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ORIGINAL ARTICLE

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Neuromuscular functioning of athletes and non-athletes in the drop jump

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Abstract In many sports vertical jumping is important. This study compared neuromuscular functioning of the lower extremity muscles together with some kinetic and kinematic parameters before and during ground contact in drop jumps from two heights [0.4 m (DJ40) and 0.8 m (DJ80)] in 7 highly trained triple-jumpers and 11 physically active controls. The triple-jumpers jumped 32% higher in DJ40 and 34% higher in DJ80, had shorter braking and total contact times, and greater average and peak vertical ground reaction forces than the controls. In both drop jumps in the electromyogram pre-activity of the vastus lateralis and gastrocnemius muscles started earlier in the jumpers than in the controls. For the control group the increase in dropping height was associated with a decrease in the propulsion force, and resulted in more extended knee and ankle angles at touch down and more flexed angles at the deepest position than for the jumpers. All angular displacements for DJ80 were larger than for DJ40 in the control group. The triple jumpers and control subjects differed with respect to their neuromuscular functioning in the drop jump exercise and they responded in a different way to the increase in dropping height.

Key words Jumping · Stretch load · Stretch speed · Specificity · training history

Introduction

In many sports, including ball games, track and field and ski jumping, vertical jumps, especially plyometric drills have been shown to play an essential role in increasing the explosive power of the lower extremities (Verhoshanski 1966). Among plyometric drills, which have also been known as stretch-shortening cycle drills (Steben and Steben 1981), drop jumping or depth jumping have been widely used (Wilt 1978). Executing a drop jump involves jumping down from a height and, upon landing, performing a maximal vertical jump. The lower extremity muscles perform a stretch-shortening cycle (SSC), during which it has been found the eccentric stretching phase influences the subsequent concentric shortening phase (Cavagna et al. 1965). During SSC, use of elastic energy and reflex activation of the neuromuscular system have been shown to be important for the production of power in the propulsive phase of the following jump (Bosco et al. 1982b).

The capability of muscle to store and use elastic energy has been found to depend on the muscle length and stretching speed (Cavagna et al. 1965), the force at the end of the stretching phase and the coupling time between the eccentric and concentric phases (Bosco et al. 1981). It has been reported that a rapid and short stretch (Cavagna et al. 1968), a high force at the end of the stretch and a short coupling time favour the use of tendomuscular elasticity (Bosco et al. 1982a, 1982c) Komi and Bosco (1978) have demonstrated that after the vertical dropping height reaches a certain level, the rebound jumping height declines. Viitasalo and Bosco (1982), however, have not reported any significant effects of dropping height on the following rebound jumping height among male students. The optimal dropping height has been found to be 0.66 m (Komi and Bosco 1978) and 0.4 m (Viitasalo 1982) for volleyball players, 0.63 m for male physical education students and 0.48 m for female students (Komi and Bosco 1978). Dropping heights as high as 1.1 m have also been reported (Bobbert 1990; Schmidtbleicher and Gollhofer 1982), being employed to create higher than optimal (in respect of jumping height) dropping heights and to produce an overload stimulus.

Myoelectrical activity (EMG) before and during the eccentric phase of contact has been found to be highly

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correlated with the contact time, contact force and angular parameters in trained athletes (Aura and Viitasalo 1989; Viitasalo and Aura 1987). This has been suggested to be due to pre-programmed patterns, dispatched from higher centres in the nervous system (Melvill-Jones and Watt 1971). It has been found that the human locomotor system is taught to fit the muscle status of external demands (Dietz et al. 1979). Pre-activation has been shown to be important both for the enhancement of the EMG during the eccentric phase of the take-off and for the timing of muscle action with respect to ground contact (Moritani et al. 1991). The activation of the muscles regulates muscle stiffness. Stretching of an active, stiff muscle during the eccentric phase of take-off stores elastic energy in the cross-bridges and tendons. It has been shown that this elastic energy can be used during the concentric phase of muscle contraction (Cavagna et al. 1971). Thus, the effects of training on neuronal control mechanisms and on muscular spring characteristics are important.

Based on the specificity of training (e.g. Hortobagyi 1982) the functioning of the neuromuscular system and the biomechanical characteristics of jumping have been shown to differ among subjects with different training backgrounds (Komi and Bosco 1978; Kyröläinen and Komi 1995a, 1995b). The present study compared neuromuscular functioning of the lower extremity muscles together with some kinetic and kinematic parameters before and during ground contact in drop jumps from two heights. Comparisons were made between highly trained triple-jumpers, and physically active controls. Two dropping heights were used to produce two eccentric stretching speeds for the leg extensor musculature. Preliminary reports have been published (Viitasalo and Lahtinen 1991; Viitasalo et al. 1996).

Methods

Subjects

A group of 18 subjects were divided into jumpers (7 triple-jumpers of Finnish national caliber) and controls (11 students with physically active life styles but no specific jumping training). The jumpers were on average aged 27.6 (SD 3.6) years, were 1.84 (SD 0.05) m tall and their mean body mass was 75.4 (SD 5.2) kg. The respective values for the control group were 20.6 (SD 2.6) years, 1.78 (SD 0.05) m and 74.0 (SD 7.4) kg. The average triple-jumping personal record of the jumpers was 16.05 (SD 0.29) m. They had a 10–15 year background of systematic sports training with various kinds of explosive strength and jumping drills including drop jumping. Informed consent was obtained from the subjects.

Protocol

Measurements were carried out during one indoor session. After warming-up the subjects performed various jumping drills with bilateral and unilateral foot contacts in a random order. The results from drop jumps from heights of 0.40 m (DJ40) and 0.80 m (DJ80) are given. These were selected to represent a generally used dropping height (DJ40) and a height representing an overload condition (DJ80). The subjects jumped from a stand on to a force platform (0.6 × 0.6 m, Honeycomb, Kistler, Switzerland) and after the bilateral contact rebounded immediately as high as possible while keeping their hands on their hips. After five to ten trials the subjects were asked to perform all further jumps with as similar a technique as possible. The subjects performed three drop jumps from both heights.

The EMG activity was recorded using bipolar surface electrodes (Beckman, 65037, Illinois, USA; 4-mm diameter, 10-mm separation) over the motor point area of the vastus lateralis, rectus femoris, biceps femoris (long head) and gastrocnemius (lateral head) muscles of the dominant leg. The pre-amplified EMG signals (60 dB, 10–500 Hz) were telemetrically (Glonner, Biomes 2000, cut-off frequency 360 Hz, 3 dB^{-1}) transmitted to a magnetic tape recorder (Racal, V-store, Southampton, UK; cut-off frequency 2.5 kHz) simultaneously with three dimensional ground reaction force signals from the force platform. An electrical goniometer (58 g) was attached to the lateral side of the right knee joint.

The EMG, goniometer and force signals were off-line A-D converted (1 kHz) to a computer for further analysis. One drop jump per subject from both heights was filmed with a Canon Scoopic 16-mm camera operating at 69 frames · s^{-1}. Due to film failure it was not possible to analyse one subject in the control group. The camera was located perpendicular to the sagittal plane at a distance of 29.2 m. When the subject touched the force platform a marker signal was turned on to synchronise the filmed data with the force and EMG signals. A light flashed in front of the jumper gave the marker on the film.

The EMG was averaged (aEMG) for two successive 50-ms periods prior to the ground contact, and for the first and second halves of the braking and the propulsion phases of contact:

$$x_{\mathrm{aEMG}}(T) = \frac{1}{T}\int_{0}^{\mathrm{T}} |x(t)|\mathrm{d}t$$

where T is the observation time, and $x(t)$ the EMG signal.

The braking and propulsion phases were determined by the contact time and minimal angle position of the knee as proposed by Aura and Viitasalo (1989). Both absolute (arbitrary units) and relative aEMG values were used. The EMG values were normalised to, e.g. maximal isometric (see Voigt et al. 1991) or concentric (see Voigt et al. 1995) values. Drop jump EMG has been shown to be also related to squatting jump EMG activity (Viitasalo and Bosco 1982) and the relationships among maximal isometric, concentric, squatting jump, countermovement jumps (eccentric and concentric) and drop jumps (eccentric and concentric) EMG activity to depend on the muscle (Viitasalo 1984). Thus, there is no standard for presentation of relative EMG values. We selected the second part of the propulsion phase as 100% because it has been supposed to be the one where untrained subjects also had enough time to produce their voluntary maximal activation level.

Duration of the pre-contact EMG activity was from the moment when the rectified EMG reached a level of 0.04 mV to touch-down on the force platform (threshold 5 N). The thresholds were selected on the bases of maximal amplitude and baseline noise. The flight times of the jumps were used to calculate the height of rise of the body centre of gravity as has been suggested by Asmussen and Bonde-Petersen (1974). Average and peak vertical forces as well as braking and propulsion times were calculated from the force-time curves (Bosco and Komi 1979). For the EMG and force analyses the two best jumps (on the basis of the jumping height) from both dropping heights were selected and averaged.

During the dropping and contact phases hip, knee and ankle angles as well as vertical location of the body centre of mass (CM) were analysed from the film using a NAC (MC-OF) analyser connected to an Ariel performance analysis system. The manually digitised raw data were smoothed with the quintic spline algorithm (smoothing factor 0.002 m). Based on Dempster (1955), the mechanical model of the jumper was assumed to consist of eight rigid body segments. The relative segmental masses and locations of segmental mass centres were used to obtain the location of the whole body CM. Values were calculated at the touch down and take-off phases as well as at the deepest bending position (between the braking and the propulsion phases). The angular displacements and average braking and propulsion angular velocities were also calculated using the film data. The vertical location of CM was determined for the last frame of contact to the stand and for the entire ground contact phase.

Statistics

Calculations were performed with a SPSS/PC+ statistical package (Norusis 1990) including mean, standard deviation of the mean and Student's t-test for independent and paired samples.

Results

The jumpers and controls differed from each other in all variables determined for both dropping heights with the exception of propulsion time (Table 1). The triple-jumpers jumped 32% higher in DJ40 and 34% higher in DJ80 than the controls. Also, the jumpers had shorter braking and total contact times and greater average and peak vertical ground reaction forces than the controls. In both drop jumps the EMG pre-activity in the vastus lateralis and gastrocnemius muscles started earlier for the jumpers than for the controls. However, in the rectus femoris and biceps femoris muscles the two groups of subjects showed fairly similar EMG pre-activity times.

The increase in dropping height from 0.4 to 0.8 m did not reveal any significant effect on the vertical jumping height or contact times (Table 1). However, the increase in dropping height caused an increase in the average and peak braking forces of both the groups and for the control group it was associated with a decrease in the propulsion force. However, the duration of the EMG pre-activity did not differ significantly between the dropping heights.

The mean dropping height for the body CM did not differ significantly between the groups. The total contact times were calculated from film (Table 2) and from the force plate data (Table 1) and were reasonably similar. When the total contact times were divided into the braking and propulsion times for the three relevant joints, the jumper group showed shorter times than the control group in both jumps, except for hip angle at DJ40. There were no significant differences between the two groups in timing patterns of the lower extremity joints at the beginning of the propulsion phase. When the durations of the braking and propulsion phases were calculated separately for the three joints, and values were compared between the two dropping heights, differences were found for the knee and ankle angles of the control group on the braking phase, and the duration was longer for the DJ80 than for the DJ40.

There were no significant differences between the groups for the joint angles in DJ40 at any of the three instants measured (Table 3). At the 0.8-m dropping height, however, three differences were found: the mean knee angle of the control group was more bent at the deepest position and the ankle angle more extended at

Table 1 Vertical jumping height, contact times and vertical ground reaction forces calculated from the force platform data, and duration of electromyogram (*EMG*) pre-activation for the jumpers (*Ju*) and controls (*Co*), and for the drop jump from 0.4 m (*DJ40*) and from 0.8 m (*DJ80*). Independent student's *t*-tests were calculated between jumper and control groups, and paired *t*-test between *DJ40* and *DJ80*

Variables	DJ40				DJ80				Ju vs Co		DJ40 vs DJ80	
	Jumpers		Controls		Jumpers		Controls		DJ40	DJ80	Jumpers	Controls
	mean	SD	mean	SD	mean	SD	mean	SD				
Jumping height (m)	0.47	0.07	0.35	0.04	0.47	0.07	0.35	0.05	**	**	ns	ns
Contact time (ms)												
braking phase	67.1	25.8	128.5	44.7	68.1	34.6	139.1	51.2	**	**	ns	ns
propulsion phase	98.7	27.9	97.5	18.8	99.7	29.0	102.0	22.9	ns	ns	ns	ns
total	165.8	12.8	226.0	60.3	167.9	21.2	241.1	73.0	*	*	ns	ns
Average vertical force ($0.001 \times N$)												
braking phase	3.49	0.36	2.29	0.77	4.32	0.70	2.67	0.86	***	***	***	**
propulsion phase	1.74	0.28	1.17	0.30	1.70	0.36	1.06	0.27	***	**	ns	*
Peak vertical force ($0.001 \times N$)												
braking phase	6.30	1.30	4.29	1.68	8.54	1.08	6.21	1.19	*	***	***	***
propulsion phase	3.49	0.23	2.46	0.72	3.61	0.55	2.24	0.69	***	***	ns	*
Duration of EMG pre-activation (ms)												
vastus lateralis muscle	78.1	9.9	45.1	9.4	87.7	6.9	49.6	10.5	***	***	ns	ns
rectus femoris muscle	43.2	6.9	46.7	12.7	47.2	11.7	50.4	17.5	ns	ns	ns	ns
gastrocnemius muscle	145.7	6.8	92.1	9.2	139.7	8.1	92.3	7.7	***	***	ns	ns
biceps femoris muscle	31.3	3.7	27.4	11.6	25.8	15.7	26.2	12.9	ns	ns	ns	ns

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, *ns* non-significant

Table 2 Actual dropping height, ground contact time and duration of the braking and propulsion phases, and timing of extension for the three leg joints from the film data for the jumpers (*Ju*) and controls (*Co*), and for the drop jump from 0.4 m (*DJ40*) and from 0.8 m (*DJ80*). Independent student's *t*-tests were calculated between jumpers and control groups and paired *t*-test between *DJ40* and *DJ80*. *CM* centre of mass

Variables	DJ40				DJ80				Ju vs Co		DJ40 vs DJ80	
	Jumpers		Controls		Jumpers		Controls		DJ40	DJ80	Jumpers	Controls
	mean	SD	mean	SD	mean	SD	mean	SD				
Actual dropping height of CM (m)	0.45	0.05	0.39	0.07	0.77	0.06	0.69	0.09	ns	ns		
Contact time (s)	0.17	0.02	0.23	0.06	0.17	0.02	0.26	0.08	*	**	ns	ns
Duration of the braking phase (s)												
hip	0.03	0.03	0.07	0.05	0.04	0.03	0.10	0.04	ns	**	ns	ns
knee	0.07	0.01	0.10	0.03	0.06	0.01	0.11	0.04	*	**	ns	*
ankle	0.07	0.01	0.10	0.03	0.07	0.01	0.12	0.03	*	**	ns	*
Duration of the propulsion phase (s)												
hip	0.14	0.03	0.16	0.05	0.13	0.01	0.16	0.04	ns	*	ns	ns
knee	0.11	0.01	0.13	0.03	0.11	0.01	0.14	0.04	*	*	ns	ns
ankle	0.10	0.01	0.13	0.04	0.10	0.01	0.14	0.05	*	*	ns	ns
Time differences between the joints in the start of extension (s)												
ankle – knee	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.02	ns	ns	ns	ns
knee – hip	0.03	0.02	0.03	0.04	0.02	0.01	0.01	0.01	ns	ns	ns	ns
ankle – hip	0.04	0.02	0.03	0.04	0.03	0.02	0.01	0.02	ns	ns	ns	ns

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, *ns* non-significant

touch down and take-off. The angular displacements of all three joints did not differ significantly at the 0.4-m height either in the braking or propulsion phase. However, the control group showed greater angular displacements in both contact phases at DJ80 for all measured joints except for the hip joint in the propulsion phase. The greatest difference between the mean displacements of the groups was 16° for the knee angle both in the braking and propulsion phases. The average angular velocities did not differ significantly between the groups.

For the jumpers the knees were more flexed for DJ80 than for DJ40 at touch down (Table 3), but there were no significant differences between angular displacements. For the control group the increase in the dropping height resulted in more extended knee and ankle angles at touch down and more flexed angles at the deepest position and all angular displacements at DJ80 were larger than at DJ40. The greatest difference of the mean displacements was 14° for the knee angle at the braking phase. Among jumpers angular velocities between the two dropping heights did not differ significantly. But in the control group an increase in the dropping height caused an increase in the mean braking angular velocity. Also the hip angular velocity at the propulsion phase increased with the dropping height.

The mean dropping heights for the control group were on average 0.06 m (DJ40) and 0.08 m (DJ80) lower than those for the jumpers due to variation in the standing positions both at the moment of last contact with the stand and at the ground touch down. These statistically non-significant differences corresponded on an average of 6.7% (DJ40) and 5.4% (DJ80) differences in the vertical velocity of the body CM at touch down between the groups.

The jumper group revealed greater myoelectrical activity during the precontact and braking phases (Figs. 1, 2). The absolute and relative data showed similar results in respect of differences between the groups. The EMG of the vastus lateralis muscle was greater for the jumpers before ground contact and during the first half of the braking phase in DJ80 and DJ40 than for the controls. Differences were found between the groups in the EMG of the rectus femoris muscle in the first part of the DJ40 braking phase and in the second part of the DJ40 DJ80 braking phase. In the activity of the gastrocnemius muscle the two groups differed at the braking phases of the DJ80. The biceps femoris muscle of the jumpers was also more active during the precontact and braking phases than that of the controls.

Among the jumpers the increase in the dropping height resulted in a tendency to increase the EMG of the vastus lateralis, rectus femoris and gastrocnemius muscles during the pre-contact and braking phases (Fig. 3). The only statistically significant differences, however, were found for the pre-activity phases of the vastus lateralis muscle. Among the control subjects EMG did not change with dropping height. Figure 4 shows raw

Table 3 Hip, knee and ankle angles, angular displacements and angular velocities at the various phases of contact calculated from the film data. Independent student's *t*-tests were calculated between jumper and control groups and paired *t*-test between drop jump from 0.4 m (*DJ40*) and from 0.8 m (*DJ80*)

Variables	Jumpers				Controls				Ju vs Co		DJ40 vs DJ80	
	DJ40		DJ80		DJ40		DJ80		DJ40	DJ80	Jumpers	Controls
	mean	SD	mean	SD	mean	SD	mean	SD				
Hip angle (°)												
touch down	134	8	142	5	142	17	146	12	ns	ns	ns	ns
deepest position	132	7	137	10	134	20	127	21	ns	ns	ns	ns
takeoff	179	4	182	5	181	7	183	11	ns	ns	ns	ns
Knee angle (°)												
touch down	140	2	145	4	140	11	145	7	ns	ns	**	*
deepest position	122	6	124	9	116	12	108	14	ns	*	ns	0.001
takeoff	170	6	171	2	171	4	170	5	ns	ns	ns	ns
Ankle angle (°)												
touch down	111	6	111	4	114	8	120	7	ns	*	ns	*
deepest position	88	4	87	5	88	5	84	5	ns	ns	ns	**
takeoff	133	6	132	5	137	5	139	4	ns	**	ns	ns
Angular displ. in braking (°)												
hip	−3	3	−5	6	−9	10	−19	15	ns	*	ns	*
knee	−17	8	−21	9	−23	9	−37	12	ns	**	ns	***
ankle	−23	5	−24	5	−26	10	−36	9	ns	**	ns	*
Angular displ. in propulsion (°)												
hip	47	7	45	7	47	17	56	18	ns	ns	ns	*
knee	47	4	47	9	54	14	63	15	ns	*	ns	*
ankle	45	6	45	4	50	7	55	7	ns	**	ns	*
Braking angular velocity ($° \cdot s^{-1}$)												
hip	−86	57	−109	80	−115	74	−172	69	ns	ns	ns	*
knee	−264	97	−315	115	−264	69	−327	40	ns	ns	ns	*
ankle	−327	69	−344	69	−281	69	−350	69	ns	ns	ns	**
Propulsion angular velocity ($° \cdot s^{-1}$)												
hip	350	69	361	63	298	52	361	63	ns	ns	ns	**
knee	464	57	458	63	424	52	458	63	ns	ns	ns	ns
ankle	464	52	487	57	424	74	418	86	ns	ns	ns	ns

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, *ns* non-significant

EMG and vertical force signals measured in DJ40 for one jumper and one control subject.

Discussion

Pre-activation

The triple-jumpers were found to start their EMG activity earlier before touch down, and their EMG pre-activities in the vastus lateralis and biceps femoris muscles were greater than those of the control subjects. The differences between the groups may have been affected by differences in their training backgrounds. Kyröläinen et al. (1991) have demonstrated that 16-week SSC training improved mechanical efficiency and that the subjects pre-activated their leg extensor muscles earlier before the impact. Kyröläinen and Komi (1995b) have also shown that the rate of EMG development was faster during the pre-activity for power-trained athletes.

The increase in the dropping height was followed by a tendency to increased aEMG pre-activity in the vastus lateralis muscle among the jumpers, while no effect on the duration of the EMG pre-activity was found. This tendency is in line with the results of Dietz et al. (1981) who have suggested that learning may modulate the preparatory activity of the neuromuscular system under varying jumping conditions.

Braking and propulsion phases

Stretching a contracting muscle generates a large force increment, of which approximately half is due to the stretch reflex, which has been shown to increase the muscle stiffness more than would be predicted from the intrinsic stiffness (Sinkjaer et al. 1988). High muscle activity during the braking phase of contact favours storage of elastic energy, which in turn during the propulsion phase of contact can be used for high power

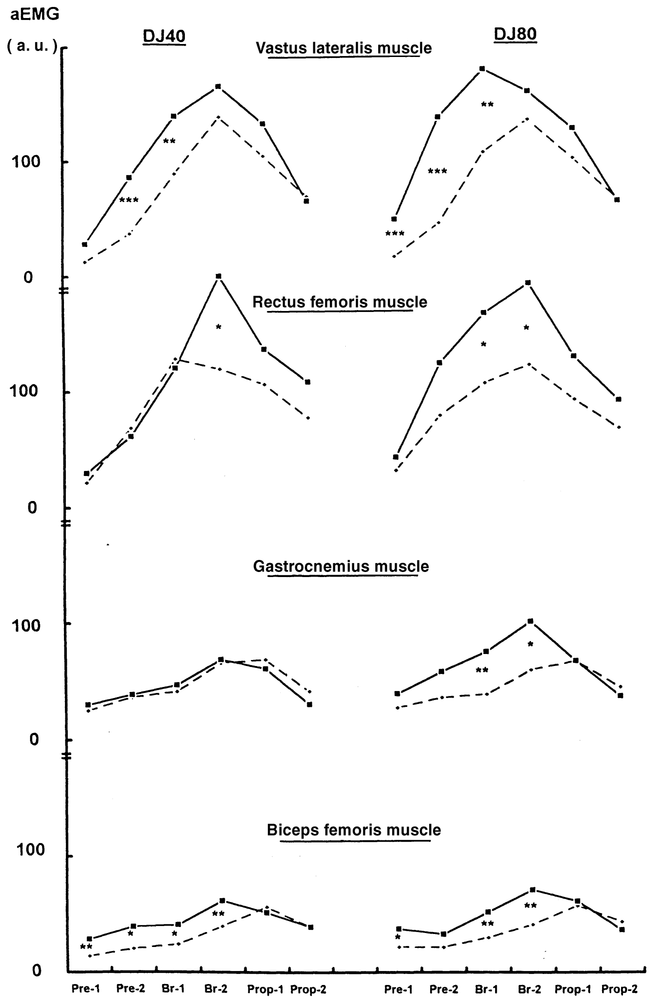


Fig. 1 Rectified and averaged electromyogram (*aEMG*) (a.u.) for the vastus lateralis, rectus femoris, gastrocnemius and biceps femoris muscles of the jumpers (*solid line*) and controls (*dotted line*) before and during the contact of drop jumps from 0.4 m (*DJ40,-left*) and 0.8 m (*DJ80 right*). Significance between groups: $^{*}P < 0.05$ $^{**}P < 0.01$ $^{***}P < 0.001$. *Pre* Pre contact phase, *Br* braking phase, *Prop* Propulsion phase

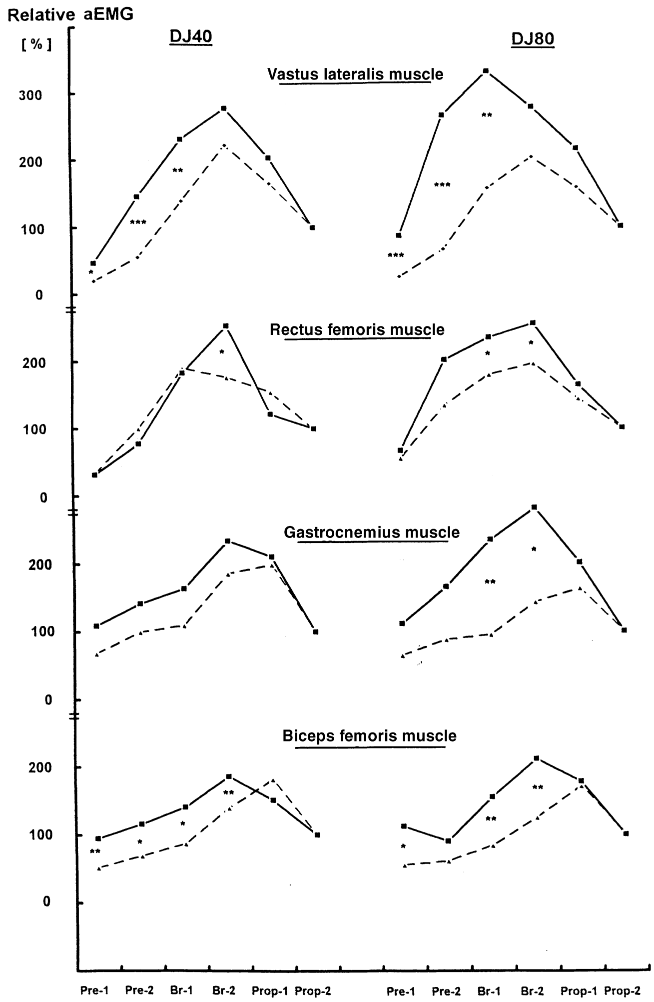


Fig. 2 Relative (the second phase of propulsion = 100%) *aEMG* for the vastus lateralis, rectus femoris, gastrocnemius and biceps femoris muscles of the jumpers (*solid line*) and controls (*dotted line*) before and during contact of *DJ40* (*left*) and *DJ80* (*right*). Significance between groups: $^{*}P < 0.05$ $^{**}P < 0.01$ $^{***}P < 0.001$. For definitions see Fig. 1

production. The differences found between the groups in the shapes of aEMG activity curves may indicate that the neuromuscular system of the jumpers, compared with that of the controls, was better prepared to withstand and use strong eccentric stretching which was seen in greater force production in the propulsion phase, and in the higher jumping height. Moritani and deVries (1979) have shown an increase in integrated EMG after weight training. Häkkinen and Komi (1985) have reported that 24 weeks of explosive type strength training increased EMG of the knee extensor musculature during the eccentric and concentric phases of drop jump contacts.

It has been suggested that the stretch reflex is velocity dependent (Gottlieb and Agarwall 1979), in sledge jumps its magnitude increasing progressively with higher stretching velocity (Kyröläinen and Komi 1995b). It has been found that in drop jumps performed from a height of 1.1 m an untrained person responded with a period of inhibition during the eccentric action phase after landing while a trained jumper responded with a period of facilitation (Schmidtbleicher and Gollhofer 1982), the facilitation in the trained jumper being an adaptation of certain reflex responses specific to certain stretch loads (Schmidtbleicher et al. 1987). The increase in the dropping height in the present study effected an increase in the braking forces both among the triple jumpers and the controls. Among the jumpers the increase in dropping height had minor effects on the jumping height, propulsion force or angular parameters. However, the controls were not able to keep their angular parameters constant when the dropping height was increased and they had to decelerate and accelerate their body mass with larger angular displacements, that is with larger muscle lengths. This would indicate that the neuromuscular system of the jumpers was better able to resist the high stretching speeds and ground reaction forces.

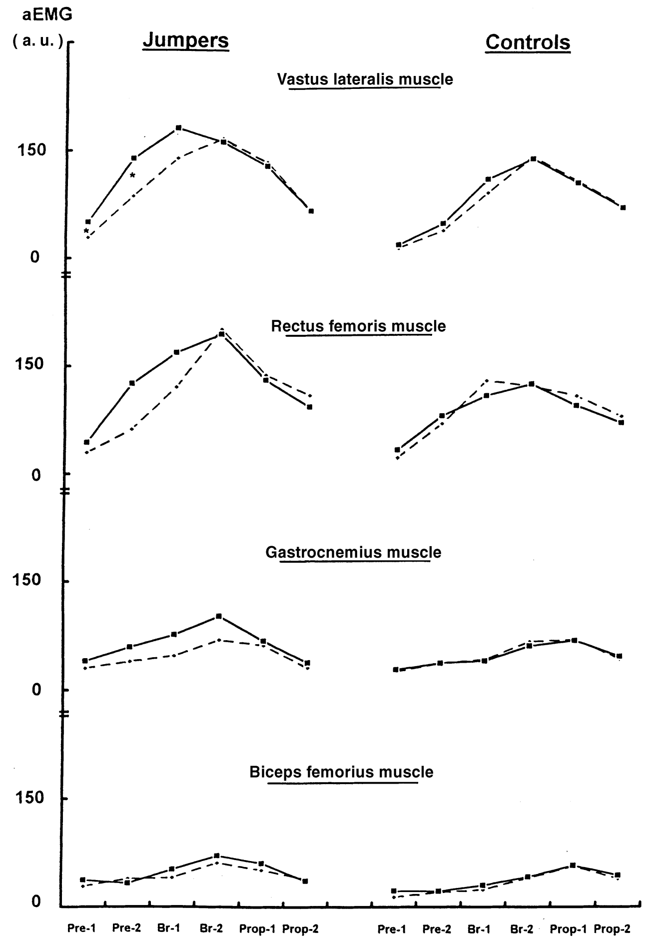


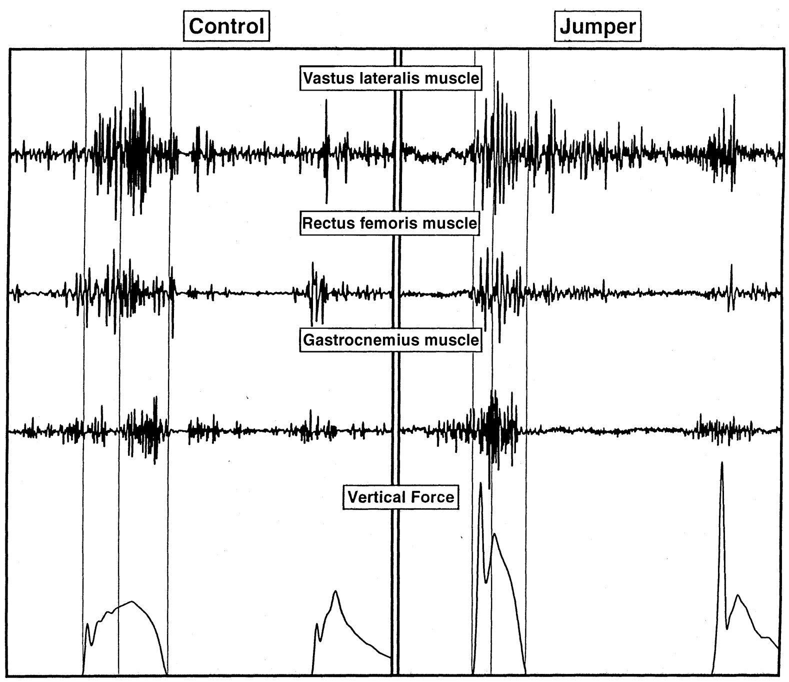
Fig. 3 *aEMG* for the four muscles and various contact phases measured for *DJ40* (*dotted line)* and *DJ80* (*solid line*). Significance between groups: $*P < 0.05$ $**P < 0.01$. For definitions see Fig. 1

Another explanation could be that the control group changed their drop jump technique when the dropping height increased.

Drop jump techniques

Bobbert et al. (1987) have reported two techniques in the performance of a drop jump: a countermovement drop jump (CDJ), which involves a large amplitude movement after landing from the drop, and bounce drop jump (BDJ), in which a small amplitude movement is typical. According to Bobbert (1990) subjects are likely to make a larger downward movement upon landing if the drop jump distance is increased and the jumping technique is not controlled. In these cases, the neuromuscular functioning during the braking phase may be more like that of landing than hopping (See Dyhre-Poulsen et al. 1991). Our subjects were not provided with any verbal or visual feedback during the measurements, but their jumping technique was evaluated before the measurements and corrections and feedback was given to ensure comparable techniques between the groups. The examples in Fig. 4 suggest a decrease (an inhibition?) in the muscle activities of the control subject at the end and after the eccentric stretch (gastrocnemius muscle) supporting the idea of Dyhre-Poulsen et al. (1991) of a landing-like braking phase of contact. The small differences between the groups in the angular parameters in DJ40 show that the differences between the groups in jumping techniques for this dropping height may not have been great. May be the control subjects were not able to maintain their jumping technique when the drop jump height was increased due to their neuromuscular

Fig. 4 Raw electromyogram and vertical force signals of drop jump at 0.4 m in one jumper and one control subject. The thin *Vertical lines* represent the beginning and the end of the braking and propulsion phases



systems being less well-trained, and as a result their technique changed from being BDJ-like to CDJ-like.

Training background

The difference between the two groups in the neuromuscular functioning may be based on differences in their training backgrounds and/or in their inherited abilities. Hortobagyi (1982) has found that in untrained male subjects drop-jumping preparation had greater influence on jumping tests than weight training. Schmidtbleicher et al. (1987) have reported that 4-week drop-jump training induced a more pronounced improvement in SSC contraction than in purely concentric contraction. Sale (1992) has suggested that when particular movement is repeated over a period of weeks or months (or years, as was the case in our adult triple-jumpers), modification takes place in the complex interactions among muscles, which results in improved performance.

Muscle fibre distribution, recruitment pattern and connective tissue

It has been suggested that muscle fibre type distribution is determined markedly by heredity (MacDougall 1992) and, for example, sprint training has no effects on fibre distribution but increases fibre areas and enzyme activities (Thorstensson et al. 1975). Fast twitch muscle volume has been shown to be increased (Goldspink 1992) and the potential to use the fast twitch population is improved. Thus differences in the muscle fibre distribution and/or volume may explain part of the intergroup differences.

The motor unit recruitment model is also of importance in explosive type force production. Mellah et al. (1990) have shown that when a monkey was trained to perform a rapid forearm flexion movement, the firing of low-threshold motor units was suppressed when higher threshold motor units were recruited.

The high activation of muscles before and during the braking phase, great forces and short braking phases transmit great forces to the connective tissues (e.g. tendons). It has been reported that tendons are able to store and release high amounts of elastic energy if exposed to very high stretching forces in a sequence of SSC contraction (Huijing 1992). It has been shown that among animals, special training modifies the metabolism of connective tissues (Suominen et al. 1980), and affects hypertrophy and improves its mechanical properties (Woo et al. 1981). Thus, in addition to possible differences in the structure and functioning of the neuromuscular contractile apparatus differences in their connective tissue may have contributed to the superiority of the triple-jumpers in the drop jump.

Triple jumpers and control subjects who had no jumping training history were found to differ in respect to their neuromuscular functioning in drop jump exercises and to respond in a different way to an increase in dropping height.

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References

Asmussen E, Bonde-Petersen F (1974) Apparent efficiency and storage of elastic energy in human muscles during exercise. Acta Physiol Scand 92:537–545
Aura O, Viitasalo JT (1989) Biomechanical characteristics of jumping. Int J Sport Biomech 5:89–98
Bobbert MF (1990) Drop jumping as a training method for jumping ability. Sports Med 9:7–22
Bobbert MF, Huijing PA, Ingen Schenau GJ van (1987) Drop jumping I. The influence of jumping technique on the biomechanics of jumping. Med Sci Sports Exerc 19:332–338
Bosco, Komi PV (1979) Mechanical characteristics and fiber composition of human leg extensor muscles. Eur J Appl Physiol 41:275–284
Bosco C, Komi PV, Ito A (1981) Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiol Scand 111:135–140
Bosco C, Ito A, Komi PV, Luhtanen P, Rahkila P, Rusko H, Viitasalo JT (1982a) Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. Acta Physiol Scand 114:543–550
Bosco C, Tihanyi J, Komi PV, Fekete G, Apor P (1982b) Store and recoil of elastic energy in slow and fast types of human skeletal muscles. Acta Physiol Scand 116:343–3349
Bosco C, Viitasalo JT, Komi PV, Luhtanen P (1982c) Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. Acta Physiol Scand 114:557–565
Cavagna GA, Saibene FB, Margaria R (1965) Effect of negative work on the amount of positive work performed by an isolated muscle. J Appl Physiol 20:157–158
Cavagna GA, Dusman B, Margaria R (1968) Positive work done by previously stretched muscle. J Appl Physiol 24:21–32
Cavagna GA, Komarek L, Mazzoleni S (1971) The mechanics of sprint running. J Physiol 217:709–721
Dempster WT (1955) Space requirements of the seated operator. WADC Technical Report. Wright-Patterson Air Force Base. Ohio, pp 55–159
Dietz V, Schmidtbleicher D, Noth J (1979) Neuronal mechanisms of human locomotion. J Neurophysiol 42:1212–1222
Dietz V, Noth J, Schmidtbleicher D (1981) Interaction between pre-activity and stretch reflex in human triceps brachii during landing from forward falls. J Physiol 311:113–125
Dyhre-Poulsen P, Simonsen EB, Voigt M (1991) Dynamic control of muscle stiffness and H reflex modulation during hopping and jumping in man. J Physiol 437:287–304
Goldspink G (1992) Cellular and molecular aspects of adaptation in skeletal muscle. In: Komi PV (ed) Strength and power in sport. Blackwell Scientific Publications, Victoria, pp 211–229
Gollhofer A, Schmidtbleicher D, Dietz V (1984) Regulation of muscle stiffness in human locomotion. Int J Sports Med 5:19–22
Gottlieb GL, Agarwall GC (1979) Response to sudden torques about ankle in man: myotatic reflex. J Neurophysiol 42:91–106
Häkkinen K, Komi PV (1985) Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. Scand J Sports Sci 7:65–76

Hortobágyi T (1982) Effects of different types of explosive strength training on speed-power muscle characteristics. Hung Rev Sports Med 23:185–196

Huijing PA (1992) Elastic potential of muscle. In: Komi PV (ed) Strength and power in sport. Blackwell Scientific Publications, Victoria, pp 151–168

Komi PV, Bosco C (1978) Utilization of stored elastic energy in leg extensor muscles by men and women. Med Sci Sports 10:261–265

Kovanen V, Suominen H, Heikkinen E (1984) Mechanical properties of fast and slow skeletal muscle with reference to collagen and endurance training. J Biomech 17:725–735

Kyröläinen H, Komi PV (1995a) Differences in mechanical efficiency between power and endurance-trained athletes while jumping. Eur J Appl Physiol 70:36–44

Kyröläinen H, Komi PV (1995b) The function of neuromuscular system in maximal stretch-shortening cycle exercises: comparison between power and endurance-trained athletes. J Electromyogr Kinesiol 5:15–25

Kyröläinen H, Komi PV, Kim DH (1991) Effects of power training on neuromuscular performance and mechanical efficiency. Scand J Med Sci Sports 1:78–87

MacDougall JD (1992) Hypertrophy or hyperplasia. In: Komi PV (ed) Strength and power in sport. Blackwell Scientific Publications, Victoria, pp 230–238

Mellah S, Rispal-Padel L, Riviere G (1990) Changes in excitability of motor units during preparation for movement. Exp Brain Res 82:178–186

Melvill-Jones G, Watt DGD (1971) Observations on the control of stepping and hopping movements in man. J Physiol 219:709–727

Moritani T, deVries HA (1979) Neural factors versus hypertrophy in the time course of muscle strength gain. Am J Phy Med 58:115–130

Moritani T, Oddson L, Thorstensson A (1991) Phase-dependent preferential activation of the soleus and gestrocnemius muscles during hopping in humans. J Electromyogr Kinesiol 1:34–40

Norusis MJ (1990) SPSS/PC+ Advanced statistics 4.0 for the IBM PC/XT/AT and PS2. SPSS, Chicago

Sale DG (1992) Neural adaptation to strength training. In: Komi PV (ed) Strength and power in sport. Blackwell Scientific Publications, Victoria, pp 249–265

Schmidtbleicher D, Gollhofer A (1982) Neuromuskuläre Untersuchungen zur Bestimmung individueller Belastungsgrössen für ein Tiefsprungtraining. Leistungssport 12:298–307

Schmidtbleicher D, Gollhofer A, Frick U (1987) Effects of a stretch-shortening type training on the performance capability and innervation characteristics of leg extensor muscles. In: de Groot G, Hollander AP, Huijing PA, Ingen Schenau GJ van (eds) Biomechanics XI-A. Free University Press, Amsterdam, pp 185–189

Sinkjaer T, Toft E, Andreassen S, Hornemann B (1988) Muscle stiffness in human ankle dorsiflexors: intrinsic and reflex components. J Neurophysiol 60:1110–1121

Steben RE, Steben AH (1981) The validity of the stretch shortening cycle in selected jumping events. J Sports Med 21:28–37

Suominen H, Kiiskinen A, Heikkinen E (1980) Effects of physical training on metabolism of connective tissues in young mice. Acta Physiol Scand 108:17–22

Thorstensson A, Sjödin B, Karlsson J (1975) Enzyme activities and muscle strength after "sprint training" in man. Acta Physiol Scand 94:313–318

Verhoshanski Y (1966) Perspectives in the improvement of speed-strength preparation of jumpers. (In Russian, translated in Yessis Rev Sov Phys Educ Sports 4:28–35, 1969) Legk Atletika 9:11–12

Viitasalo JT (1982) Anthropometric and physical performance characteristics of male volleyball players. Can J Appl Sport Sci 7:182–188

Viitasalo JT (1984) Electromechanical behavior of the knee extensor musculature in maximal isometric and concentric contractions and in jumping. Electromyogr Clin Neurophysiol 24:293–303

Viitasalo JT, Aura O (1987) Myoelectrical activity of the leg extensor musculature before ground contact in jumping. In: Jonsson B (ed) Biomechanics X-B. Human Kinetics, Champaign, Ill., pp 695–700

Viitasalo JT, Bosco C (1982) Electromechanical behaviour of human muscles in vertical jumps. Eur J Appl Physiol 48:253–261

Viitasalo JT, Lahtinen J (1991) Lower extremity EMG-activity of athletes and non-athletes in jumping. In: Anderson PA, Hobart DJ, Danoff JV (eds) Electromyographical kinesiology. Elsevier Science, Amsterdam, pp 461–464

Viitasalo JT, Salo A, Lahtinen J (1996) Stretching speed, training background and neuromuscular functioning in drop jump. In: Marconnet P, Gaulard J, Margaritis I, Tessier F (eds) First Annual Congress, European College of Sport Science. Book of Abstracts. University of Nice Sophia-Antipolis, Nice, pp 194–195

Voigt M, Simonsen EB, Dyhre-Poulsen P (1991) Elasticity in human jumping. In: Marshall RN, Wood GA, Elliot BC, Ackland TR, McNair PJ (eds) XIIIth International Congress on Biomechanics, Book of Abstracts. PK Commercial and Instant Print, Hamilton Hill, pp 577–578

Voigt M, Simonsen EB, Dyhre-Poulsen P, Klausen K (1995) Mechanical and Muscular factors influencing the performance in maximal vertical jumping after different prestretch loads. J Biomech 28:293–307

Wilt F (1978) Plyometrics – what it is and how it works. Mod Athlete Coach 16:9–12

Woo SL-Y, Gomez MA, Amiel D, Ritter MA, Gelberman RH, Akeson WH (1981) The effects of exercise on the biomechanical and biochemical properties of swine digital flexor tendons. J Biomech Eng 103:51–56