elastic energy is stored and can be reutilized during the concentric contraction (Cavagna et al., 1968). However, van Ingen Schenau and colleagues (1997b) argued storage of more energy implied that a further elongation of SEC occurred at the expense of the length of the contractile elements. Consequently, the contractile components would do less work during the subsequent concentric contraction.

The force enhancement of skeletal muscle by active stretching has been well documented (K.A. Edman et al., 1978; Hill, 1938). An active stretch can induce the potentiation of the contractile machinery, in which the force-velocity curve is shifted towards higher force values for a given velocity. Also, the interaction between the series elastic component and the contractile machinery plays a role in the enhanced performance (Ettema et al., 1992).

It is quite likely that a higher active state, reflex activity, the potentiation of contractile machinery, and storage and release of elastic energy interact in some manner to produce SSC enhancement. The amplitude of enhancement may depend on activation level, stretch load (velocity), muscle-length and time-dependent characteristics of the motion (Cronin et al., 2001). Therefore, a high level of force prior to shortening, stretch reflex, potentiation of the contractile machinery, and the storage and release of elastic energy may interact in some manner to enhance performance during SSCs (Cronin et al., 2001).

The stretch load (velocity) is one of important factors that influence the stretch amplitude, stretch duration time, elastic energy storage and fascicle length change. There are several critical conditions for an effective SSC to take advantage of these performance enhancement mechanisms: a fast stretch speed increases force development before shortening (van Ingen Schenau et al., 1997b) and facilitates the stretch reflex (Komi, 2000; Komi & Gollhofer, 1997), a short lengthening amplitude takes advantage of the short range of stiffness and enhances the storage of elastic energy (Komi, 2000), a minimized fascicle length change optimizes the release of elastic energy (Finni, Ikegawa, Lepola, & Komi, 2003; Fukunaga, Ichinose, Ito, Kawakami, & Fukashiro, 1997). A heavy stretch load or a great stretch speed may overstretch the fascicle, tendon and whole muscle, consequently the power and work output will be dramatically reduced. On the contrary, the eccentric contraction can be finished in a very short time with a light load or a small stretching velocity, but the force development, stretch reflex, and elastic energy storage and release may also dramatically reduced. Studies (Bobbert, Huijing, & Ingen Schenau, 1987b; Komi & Bosco, 1978) have showed the presence of an optimal stretch load (drop height) to maximize the power output, implying that the stretch load plays an important role in mechanical output during the SSC. In one study (Takarada, Iwamoto, Sugi, Hirano, & Ishii, 1997) tested the effects of eccentric force on the power output during concentric actions in countermovement jump. It was reported that both peak and mean power outputs increased initially with eccentric force, but they began to decline when the eccentric force exceeded 1.4 times the sum of load and body weight. The same trend was found in drop jumps (Bosco et al., 1981). It is still not very clear how the different stretch load (velocity) affect each enhancement mechanism to maximize the power output. Another remaining question is why the muscle work and power output were reduced when stretch force exceeded a certain level.

Another important factor which influence muscle performance during SSC is preactivation (Komi, 2000). To prepare the muscles to receive high impact forces, muscles were strongly pre-activated in running and jumping, especially in long jump (Kyrolainen, Finni, Avela, & Komi, 2003). Preactivation and prelanding activity appears to be able to affect those enhancement mechanisms and muscle mechanical output (Kyrolainen, Komi, & Belli, 1999). First of all, it may create a beneficial situation for muscles to develop maximum force in a short time (van Ingen Schenau et al., 1997b). It may take as much as 300 ms to develop the highest force. The force development depends on stimulation dynamics (the development of muscle stimulation), excitation dynamics (the development of muscle active state in response to stimulation), and contraction dynamics (the development of force in response to active state). In these fast SSCs, such as drop jumps, the muscles reach the maximum force value in less than 100 ms. When muscles are strongly pre-activated before landing, the process of stimulation dynamics and excitation dynamics may happen before landing. Therefore, the force could develop much faster after landing.

Secondly, another function of pre-activation is to increase sensitivity of muscle spindles to enhance stretch reflexes (Gottlieb, Agarwal, & Jaeger, 1981), which subsequently increases tendomuscular stiffness (Komi, 2000) and enhances force production (Kyrolainen, Avela, & Komi, 2005).One study (Linnamo, Strojnik, & Komi, 2006) showed that the force potentiation was greater at higher stretching velocities but only when maximal preactivation preceded the stretch, while the velocity dependence was not observed at lower preactivation levels. Therefore, the significance of the preactivation's effect on SSC performance is convincing (Kyrolainen et al., 1999). However, no study has quantitatively analyzed the influence of pre-activation level on the mechanical output during SSC.

Experiments

Because the stretch amplitude and fascicle length change are the results of the stretch load, muscle pre-activation level and muscle activation level, and we assume the development of muscle activation level is constant during every SSC exercise, the stretch load and muscle preactivation level might be the two important acute factors we can adjust. Although a number of studies described the directly proportional relationship between stretch load and enhancement of the concentric contraction, no studies in the literature have exploited how to maximum muscle mechanical output during SSC and the contribution of muscle preactivation and stretch load on muscle performance. Therefore, the purpose of this dissertation is to systematically examine influences of the preactivation and the stretch load on muscle mechanical output during SSC. For this purpose, in the first study (Chapter 2), the drop jump was used to illustrate how to maximize muscle mechanical output during human dynamic exercises. We examined the hypothesis that an approach preceding drop jumps enhances low extremity mechanical output and predicted the enhancement is associated with increased preactivation level. In the second study (Chapter 3), we investigated muscle activity of seven major low extremity muscles during drop jumps and examined the hypothesis that the greater preactivation will resulted in greater muscle activation level during SSC. In the third study (Chapter 4), stretch load and pre-activation were used as inputs for a muscle model to calculate muscle force, muscle velocity and muscle power. This model quantified how the different pre-activation level and stretch load (velocity) affect these enhancement mechanisms and finally determine the muscle mechanical output. More specifically, the role of elastic energy reutilization during concentric phase and the influence of muscle force level before shortening on muscle mechanical output were examined during SSC under combination of different stretch loads and pre-activation levels. A comprehensive discussion of three studies was presented Chapter 5. The results and conclusions from these three studies will not only increase our knowledge on muscle function and dynamical human movement, but also provide a possible solution to maximize muscle performance and improve human performance.

Chapter 2: Influence of a Horizontal Approach and Drop Height on the Mechanical Output during Drop Jump

Introduction

Plyometric exercise, a form of the stretch-shortening cycle exercise, is a movement performed by starting with a movement to the opposite direction (1990). As one of the most popular plyometric exercises, drop jump is performed by stepping off a raised platform and immediately jumping vertically after landing on the ground (Bobbert, 1990). Several studies (Brown, Mayhew, & Boleach, 1986; Matavulj, Kukolj, Ugarkovic, Tihanyi, & Jaric, 2001; Steben & Steben, 1981) have reported that drop jump training effectively improved vertical jumping height. It is assumed that this increase in vertical jumping height is the result of an enhanced muscle mechanical output during the concentric phase as illustrated by the greater power output observed in drop jumps as compared to vertical jumps starting from the ground level (M.F. Bobbert, P.A. Huijing et al., 1987b). Increasing the peak power output is the most important concern in the training of explosive exercises as there is a high correlation ($R = 0.82$, $P<0.01$) between the take off velocity and the peak joint power of the lower extremity (T. Horita, P. V. Komi, C. Nicol, & H. Kyrolainen, 2002a).

The mechanisms thought to contribute to greater power output during a drop jump are the stretch reflex (Bosco & Komi, 1979; Komi & Bosco, 1978; Komi & Gollhofer, 1997), the storage and utilization of elastic energy (Bosco & Komi, 1979; Komi & Bosco, 1978), and potentiation of the contractile machinery (M.F. Bobbert, P.A. Huijing et al., 1987b). First, the stretching of muscles during landing of a drop jump may trigger a stretch reflex (Nicol, Komi, Horita, Kyrolainen, & Takala, 1996). The stretch reflex may increase muscular stiffness leading to an improved ability to utilize storage of potential elastic energy (Walshe, Wilson, & Ettema, 1998). The effect of stretch reflex is increased with stretching velocity (Bosco et al., 1981; Kallio, Linnamo, & Komi, 2004). Second, elastic energy stored in the series elastic elements during stretching can be released during shortening (Bosco et al., 1981). The storage and utilization of elastic energy is enhanced with high stretch speed, high eccentric force and short time delay after the stretch (Bosco et al., 1981). Third, the stretch may induce potentiation of the contractile machinery (Cavagna & Citterio, 1974; K.A. Edman et al., 1978). This potentiation has been shown to increase with speed of stretch and to decrease with the amount of time delay after the stretch (K.A. Edman et al., 1978). To be an effective training method, drop jumping should fully exploit these mechanisms to enhance athletic performance.

Increased drop height appears to exploit these enhancement mechanisms facilitating the power output. However, there seems to be a ceiling effect of increasing the power output associated with drop height. Bobbert, Huijing, and van Ingen Schenau (1987) reported that although increased ground reaction forces during the push-off phase have been found when drop height was increased from 40 cm to 60 cm, there were no increases in the maximum net moment and maximum net power output about the knee and ankle joints (physically active male students). Komi and Bosco (1978) reported that the participants had their highest jumps in drop jumps from the heights of 62 cm (male physical education students and male volleyball players) and 50 cm (female physical education students). Because there is a high correlation between the takeoff velocity and the peak joint power during the push-off phase (Horita et al., 2002a), it can be assumed that the highest peak joint power would be produced at the optimal drop height. Therefore, an optimal drop height related to the highest joint power output in the drop jumps seems to exist at approximately 40 - 60 cm for physically active male college students. To optimize the performance gains, it is necessary to use the training strategies that could maximize the mechanical power output of the exercise (Walshe et al., 1998). However, it remains unclear whether there are other training strategies that could further increase the power output produced during drop jump from the optimal drop height.

In the aforementioned studies, all drop jumps were standing jumps without an approach. Studies have shown that a horizontal approach preceding vertical jumps (vertical jump and approach were at the same ground level) could also increase jump heights. Saunders (1980) reported that vertical jump heights of two-foot jumps increased with approach speeds up to 50-60% of maximum sprint speed. It has been assumed that an approach forces the muscles to stretch in the first half of the take-off phase, which may enhance the stretch reflex and the storage of elastic energy (Dapena & Chung, 1988). Similar enhancement mechanisms may therefore be associated with increased drop height and increased approach speed. However, the greater approach speed (horizontal velocity) may also be associated with greater muscles preactivation (Kyrolainen et al., 1999), which may have additional effects on the drop jump performance. Although increasing the drop height beyond the optimal height could not increase the power output further, would this limitation be exceeded by an approach preceding drop jumps? This question remains unclear because no reports have so far been available regarding the effect of an additional approach on drop jump performance.

Therefore, the purpose of this study was to investigate influence of a horizontal approach on mechanical output during drop jumps. More specifically, power output of lower extremity joints, joint angles, and angular velocities were studied. The hypothesis was that the approach preceding drop jumps would increase power output during the push-off phase and even exceed the limit of optimal drop height due to the performance changes induced by the approach.

Methods

Participants

Twelve physically active male university students (Mean age=24 year, SD = 3; Mean height = 1.8 m, SD = 0.1; Mean body mass = 76 kg, SD = 5) were recruited for this study from a physical activity class. Prior to participation, procedures were described to the participant and all questions were addressed. Each participant signed a written consent form approved by the Institutional Review Board.

Protocol

Participants completed one-week drop jump training for familiarization. Training involved three sessions during which combinations of drop jumps with and without an approach at different drop heights were performed. In the first session, participants performed the vertical jump (countermovement jump) 16 times. In the second session, participants performed four drop jumps from drop height of 15 cm for each of four approach conditions (zero, one, two, and three steps), totally 16 trials. In the third session, participants also performed four drop jumps from drop height 45 cm for each of four different approach conditions (zero, one, two, and three steps), totally 16 trials. Participants were instructed to follow four performance requirements: 1) use consistent and moderate approach speeds and step lengths for each condition; 2) step off the raised platform without jumping up to avoid adding drop height (monitored visually); 3) step off the platform with the right foot and use both feet simultaneously for the landing; and 4) perform each jump with maximal effort. These performance requirements were also applied during data collection.

Prior to data collection, participants had approximately 12 minutes warm up, including 8 minutes running on a treadmill and 4 minutes jump exercises (one standing drop jump and one drop jump with two approach steps from drop height of 15 and 30cm.). After warm up, five reflective markers were placed on the left leg of the participant at the anterior superior iliac spine, hip, knee, ankle, and fifth metatarsal-phalangeal joint. Figure 2.1 shows a schematic of the instrumentation and the jump platform used in the study. To minimize the difference of approach speed and step lengths among participants and different drop heights, the initial positions for zero, one, two and three steps were set on the surface of the jump platform. A camera of Motion Analysis system (Motion Analysis Corporation, Santa Rosa, CA) was used to collect the movement trajectories of each marker at 60 Hz. A force platform

(Advanced Mechanical Technology Inc, Watertown, MA) was used to record the vertical and anterior-posterior (AP) ground reaction forces at 1200 Hz. Kinematic and force data were collected simultaneously with internal synchronization and combined to calculate joint moments about the mediolateral axis at the ankle, knee, and hip joints. The center of the force platform was set as the origin of the laboratory reference frame during the calibration process. Center of pressure calculated from force platform data then coincided with the coordinates in the laboratory reference frame.

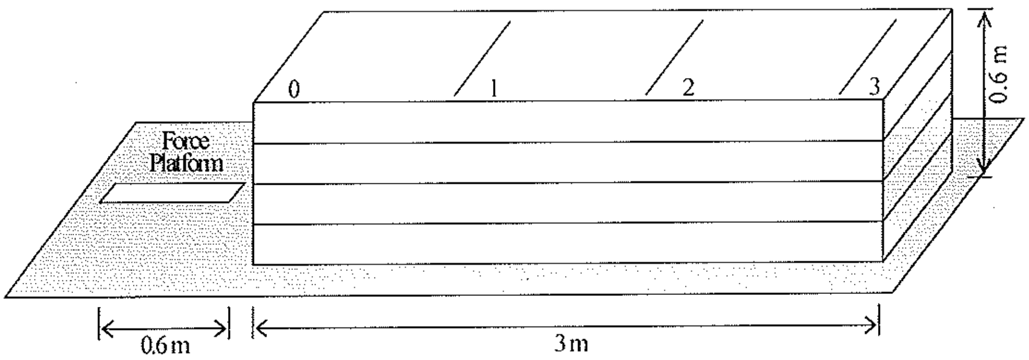

Figure 2.1. Schematic presentation of the jump platform for drop jumps and the instrumentation used in the study. 0, 1, 2, and 3 on the surface of the jump platform represent the initial positions for zero, one, two and three steps.

Participants performed drop jumps from four different heights: 15, 30, 45, and 60 cm in randomized order. The order of drop heights was randomized across the participants. From each drop height, the participants performed one trial for each of four different approach conditions (zero, one, two, and three steps) in a random order. In all, participants performed 16 trials. Every trial was monitored visually and self-evaluated by the participants. Participants repeated a trial if they or the investigators felt the performance requirements were not fulfilled. The instant of lowest knee vertical position during the drop jump was used to divide the jump into downward (from the instant of touch down to the instant of lowest knee vertical position) and push-off phases (from the instant of lowest knee vertical position to the instant of toe-off).

Data Analysis

Position data were smoothed with a fourth order Butterworth, zero-lag digital filter (cut off frequency 6 Hz). Joint angles, angular velocities, and accelerations were calculated by using finite difference differentiation of the smoothed position data. Joint angles were defined as zero when participants were standing at anatomical position. A 2-D lower extremity link segment model and body segment parameters (D.A. Winter, 1979) were used to obtain instantaneous net moment and power about hip, knee, and ankle joints. The force data were resampled at 60 Hz for calculating moments and power outputs. A 4 (drop heights) × 4 (the number of approach steps) factorial ANOVA with repeated measures was applied to all measured variables to determine any significant effects and interactions of drop height and the number of approach steps. Post hoc means comparisons were performed using Tukey's test. Significance level was set at alpha = 0.05.

Results

Figure 2.2 and 2.3 present exemplar time histories from a single subject for the vertical component of ground reaction force (Fz) and the individual and summed powers. The curves are similar to those of the other participants.

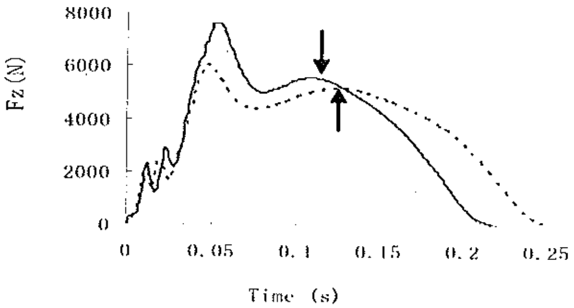

Figure 2.2. Exemplar vertical component of ground reaction force from one subject at the drop height of 60cm with 2 approach steps (solid line) and without approach step (dashed line). The down arrow indicates the start of the push-off phase during the drop jump at the drop height of 60cm with 2 approach steps. The up arrow indicates the start of the push-off phase during the drop jump at the drop height of 60cm without an approach.

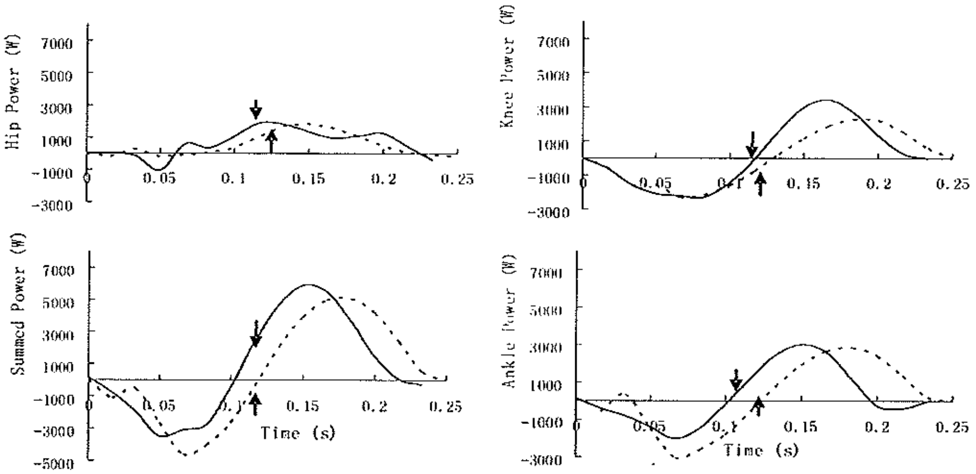

Figure 2.3. Summed Power, hip joint power, knee joint power, and ankle joint power from one subject at the drop height of 60cm with 2 approach steps (solid line) and without approach step (dashed line). The down arrow indicates the start of the push-off phase during the drop jump at the drop height of 60cm with 2 approach steps. The up arrow indicates the start of the push-off phase during the drop jump at the drop height of 60cm without an approach.

The horizontal approach velocity was estimated by using the horizontal velocity of the hip after stepping off the jump platform. The velocity is different from, but highly correlative with the velocity of the center of gravity. With an approach, the estimated horizontal velocity increased significantly [F (3, 33) = 108, P <0.001] from 0.99 ± 0.17 (0 step), to 1.76 ± 0.36 (1 step), 2.17 ± 0.4 (2 steps), and 2.37 ± 0.41 m/s (3 steps). No significant differences were identified for drop height [F (3, 33) = 0.88, P = 0.463] nor the height-approach interaction [F (9, 99) = 1.23, P = 0.282].

Before presenting the effects of the drop height and the number of approach steps on all measured variables, we examined the interactions between the drop height and the number of approach steps. No significant interaction for any variable was observed. Table 2.1 shows the results of interactions for major variables.

Since our main focus was the mechanical performance during the push-off phase, the main factors in the push-off phase will be presented first. Joint angles at the start of the push-off phase would help to explain observations during push-off and will be presented next.

Lastly, the main factors in the downward phase will be presented to explain the first two data sets.

Table 2.1. Interaction tests (Drop Height x Approach Steps).

Variables	F-ratio value	P-value
Summed peak Power (W)	1.86	0.07
Peak hip Power (W)	0.77	0.64
Peak knee Power (W)	0.49	0.88
Peak ankle Power (W)	1.38	0.21
Peak hip moment (Nm)	0.39	0.94
Peak knee moment (Nm)	1.36	0.21
Peak ankle moment (Nm)	1.42	0.19
Peak ground reaction force (N)	1.35	0.22

Note: Source and error degrees of freedom for all tests were 9 and 99, respectively.

Main Factors in the Push-off Phase (Table 2 and Table 3)

The peak summed power during the push-off phase demonstrated a quadratic trend (inverted "u") across drop heights and peaked at the drop height of 30 cm. But the drop height of 30 cm and 45 cm were in the same homogenous group, at which the summed power was approximated 10% greater than that at the drop height of 60 cm. When an approach was used summed peak power increased linearly and was more than 10% greater than standing drop jumps (0-step). But there were no significant differences between 1-step, 2-step, and 3-step conditions. The differences in the summed power were accompanied with differences in the knee joint power and knee joint moment (with changes in approach steps) or ankle joint power and ankle joint moment (with changes in drop heights).

Joint Angles at the Start of the Push-off Phase (Table 4 and Table 5)

The joint angles of the lower extremity at the start of the push-off phase serve as the initial condition for power production during the push-off phase. There was no significant influence of drop height on the hip joint angle and knee joint angle. Although the ankle joint angle increased linearly with drop height, no significant differences were found between any adjacent drop height and only significant difference was found between the drop height of 15 cm and 60 cm. When an approach was used, all three joint angles tended to exhibit decreases

Table 2.2. Variables during the push-off phase for each drop height

	H1		H2		H3		H4		F (3,33)	P value	Homogenous Group
	M	SE	M	SE	M	SE	M	SE			
Summed peak Power (W)	6170	310	6720	376	6430	362	5950	387	9.63	<0.001	(H1)(H2, H3)(H3, H4)
Peak hip Power (W)	1452	117	1498	108	1381	125	1332	114	0.68	0.568	
Peak knee Power (W)	2961	108	3192	125	3157	115	3030	130	1.3	0.289	
Peak ankle Power (W)	2355	93	2525	91	2179	79	2065	106	5.19	0.005	(H1, H2, H3) (H1, H3, H4)
Peak hip moment (Nm)	415	25	450	23	435	25	426	23	1.04	0.388	
Peak knee moment (Nm)	533	17	564	20	581	22	550	25	1.79	0.168	
Peak ankle moment (Nm)	406	15	438	16	395	15	359	17	6.17	0.002	(H1,H2,H3) (H1,H3,H4)

Note. H1 = drop height of 15 cm, H2 = drop height of 30 cm, H3 = drop height of 45 cm, H4 = drop height of 60 cm; M = mean; SE = the standard error of the mean.

Table 2. 3. Variables during the push-off phase for each approach level

	0s		1s		2s		3s		F (3,33)	P value	Homogenous Group
	M	SE	M	SE	M	SE	M	SE			
Summed peak Power (W)	5868	188	6363	190	6493	183	6579	198	12.72	<0.001	(0s) (1s, 2s, 3s)
Peak hip Power (W)	1438	121	1405	104	1356	112	1465	126	0.35	0.791	
Peak knee Power (W)	2705	106	3032	95	3340	125	3292	130	11.58	<0.001	(0s, 1s) (1s, 2s, 3s)
Peak ankle Power (W)	2214	78	2304	94	2266	86	2358	119	0.77	0.517	
Peak hip moment (Nm)	444	25	445	24	424	22	414	26	1.41	0.261	
Peak knee moment (Nm)	501	18	547	19	595	22	585	24	13.76	<0.001	(0s) (1s, 3s) (2s, 4s)
Peak ankle moment(Nm)	386	16	402	17	397	15	414	18	0.88	0.462	

Note. 0s= drop jump without an approach, 1s= drop jump with one approach step, 2s= drop jump with two approach steps, 3s= drop jump with three approach steps; M = mean; SE = the standard error of the mean.

Table 2.4. Joint angle at the start of the push-off phase for each drop height

	H1		H2		H3		H4		F (3,33)	P value	Homogenous Group
	M	SE	M	SE	M	SE	M	SE			
Hip angle (deg)	42	2.7	41	2.8	43	2.9	47	4	1.02	0.395	
Knee angle (deg)	61	2	61	1.7	64	2	65	1.7	2.58	0.07	
Ankle angle (deg)	25	0.97	26	1.03	27	1.03	28	0.97	4.01	0.016	(H1, H2, H3) (H2, H3, H4)

Note. Joint angles were defined as zero when subjects were standing.

Table 2.5. Joint angle at the start of the push-off phase for each approach level

	0s		1s		2s		3s		F (3,33)	P value	Homogenous Group
	M	SE	M	SE	M	SE	M	SE			
Hip angle (deg)	48	4	46	3.4	41	2.9	38	2.8	6.77	0.001	(0s, 1s) (1s, 2s) (2s, 3s)
Knee angle (deg)	66	2	64	2	61	1.9	59	2	8.73	<0.001	(0s, 1s) (1s, 2s) (2s, 3s)
Ankle angle (deg)	29	0.6	27	0.6	25	1	24	1.1	8.79	<0.001	(0s, 1s) (1s, 2s, 3s)

Table 2.6 Variables during the downward phase for each drop height

	H1		H2		H3		H4		F (3,33)	P value	Homogenous Group
	M	SE	M	SE	M	SE	M	SE			
Peak Hip ω (deg/s)	-103	21	120	26	229	103	292	103	0.57	0.639	
Peak knee ω (deg/s)	-338	20	-411	14	-477	11	-451	11	26.71	<0.001	(H1) (H2, H3) (H3, H4)
Peak ankle ω (deg/s)	-270	15	-359	18	-407	13	-440	11	54.52	<0.001	(H1) (H2) (H3, H4)
Hip flexion (deg)	17	2	18	2	18	4	24	4.3	1.27	0.301	
knee flexion (deg)	37	2.3	40	1.7	45	1.7	50	1.7	11.28	<0.001	(H1, H2) (H2, H3) (H3, H4)
Dorsiflexion (deg)	32	3.4	35	1.4	40	1.1	42	1	5.74	0.003	(H1, H2, H3) (H2, H3, H4)
Downward duration (s)	0.17	0.01	0.16	0.01	0.17	0.01	0.17	0.007	0.12	0.951	
PFz (N)	3435	113	3967	153	4084	149	4548	169	16.61	<0.001	

Note. PFz = Peak value of the vertical ground reaction force

Table 2.7 Variables during the downward phase for each approach level

	0s		1s		2s		3s		F (3, 33)	P value	Homogenous Group
	M	SE	M	SE	M	SE	M	SE			
Peak Hip ω (deg/s)	-183	25	-244	105	-116	27	-208	103	1.25	0.308	
Peak knee ω (deg/s)	-409	20	-416	17	-416	16	-435	16	1.68	0.191	
Peak ankle ω (deg/s)	-336	17.5	-361	18.5	-383	17.4	-395	15.4	6.25	0.002	(0s, 1s) (1s, 2s, 3s)
Hip flexion (deg)	23	2.8	21	4	15	1.7	18	3.4	1.12	0.355	
knee flexion (deg)	46	2.6	44	2.1	41	2.1	41	2.2	4.66	0.008	(0s, 1s) (1s, 2s, 3s)
Dorsiflexion (deg)	36	1.5	36	1.6	37	1.6	40	3.4	0.96	0.423	
Downward duration (s)	0.18	0.01	0.17	0.006	0.16	0.005	0.15	0.01	5.62	0.003	(0s,1s,2s) (2s, 3s)
PFz (N)	3518	134	4014	158	4225	163	4278	153	8.83	<0.001	(0s) (1s, 2s, 3s)

Linearly, but no significant differences were found between any adjacent approach conditions. Compared with standing drop jumps, a 3-step approach decreased significantly all three joints angles (hip: 21%, knee: 11%, and ankle: 17%).

Main Factors in the Downward Phase (Table 6 and Table 7)

The downward movement phase was attributable to the hip, knee, and ankle flexion (dorsiflexion) motions during landing. During the landing phase peak knee flexion velocity presented a quadratic pattern across drop height while peak ankle flexion velocity (63%), dorsiflexion (31%), knee flexion (35%) and peak vertical force (32%) all tended to increase linearly.

With an approach ankle flexion velocity (9%) and vertical force (22%) showed increases while knee flexion (11%) and downward duration (17%) decreased. Increasing drop height resulted in a greater knee flexion and dorsiflexion. However, increasing approach steps resulted in smaller knee flexion and reduced downward duration time.

Discussion

The most important observation of this study was that the peak summed power during the push-off phase increased with approach across all tested drop heights and exceeded the ceiling effect of power output with increasing drop height. The most significant influence of the approach was observed between zero and the one step approach, although power output increased further with more approach steps. The effect of approach on the peak summed power output was accompanied by the increase of the peak knee power. Although there was no observed interaction between the effects of the number of approach steps and the drop height, it should be noted that the highest summed power produced in the drop jump from the drop height of 30 cm with a three-step approach was approximately 20% greater than the highest summed power produced in the standing drop jump from the drop height of 45 cm. The results supported our hypothesis that the drop jump with an approach increased the power output of lower extremity.

The present results agree with the data reported in the literature. For standing drop jumps, Bobbert et al. (1987) reported the peak ankle power significantly decreased from 2.3 kW to 2.1 kW when drop height increased from 40 cm to 60 cm. In comparison, our results showed the peak ankle power observed in standing drop jumps significantly decreased from 2.3 ±0.7 kW to 1.9 ± 0.6 kW, when the drop height increased from 45 cm to 60 cm. The optimal drop height for standing drop jump found in the present study, 45 cm, was very close to 40 cm reported by Bobbert et al. (1987), but was lower than 62 cm reported by Komi and Bosco (1978). This difference may be due to different recruitment of participants. The participants in their study were male physical education students and male volleyball players, who should have a better jump ability than male students recruited from a physical activity class in this study.

The present results also provided possible explanations for the finding that the peak power output increased with the drop height before reaching the optimal height but decreased with the drop height beyond the optimal height. The increased muscle power output associated with the drop height may be due to an increased angular velocity of dorsiflexion in the downward phase. The increased stretch speed may enhance the stretch reflex, storage and reutilization of elastic energy, and the potentiation of the contractile machinery (M.F. Bobbert, P.A. Huijing et al., 1987b; Bosco et al., 1981; K.A. Edman et al., 1978; Kallio et al., 2004). Therefore, it was not surprising to find an increased ankle power and an increased summed power in the push-off phase with the drop height (below the optimal height). On the other hand, a further increase in drop height above the optimal height would not increase or even decrease the mechanical output, which may be explained by a large dorsiflexion that occurred in the downward phase when the drop height increased above the optimal drop height. The relationship between large stretch in the downward phase and small mechanical output during the push-off phase may be related to the concept of "short range stiffness" (Rack & Westbury, 1974). Short range stiffness means that the muscle performs like a spring when the length change during stretch is very short. With the drop height beyond the optimal height, ankle plantar flexors would have been overstretched, and therefore, the muscles power output decreased due to the possible reduced effect of short range stiffness (Bosco & Komi, 1979).

An interesting finding of this study was that drop jumps with an approach exceeded the ceiling effect of power output associated with increasing drop height. In contrast to the effects of increasing drop height, increasing the number of approach steps did not result in a greater downward movement due to reduced downward duration time. Actually the increased approach steps decreased the downward movement, the knee joint angle and ankle joint angle at the start of the push-off phase. With an approach, participants could benefit from the effect of short range stiffness and shorter time delay between the eccentric contraction and push-off phase. Consequently, with an approach, a greater power output was produced, which even exceeded the power output produced during the drop jump from the optimal drop height.

The possible explanation for smaller downward movement and shorter delay time associated with an approach may be due to muscle preactivation. Kyröläinen and Komi (1995) reported a faster rate of EMG development during the preactivation phase resulted in a more effective braking phase, and successive high activation during the braking phase resulted in a good performance. There may be two reasons for this: first, with a higher activation level in the preactivation phase, it takes less time for muscle activation and force to reach their maximum, and therefore the force level in the entire eccentric phase increased; second, an activated muscular system is a necessary condition for a high stretch reflex (Komi & Gollhofer, 1997). Combined with the present results, it can be speculated that the approach increased the activation level of leg muscles in the preactivation phase. With higher muscle activation level and correspondingly higher force in the eccentric phase, higher leg stiffness, and a greater stretch reflex, the leg extensor muscles could finish eccentric contraction in a smaller range and shorter duration time (see Figure 4 for schematic representation). It is suggested that future studies should investigate muscular activity during the drop jump with an approach.

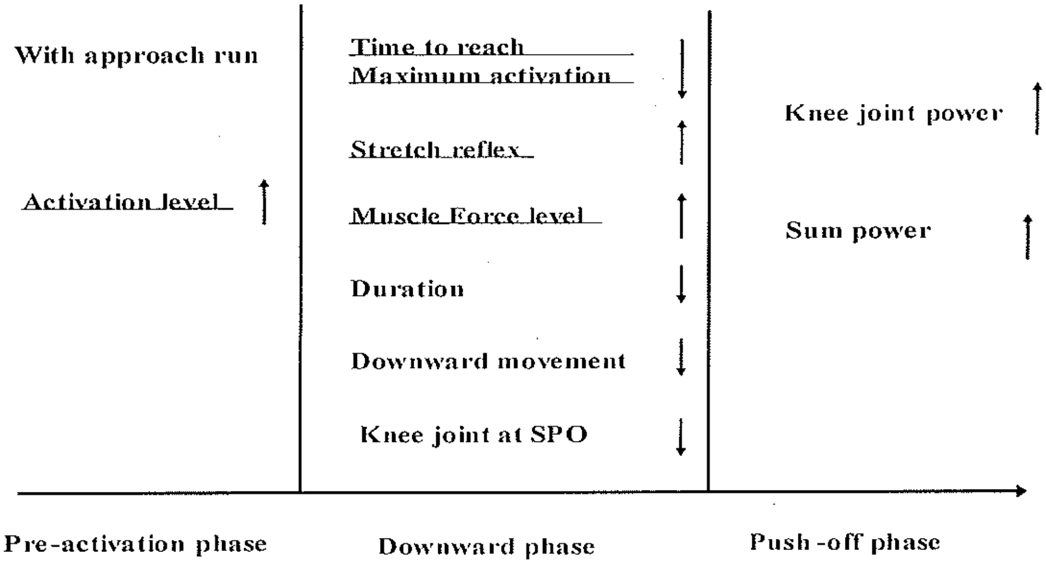

Figure 2.4. Schematic representation of the suggested effects of the approach on drop jump (see the text for details). The underline indicates hypothesis. The up arrow indicates increase. The down arrow indicates decrease. (SPO – start of the push off phase).

One potential confounding factor is the horizontal speed before take off. We controlled the approach step lengths and minimized the difference in the horizontal speeds among participants, but we did not measure the horizontal approach speeds. Also, we estimated that the approach speed increased with more approach steps, but we did not know how much speed increased with more approach steps. Although this will not alter the fact that approach increases mechanical output of drop jump, we can not determine quantitatively the relationship between the approach speed and muscle power out during drop jump. This also needs to be examined in the future.

In designing a training exercise, the views and comments of experienced training experts should not be neglected. Verhoshanski (1967), who introduced the performance of drop jumps as a training exercise, identified the different performance characteristics in drop jump between masters and beginning sportsmen. The masters had less flexion of the leg and more quickly switch muscle from eccentric to concentric than the beginners. Verhoshanski (1967) suggested this was because the reactive ability of the nerve-muscle apparatus in the masters was higher and their muscles had the ability to fulfill effective work of an explosive exercise. The masters' characteristics identified by Verhoshanski (1967) were consistent with those in drop jumps with an approach observed in this study. Verhoshanski (1967) also pointed out that athletes who wanted to raise the effectiveness of their training by using a higher drop height could not succeed because further rising of the height for drop jump materially changed the take-off mechanism. In other words, the exercises lose their meaning. Combining this view and the results of this study, it may be concluded that adding an approach preceding the drop jump can offer a better alternative to raising the drop height for further increasing power output. However, the effects of an approach need to be tested in the long-term training studies.

Besides its efficacy and efficiency, the safety of the training exercise is another important aspect to be considered. There were no reports from previous drop jump studies indicating serious injuries (Bobbert & van Ingen Schenau, 1990). Compared to standing drop jumps from the same drop height, the drop jump with an approach may be associated with less knee flexion, less dorsiflexion, and greater impact. Therefore, there may be an increased potential for injuries. However, the drop jump with an approach could produce greater power output from a lower drop height, which might have reduced the impact force. Another difference between drop jump with and without an approach may be the muscles preactivation levels. One study (Baratta et al., 1988) report that decreased balance in strength and recruitment of the flexor relative to the extensor musculature may put the ACL at a greater risk of injury. It is suggested that the approach may increase the activation level of leg extensor in the preactivation phase and this could cause agonist-antagonist imbalance. However, Kyröläinen, Komi and Belli (1999) reported that the coactivity of agonist and antagonist muscles (vastus lateralis vs. biceps femoris) just before and after touchdown increased with running speed. Therefore, the approach prior to drop jump may not decrease balance in strength and recruitment of the flexor relative to the extensor. A comprehensive injury risk investigation on the drop jump with an approach is needed. Some safety precautions also need to be addressed. First, it is necessary for coaches and athletes to increase the drop height and the approach speed gradually. Second, a gymnastic mat and shock-absorbing shoes can be used for absorbing the impact of landing (Bobbert & van Ingen Schenau, 1990).

In summary, drop jump with an approach produced a greater power output which even exceeded the ceiling effect of increasing drop height. The greater power output may be due to the greater "short range stiffness" that is associated with smaller downward movement observed in the drop jump with an approach. It is suggested that drop jumps with an additional approach may be a better training method than the standing drop jumps for explosive exercises.

Chapter 3: Effects of Drop Height and Approach on Muscle Activity during Drop Jumps

Introduction

Drop jump, as one of the most popular plyometric exercise that involves stretch shortening cycle, has been proved very effective to improve vertical jump performance due to greater lower extremity power output. The underlying principle of this improvement is that muscles can contract rapidly and produce more power after it has been pre-stretched quickly. The explanations for this enhancement are not very convincing in the literature (Bobbert, 1990; Komi, 2000; van Ingen Schenau et al., 1997a, 1997b). Knowledge of muscle activity during drop jumps is essential for understanding mechanical output enhancement mechanisms during SSC.

Studies (Bobbert, Huijing, & Ingen Schenau, 1987a; Komi & Bosco, 1978) have showed the presence of an optimal stretch load (drop height) to maximize the power output, implying that the stretch load plays an important role in mechanical output during the SSC. However, the effects of stretch load (drop height) on muscle activity are still not very clear. Bobbert et al. (M.F. Bobbert, P.A. Huijing et al., 1987b) reported that while the moments and power outputs about knee and ankle joints reached greater values with a greater stretch load, the EMGs of rectus femoris (RF), gastrocnemius (GA), vastus medialis (VM) and soleus (SO) were not very helpful in explaining the difference in mechanical output because the increased stretch load did not cause a large difference in the activation levels of muscles in both eccentric and concentric phase. Hakkinen et al. (Hakkinen, Komi, & Kauhanen, 1986) also reported that no significant differences were observed in the integrated EMG of vastus lateralis (VL) and VM for the eccentric and concentric phases when drop height increased from 20cm to 80cm. However, Takarada et al. (Takarada, Hirano, Ishige, & Ishii, 1997) reported that aEMG of biceps femoris (BF) and GA increased with the eccentric force. Interestingly, while Gollhofer and Kyrolainen (Gollhofer & Kyrolainen, 1991) reported that EMG of GA, SO, and VM demonstrated similarities or small variations for the preactivation phase (100 ms or 50 ms before touchdown)with the extra load, Aura and Komi (Aura & Komi, 1986) reported that aEMG of VL, VM, and GA increased for both preactivation phase and eccentric phase when the stretch load was increased. Therefore, more studies are needed to clarify the relations between stretch loads and muscle activity.

Besides increasing drop height (below than optimal drop height), studies also found the approach run preceding jump can improve vertical jump performance (Saunders, 1980). Our previous study has showed the approach run preceding the drop jump could increase the power output further and even exceeded the limitation of power output associated with increasing the drop height. The main reason is that approach run could decrease downward duration time and downward movement. A shorter downward duration time and smaller downward movement could benefit from the short range stiffness and the stretch reflex (Komi, 2000). However, the muscular activities associated with these changes were not clear.

Because the pre-activation level is a important factor that can significantly influence SSC performance and it appeared to increase with more approach steps (Kakihana & Suzuki, 2001) or greater running speed (Kyrolainen et al., 1999), we hypothesized that the approach run preceding the drop jump increased the activation level of leg extensor muscles in the preactivation phase. Correspondingly increased muscle activation and tension level in the eccentric and concentric phase, therefore, the leg extensor muscles could finish eccentric contraction in a smaller range and shorter duration time. In this study, we examed this hypothesis. Also, if the preactivation of muscle increased during drop jumps with approach run, the stretch reflex may play an important role in enhancing muscle power output due to increased sensitivity of muscle spindles. Thus, we would like to exam the possible connect between muscle pre-activation and muscle activity during eccentric phase and concentric phase.

On the other hand, the coactivity of the agonist and antagonist is necessary to maintain joint stability (Baratta et al., 1988). If the muscle activity of leg extensors in the preactivation phase increases and the leg flexors' EMG do not increase, the reduced coactivity of leg extensors and flexors may put athletes in a position where they are at higher risk of an ACL injury because of muscular imbalance. Therefore, we also examed the coactivation ratio of the agonist and antagonist under different drop heights and different approach levels.

The purpose of this study was to investigate the effects of approach run and drop height on the muscle activity of low extremity muscles during drop jumps. EMG of major leg muscles during preactivation, eccentric, and concentric phases were examined under combinations of different drop heights and approach steps. It was expected that the results would help us better understand the enhancement mechanisms and influence of stretch reflex in SSCs.

Methods

Participants

Ten physically active male university students (age: 23 ± 3; height: 1.79 ± 0.1; body mass: 75 ± 5) were recruited for this study. Prior to participation, procedures were described to the participant and all questions were addressed. Each participant signed a written consent form as approved by the Institutional Review Board.

Protocol

Participants had a one-week drop jump training for familiarization. Training involved three sessions during which combinations of drop jumps with and without approach run at different drop heights were performed. In the first session, participants performed the vertical jump (countermovement jump) 16 times. In the second session, participants performed four drop jumps from drop height of 15 cm for each of four approach conditions (zero, one, two, and three steps), totally 16 trials. In the third session, participants also performed four drop jumps from drop height 45 cm for each of four different approach conditions (zero, one, two, and three steps), totally 16 trials. Participants were instructed to follow four performance requirements: 1) the approach speeds should be moderate and step lengths should be consistent for each condition; 2) participants should step off the raised platform instead of jump up (no potential drop height was added when participants performed drop jumps with approach runs); 3) participants should step off the raised platform with their right foot, but they use both feet landing simultaneously; and 4) participants should perform each jump with their maximal effort. These performance requirements were also applied during data collection.

Prior to data collection, participants had approximately 12 minutes warm up, including 8 minutes running on a treadmill and 4 minutes jump exercises (one standing drop jump and one drop jump with two approach steps from drop height of 15 and 30cm.). After warm up, surface electromyography (SEMG) electrodes were placed on the surfaces of Gluteus Maximus (GM), Rectus Femoris (RF), Biceps Femoris (BF), Vastus Lateralis (VL), Tibialis Anterior (TA), Gastrocnemius (GA) and Soleus (SO) of subject's left leg. The electrodes were placed longitudinally over the muscle belly with an interelectrode distance of

2 cm. The distances between the electrode pairs were at least 3 cm. Therefore, the distance between the electrode pairs has been assumed to cause no significant influence on surface EMG patterns and the degree of cross-talk should be very small and no significant(D. Winter, Fuglevand, & SE, 1994). Additionally, three reflective markers placed on the left leg of the participant at hip, knee, and ankle joint. Figure 1 shows a schematic presentation of the instrumentation and the jump platform used in the study. To minimize the difference of approach speed and step lengths among participants and different drop heights, the initial positions for zero, one, two and three steps were set on the surface of the jump platform. Participants performed drop jumps from four different heights: 15, 30, 45, and 60 cm. The order of drop heights was randomized across the participants. From each drop height, the participants performed one trial for each of four different approach conditions (zero, one, two, and three steps) in a random order. In all, participants performed 16 trials. Every trial was monitored visually and self-evaluated by the participants. Participants would have to repeat the trial if any performance requirements were not fulfilled or they thought that was not a maximal effort.

Data Recording

A camera of Motion Analysis system (Motion Analysis Corporation, Santa Rosa, Ca) was used to collect the movement trajectories of each marker at 60 Hz. A force platform (Advanced Mechanical Technology Inc, Watertown, MA) was used to record the ground reaction forces at 1200 Hz. The surface EMG activity of the Gluteus Maximus (GM), Rectus Femoris (RF), Biceps Femoris (BF), Vastus Lateralis (VL), Tibialis Anterior (TA), Gastrocnemius (GA), and Soleus (SO) were recorded using surface bipolar electrodes (Ag-AgCl, 1 cm diameter, MA-310, Motionlab Systems, Baton Rouge, USA). The EMG signals were amplified with an adjustable gain of up to 20,000 with a common mode rejection ratio (CMRR) of 100 db and band pass filter for frequencies in the range of 20-500 Hz (MA-300 EMG System, Motionlab Systems, Baton Rouge, USA). Kinematic, EMG, and ground reaction force data were collected simultaneously with internal synchronization. The EMG signal was digitized at a sampling rate of 1200Hz. Each muscle's EMG activity was full-wave rectified and normalized as a percentage of the highest value recorded during the 16 trails of drop jumps. The EMGs were then averaged (aEMG) in the pre-activation (50ms before touchdown), downward (from touchdown to knee reach the lowest point) and pushoff (from the lowest knee point to take off) phases.

The onset and offser of the ground reaction force was used as a reference point to identify the beginning and the end of contact. The instant of lowest knee vertical position during the drop jump was used to divide the jump into downward (from the instant of touch down to the instant of lowest knee vertical position) and push-off phases (from the instant of lowest knee vertical position to the instant of toe-off).

Data Analysis

Position data were smoothed with a fourth order Butterworth, zero-lag digital filter (cut off frequency 6 Hz). The antagonist-agonist coactivation ratio was calculated by the normalized BF aEMG divided by the average of RF and VL aEMG. The antagonist-agonist coactivation ratio was calculated by the normalized BF aEMG divided by the average of RF and VL aEMG. Ratio data were log transformed to insure normality.

A 4 (drop heights) × 4 (approach steps) factorial ANOVA with repeated measures was performed to determine any significant effects and interactions of drop height and the number of approach steps. Post hoc means comparisons were performed using Tukey's test ($\alpha=0.05$).

Results

Figure 3.1 shows one subject time histories of the EMG of all examined muscles for standing drop jump and drop jump with 3-step approach at drop height of 30 cm. The curves are similar to those of the other subjects. No significant changes took place in the aEMGs of BF, GM, RF, SO and VL under different drop heights in the preactivation, downward and pushoff phases (table3.1). GA is the only muscle to show increased muscle activity from 39.8% (drop height: 15 cm) to 68.9% (drop height: 60cm)) with increasing drop height during the preactivation phase. The aEMG of TA during the preactivation also influenced by the drop height, but it decreased with greater drop heights. All examined muscles except TA showed significant increases in the aEMG during the preactivation phase with approach steps. Compared to standing drop jumps, 3-step approach increased muscle activity of knee extensors during preactivition as much as 20% (VL) or 28% (RF). The muscle activity of GM and BF also increased as much as 25% or 20% during preactivation with a 3-step approach. However, muscle activities of planter flexors SO and GA during the preactivation increased no more than 15% when approach steps preceded the drop jumps. During the downward phase, only four muscles showed significant increases in the aEMG and the magnitude of increase was less than that of the preactivation phase. During the pushoff phase, no significantly increased muscle activity was observed for all examined muscles between (Figure 2). No interactions were found between the number of approach steps and drop heights for all examined muscles during any phase.

Although the muscle activities of VL and RF increased significantly with more approach steps, the knee joint antagonist-agonist coactivation ratio remained unaltered with different approach steps during the preactivation and downward phases (Figure 4). The reason is that the aEMG of BF increased with the steps of approach run significantly from 36.3 to 56.6 (0 to 3 steps) during the preactivation phase and from 53.7 to 69.5 (0 to 3 steps) during the downward phase across all the drop heights. The antagonist-agonist coactivation ratio increased with approach significantly ($p < 0.001$) during the pushoff phase because the muscle activity of BF remained high but the muscle activities of VL and RF reduced slightly.

Table 3.1 Statistics results for aEMG among different steps and drop height conditions.
F(3,27)

			BF	GA	GM	RF	SO	TA	VL
pre50	Height	F	0.200	12.540	2.28	1.57	2.41	5.230	1.79
		P	0.895	<0.001	0.102	0.220	0.089	0.006	0.173
	Steps	F	5.000	3.850	9.750	11.730	5.050	1.96	4.240
		P	0.007	0.020	<0.001	<0.001	0.007	0.144	0.014
downward	Height	F	1.24	1.47	1.8	0.42	5.210	1.82	0.76
		P	0.315	0.246	0.170	0.741	0.006	0.168	0.528
	Steps	F	3.690	1.9	1.97	3.850	4.22	0.09	5.1
		P	0.024	0.153	0.142	0.021	0.014	0.966	0.006
pushoff	Height	F	1.78	2.06	1.08	0.43	1.27	1.27	0.01
		P	0.174	0.129	0.374	0.735	0.304	0.305	0.998
	Steps	F	0.04	1.13	2.78	8.490	0.37	1.3	1.72
		P	0.990	0.356	0.061	<0.001	0.775	0.293	0.186

Discussion

This study examined the influence of approach and drop height on the muscle activity level during the preactivation, downward, and pushoff phase of drop jumps. The main findings were as follows: 1) Approach runs increased muscle preactivation level of all tested muscles but TA; 2) increasing drop height could not enhance the preactivation level of all examined muscles but GA; 3) Although approach runs increased joint power outputs during the pushoff phase, no significantly increased muscle activities were observed; and 4) Approach run did not reduce the knee joint antagonist-agonist coactivation ratio during drop jumps. The most important finding is that the approach run preceding drop jumps increased

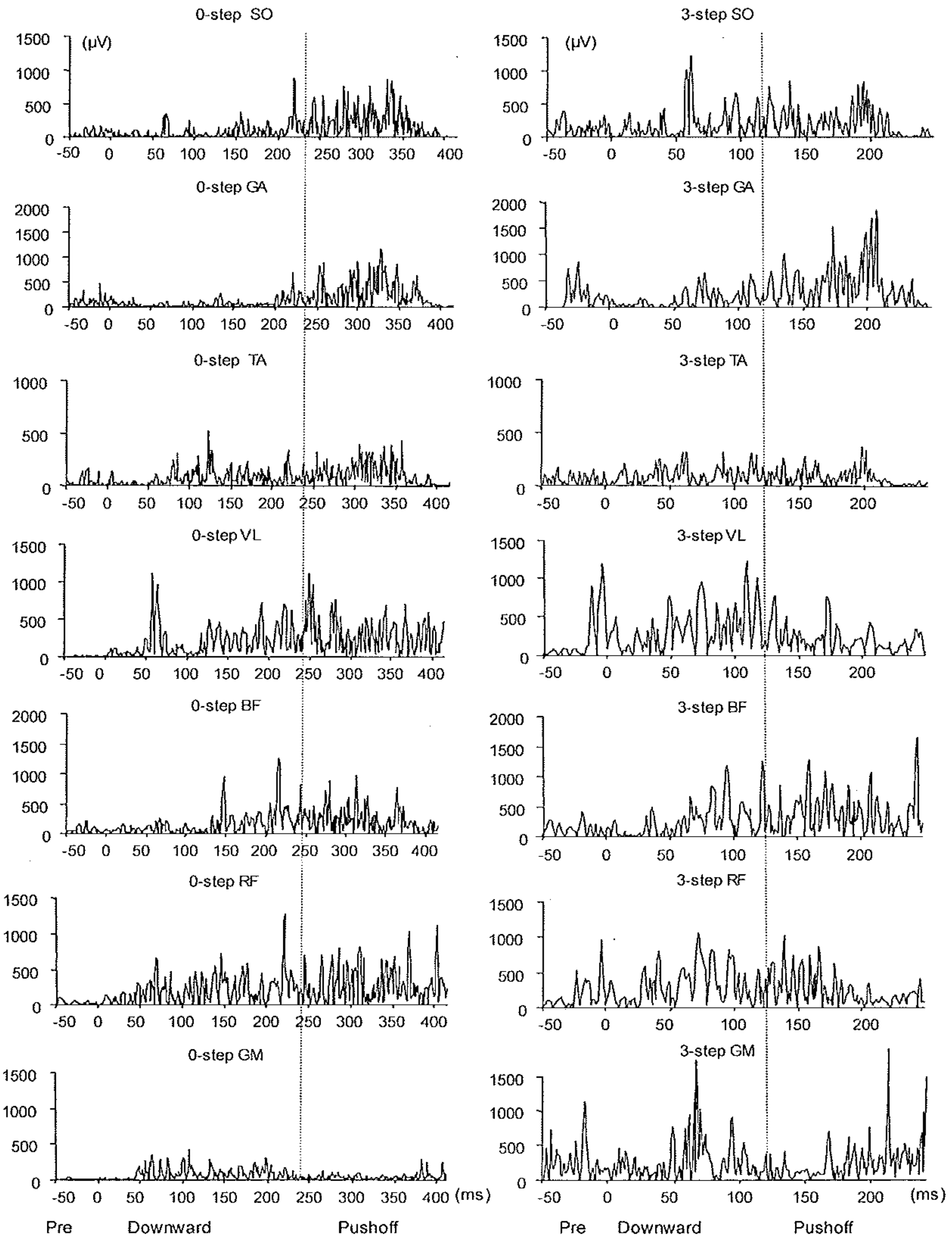

Figure 3.1 Exemplar of rectified EMG records from a subject at the drop height of 30cm with 3 approach steps and without approach step. The dish line indicates the start of the push-off phase during the drop jump.

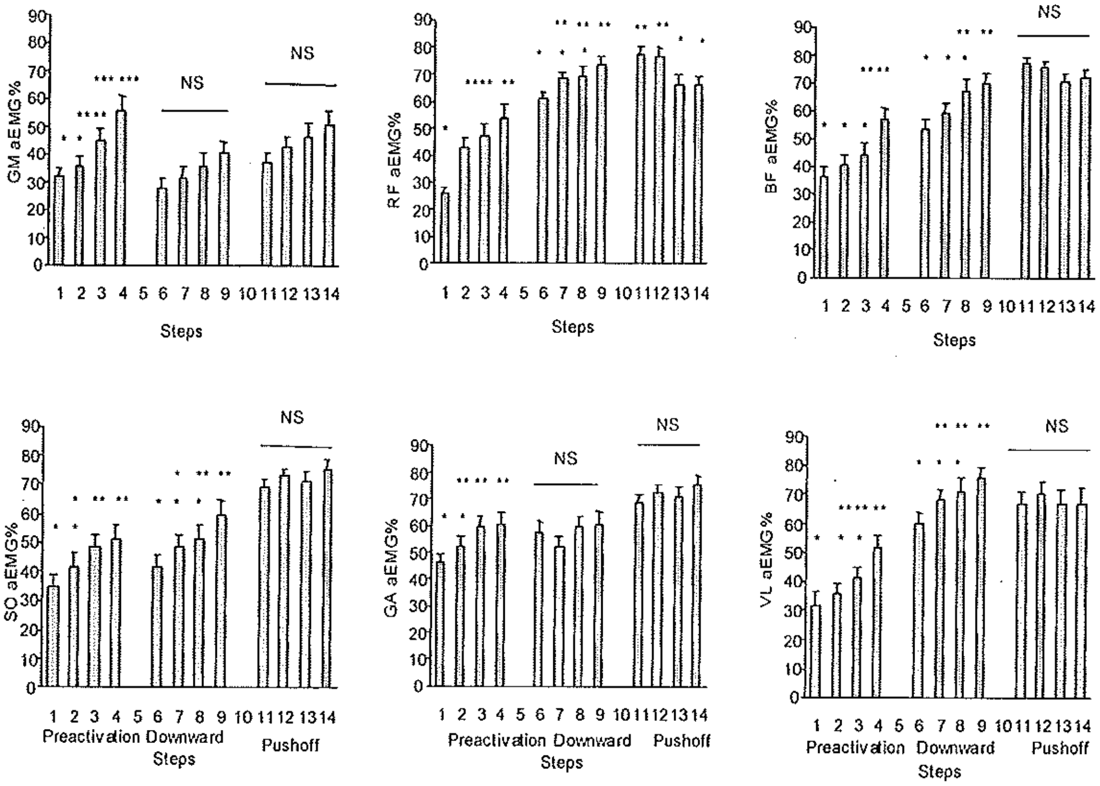

Figure 3.2 Changes in aEMG associated with changes in approach steps.

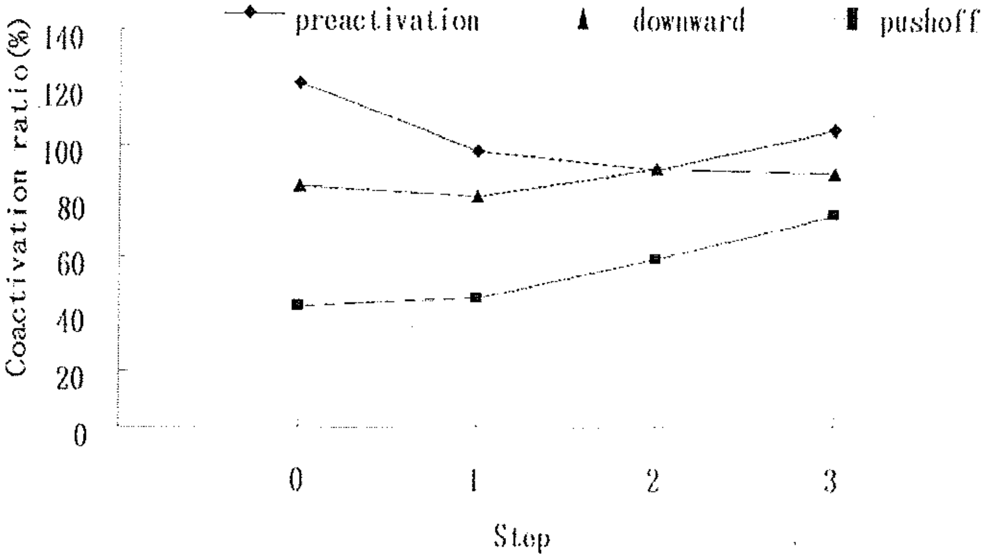

Figure 3.3 Changes in Coactivation ratio associated with changes in approach steps.

the preactivation level during the drop jump. The results supported the hypothesis that the approach run preceding the drop jump increased the activation level of leg extensor muscles in the preactivation phase and correspondingly increased muscle activation and tension level in the eccentric phase, therefore, the leg extensor muscles could finish eccentric contraction in a smaller range and shorter duration time. The changes of muscle activities associated with approach run observed in the present study are consistent with studies on running (Kyrolainen et al., 2005; Kyrolainen et al., 2003) and long jump (Kakihana & Suzuki, 2001; Kyrolainen et al., 2003).

The preactivation is interpreted as a preprogrammed neuronal activation part, which has important functions (Dietz, Schmidtbleicher, & Noth, 1978 ; Gollhofer & Kyrolainen, 1991). First of all, it creates a beneficial situation for muscles to develop maximum force in a short time. For slow movements, it takes about 300 ms to develop the highest force (Ingen Schenau G.J.van., Bobbert M.F., & A., 1997b). However, in fast SSCs, such as drop jumps, the muscles reach the maximum value in less than 100 ms. When muscles are strongly preactivated before landing, the process of stimulation dynamics and excitation dynamics may happen before landing (Ingen Schenau G.J.van. et al., 1997b). Therefore, the force could develop very fast after landing. Another function of preactivation is to increase sensitivity of muscle spindles to enhance stretch reflexes (Gottlieb et al., 1981), which subsequently increases tendomuscular stiffness (Komi, 2000) and enhances force production (Kyrolainen et al., 2005). Kyrolainen et al. (Kyrolainen et al., 2005) reported that at higher speeds, the aEMG activities of the gastrocnemius, vastus lateralis, biceps femoris and gluteus maximus exceeded 100% MVC. This result provided evidence to support that the increased preactivation level enhances the functional role of stretch reflexes. Recently, Linnamo et al. (Linnamo et al., 2006) reported that the force potentiation is related to preactivation levels. Results showed that the force potentiation was greater at higher stretching velocities but only when maximal preactivation preceded the stretch. At lower preactivation levels the velocity dependence was not observed (Linnamo et al., 2006). There functions of preactivation may have contributed to greater muscle mechanical output during drop jumps when an approach was used.

Although approach increased muscle power output during push off phase, no significantly increased muscle activities in this phase were observed. This phenomenon may be due to increased EMG activity in the eccentric phase. Studies (van Ingen Schenau et al., 1997b), (Vos, Harlaar, & Ingen Schenau, 1991) have showed that the delay at which the highest correlation between EMG and force existed was 90 ms -100 ms. The EMG activity during the eccentric phase is controlled partly by the preactivation process, but also by the refectory loops during the eccentric phase (Hulliger & Vallbo, 1979; Nichols & Houk, 1976). The activation of the Ia-afferents from the muscle spindle as a consequence of stretch is the main factor in the reflex control of the EMG activity during the eccentric muscle contraction. The increase in EMG during downward phase must mean that relatively more activation takes place during the eccentric phase implying that more attached cross bridges will be stretched, which can improve muscle stiffness and consequently its recoil capacity (Hoffer & Andreassen, 1981; Nichols & Houk, 1976). Therefore, greater power output could be produced without greater activation level during pushoff phase due to greater activation level in preactivation and eccentric phase. However, like GM and GA, greater preactivation does not necessarily result in great activation level in eccentric phase. The possible reason is that no stretch reflexes occured in these two muscles. Our previous study showed that the hip joint did not yield during the downward phase. Kuroawa et al. (2003) reported that the muscle fibers of the GM were not stretched during downward movement. Even without greater activation level in eccentric phase, greater preactivation may have created a favorable condition for muscles to exert eccentric contraction.

There are some disagreements in the literature about the effects of stretch load on muscle activity. However, the present results are in agreement with findings from the studies (M.F. Bobbert, P.A. Huijing et al., 1987b; Gollhofer & Kyrolainen, 1991; Hakkinen et al., 1986) in which drop jumps were performed. In contrast, other studies (Aura & Komi, 1986; Ishikawa & Komi, 2004) reported that the muscle activity in preactivation and eccentric phases increased with stretch load, but sledge jumps rather than drop jumps were used in these studies. Although muscles involved in SSC in both sledge jumps and drop jumps, the amount of muscle activity in sledge jumps differed clearly with that in drop jumps and the preactivation correlated even negatively with the take off velocity (Kyrolainen & Komi, 1995). The similarity of muscle activities among different drop heights emphasizes that enhancement of muscle performance associated with drop height was attribute primarily to reutilization of elastic energy rather than increased muscle activities. However, the results presented in this study cannot deny that stretch reflexes do not occur in SSC exercises such as drop jump. The short latency stretch reflex component (SLC) occurred in drop jumps has been observed in studies (Gollhofer, Strojnik, Rapp, & Schweizer, 1992; Komi & Gollhofer, 1997). Increasing drop height may increase the stretch velocity and then facilitate the stretch reflex because the effect of stretch reflex is increased with stretching velocity (Kallio et al., 2004). However, the differences in stretch velocity associated with drop heights in this study may not be great enough to affect the amount of stretch reflexes. Another possible reason for no difference in muscle activity is inhibition. At the greater drop height, inhibitory may be increased and functionally serve as a protection strategy to prevent muscle and tendon injury (Komi & Gollhofer, 1997). This inhibitory effect may offset the facilitation associated with increased stretch velocity. Also, different muscles and different subjects may respond differently to the change of stretch load. In agreement with the present results, Kyrolainen and Komi (Kyrolainen & Komi, 1995) also reported that the GA behaved in a manner different from the other examined muscles during drop jumps. They also reported (Kyrolainen & Komi, 1995) that while the power-trained athletes demonstrated higher EMG in the optimal drop height condition, the endurance-trained athletes showed no different EMG in the optimal condition. The current results also demonstrated that not all muscles EMGs have clear bursts. Therefore, in general, greater drop height does not increase muscle activity.

For the safety issue, it is a good strategy to maintain the antagonist-agonist coactivation ratio because coactivation increases the stability of a joint and the antagonist-generated torques are not greater than 10% of the maximal extension torque (Baratta et al., 1988). The current results showed that drop jumps with approach run did not change knee joint antagonist-agonist coactivation ratio. While the approach run induced a greater power output in drop jumps, it also increased the muscular activity of hamstrings. Combined with our previous studies, the results indicate that approach run can increase lower extremity power out put without reducing the antagonist- agonist coactivation ratio. Approach run can be employed to improve performance without sacrificing injury prevention.

In summary, muscle preactivation in the stretch-shortening cycle is extremely important for lower extremity muscle activities in eccentric phase and finally contributes to greater power output during concentric contraction phases. An approach run preceding the drop jump is an effective and safe strategy to increase muscles preactivation level, as it does not change knee joint antagonist-agonist coactivation ratio.