Eur J Appl Physiol (1996) 72: 553–562

ORIGINAL ARTICLE

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Effects of differently induced stretch loads on neuromuscular control in drop jump exercise

Accepted: 20 September 1995

Abstract The neuromuscular characteristics of the triceps surae and vastus lateralis muscles and interactions between the pre-activation of these muscles and the muscle output itself during ground contact were investigated during various types of stretch-shortening cycle muscle loading. The loading of the muscles was effected by using three different types of drop jump exercise. These jumps allowed separate modifications of the loading of the leg extensor muscles by changing the velocity of the centre of gravity (CG) or by changing directly the body mass, which was also affected by changing artificially the acceleration of the CG. It was found that the eccentric peak angular velocity of the ankle joint was related to the various precontact and eccentric parameters in all the different types of jumping exercise. The correlations were higher for the gastrocnemius muscle ($P < 0.001$) than for the soleus muscle (n.s., $P < 0.01$). In all the experimental conditions, the pre-activation of the measured muscles started well before the impact of contact with the ground. However, the duration of the pre-activation phase depended on the type of stretch exercise. The results would suggest a clear interaction between the pre-activation of the muscles and that part of the muscle output which is effected by the segmental stretch reflex system. The control mechanism of the pre-activation itself appears to be multiple in character. It seems reasonable to assume that the pre-activation is preprogrammed, but which can, however, be modified by proprioceptive, vestibular and visual inputs. Thus, the possibility of conscious modification of the expected muscle load must be considered.

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Key words Neuromuscular control · Pre-activity · Stretch-reflex · Electromyography · Drop jump

Introduction

In numerous studies it has been observed that in jump performances the leg extensor muscles are activated before the feet contact the ground both in humans (Melvill Jones and Watt 1971) and animals (Dyhre-Poulsen and Mosfeldt Laursen 1984). This has been regarded as a pre-activation or pre-innervation phase (Komi et al. 1987).

Melwill Jones and Watt (1971) have suggested that the pre-activation is programmed and dispatched from higher centres as a single entity before landing, the correct timing and sequence of the muscle contractions have been learned through previous experience. This has been confirmed by many studies. Schmidtbleicher and Gollhofer (1982) have observed a clear relationship between both the duration and the amount of the muscle pre-activation and the dropping height from which the subject jumped. Komi et al. (1987) have demonstrated that the amount of pre-activation increases with increasing running speed. Furthermore, Gollhofer (1987) has found that the steepness of the rise in pre-activation electromyogram (PRE EMG) increased with increasing surface hardness. However, the recent results of Avela et al. (1994) have suggested that the control of landing is not solely regulated by the previous learning process, but that it could also be influenced by the relatively fast adaptation of the vestibular apparatus. Along these lines Greenwood and Hopkins (1976) have found that in sudden falls in humans the second peak of EMG activity of lower limbs is related to the timing of landing. They have therefore suggested it as evidence of the vestibular apparatus being involved in the initiation of this response. Dietz (1992) has suggested that the actual weighting of proprioceptive, vestibular and visual inputs to the equilibrium control is content dependent and profoundly modifies the central programme.

It has been documented that the pre-activation phase plays an important role in preparing the muscle to resist high impact forces (Kyröläinen et al. 1989) and in temporarily storing elastic energy for later re-use during the push-off phase of the contact (Asmussen and Bonde-Petersen 1974). Thus, for the utilization of the elastic energy, the muscles must show a high degree of elastic stiffness. This is in an agreement with Gollhofer et al. (1992) according to whom an effective stretch-shortening cycle (SSC) can be performed only if there is a marked stiffness of the muscle-tendon complex throughout the total period of contact. However, high stiffness responses have been found to be present only with active reflex functions (Nichols and Houk 1976). Burke et al. (1978) have reported that during active lengthening contraction (eccentric action) the muscle spindle responses were greater than during passive stretch of similar amplitude and velocity, suggesting increased fusimotor outflow and reflex responses.

Dyhre-Poulsen et al. (1991) have studied muscle stiffness and H-reflex modulation during hopping and jumping. They have suggested that the EMG pattern was adapted to the motor task. During landing the alternating EMG pattern after touch-down was programmed and only little influenced by reflexes. However, during hopping reflexex could contribute to the initial EMG activity. Thus, they have concluded the possibility of the programmed EMG contributing to the development of negative or positive stiffness and changing the muscles from a spring to a damping unit and conversely.

The present study was undertaken to investigate possible interactions between the pre-activation of the muscles and the muscle output itself during the contact period. In addition we also wished to continue our earlier study (Avela et al. 1994) and to try to clarify the control mechanisms of the precontact activation. In SSC types of movement the loading of the muscles can be modified by either changing the velocity of the centre of gravity (CG) or by changing the body mass, which can also be affected by changing the acceleration of CG. Three different types of drop jump exercise were therefore used and they allowed modification of the loading of the leg extensor muscles by changing these parameters separately.

Methods

Subjects

Nine male power trained athletes volunteered to participate in the study. They were all familiar with drop jump exercise. This avoided possible influences of learning which might occur with subjects unfamiliar with this kind of exercise. The subjects had a mean age of 24.0 (SD 4.0) years, their mean height was 185.2 (SD 7.8) cm and mean body mass was 79 6 (SD 6.4) kg. They were fully informed of the procedures and the risks involved in this study and they gave their informed consent. They were also allowed to withdraw from the measurements at will. This study was approved by the University Research Ethics Committee.

Experimental procedures

The loading of the leg extensor muscles was obtained with three different types of drop jump exercise with three different loading conditions in each, which were:

1. Normal drop jumps (DJ) (Komi and Bosco 1978), performed from three different heights: 0.66 m (DJ66), 0.46 m (DJ46) and 0.29 m (DJ29) (Fig. 1A). The selected parameters of these jumps can be seen in Table 1.
2. Sledge jumps (SlJ) in a special sledge apparatus (Kaneko et al. 1984) with three different extra loads: body mass plus 20% (SlJ + 20), body mass (SlJ0) and body mass minus 20% (SlJ − 20) (Fig. 1B). The changes of the body mass were obtained by extra loads. Reduced body mass conditions were possible due to the low and constant acceleration of 4.68 $m \cdot s^{-2}$. This acceleration was achieved by the inclination of the sledge rail, which was 28.5°. The impact velocity was set constant at 3.0 $m \cdot s^{-1}$. The dropping height was 0.96 m in all the three types of jump (Table 1).
3. Lifting block jumps (LBJ) with three different accelerations: gravity plus 20% (g + 20), gravity (g) and gravity minus 20% (g − 20). Simulated changes in the accelerations were obtained with a special lifing block system (LBS) (Fig. 1C) (designed and manufactured in our laboratory; Avela et al. 1994). With differently placed extra loads (EL) different accelerations could be achieved.The lifting block wheel ratio (LBWR) was three to one, which allowed the EL to pull the subject down with an acceleration greater than 9.81 $m \cdot s^{-2}$ when putting the EL at the end of the lifing wheel rope. When requiring accelerations lower than normal gravity EL was used at the end of the upper rope of the system. Dropping velocity at the moment of touchdown was set at 3.0 $m \cdot s^{-1}$ in all three types of jump. The dropping height (h) was calculated according to the following equation:

$$h = \frac{v^2}{2a} \quad (1)$$

The EL needed in the different conditions were obtained by:

$$EL = \frac{m(a - g)}{g} + OL \cdot (LBWR) \quad (2)$$

where g is gravity (9.81 $m \cdot s^{-2}$), a is the desired gravity condition ($g \pm x\%$), v is the constant velocity (3.0 $m \cdot s^{-1}$), m is the mass of the subject. OL is the opposite load (2 kg or $LBWR \cdot 2$ kg), $LBWR$ was used only when a condition greater than 9.81 $m \cdot s^{-2}$ was required. The corresponding impact parameters for LBS are shown in Table 1.

In all the jumping conditions EL were blocked-off electrically at the moment of touchdown. An electric impulse from a resistive plate (Digitest Ltd, Muurame, Finland) placed over the force platform, served as a trigger for the release. By releasing EL at the beginning of the braking phase, the mechanical effects of the different gravity conditions could be reduced and only the indirect effects on the muscle stretching velocities were obtained through possible changes in the pre-activation of the muscles.

The impact effect of the different jumping conditions was calculated in forms of power according to the following equation:

$$P = v \cdot (m \; a) \quad (3)$$

where P is the impact power, v is the impact velocity, m is the body mass and a is the acceleration. Three sets of comparable types of

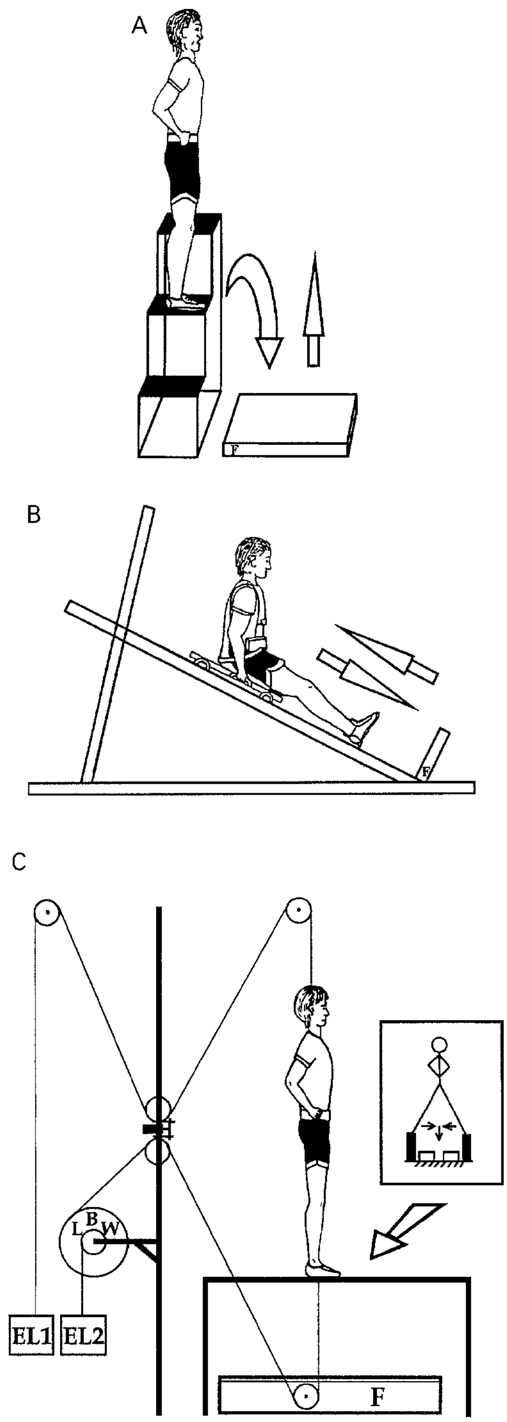

Fig. 1 Diagrams of the different types of jumping exercise. **A** Normal drop jumps. **B** Sledge jumps. The extra loads were placed on the chair behind the subject. **C** Lifting block jumps. The essential parts of the system are as follows: *EL1* place for the extra load when an acceleration less than 9.81 $m \cdot s^{-2}$ was required, *EL2* place for the extra load when acceleration greater than 9.81 $m \cdot s^{-2}$ was required, *LBW* lifting block wheel with the ratio of 3:1. *F* Force platform

load were available with regard to the impact effect: DJ66, SJ + 20 and g + 20; DJ46, SL0 and g; DJ29, SJ − 20 and g − 20 were set to correspond the same impact effects (Table 1).

Measurements and analyses

The subjects performed DJ with three different types of load in three different types of DJ exercise, without previous training with LBS and sledge. The order of the conditions and the type of the DJ exercise was selected randomly for each subject. From each condition six successful maximal DJ were performed with 1-min recovery (a total of $3 \cdot 3 \cdot 6 = 54$ jumps). Recovery phases between the different conditions were from 5 to 10 min. The jumps were done with the least knee bending and the hands were kept on the hips during the entire movement.

Lateral gastrocnemius (GA), medial soleus (SOL) and vastus lateralis (VL) muscles were selected for the EMG recordings. The EMG-signals were recorded using bipolar surface electrodes (Beckman miniature skin electrodes 650437, Ill., USA) fixed with a constant interelectrode distance of 20 mm. The electrodes were placed longitudinally on the muscle belly of the lateral head of GA, on the edge of the medial side of SOL and on the muscle belly of VL. All the EMG signals were transferred telemetrically (delay less than 1ms), amplified by FM-microvolt amplifier (Glonner Electronic GmbH, Munich, Germany) and finally transferred through an A-D converter (sampling rate 500 Hz), which also full-wave rectified the signals, to a Victor Sirius microcomputer (Victor Technologies, Inc., Calif., USA) for storage and further analyses.

It was important to ensure that the EMG responses came from the examined muscles only. The exact extent of EMG cross-talk was not measured in the present study. However, in the study of Nicol et al. (in press), where the electrode displacements and the electrodes used were identical to those in this study, the cross-spectra and cross-correlation values for the lateral GA and medial SOL muscles were as follows: maximal isometric plantar flexion: r_{xy} 0.08 (SD 0.12), maximal concentric extension: r_{xy} 0.17 (SD 0.08), maximal drop jump on the sledge: r_{xy} 0.18 (SD 0.29). The range of correlation coefficients for all the test performances was from 0.02 to 0.29. Furthermore, the cross-talk measurements in our laboratory (Nicol et al., in press) have also included measurements similar to those reported by Moritani et al. (1991). Near-maximal percutaneus stimulations (Neuropack Four MINI, 30–50 mA, 0.1 ms rectangular pulse wave) were delivered to evoke compound mass action potentials (M-waves) in lateral GA. The extent of cross-talk was determined by the relative amplitudes of the M-wave recorded from the medial SOL. In these recordings the mean peak-to-peak M-wave amplitude was 7.39 (SD 3.14) mV for the lateral GA and 0.20 (SD 0.12) mV for the medial SOL, resulting in a cross-talk of 2.7 (SD 0.8)%. This value was lower than that of 6% reported by Moritani et al. (1991). It can therefore be assumed that the extent of cross-talk between lateral GA and medial SOL was neglible in the present experiments.

The corresponding ankle and knee joint movements, measured by electrical goniometers (designed and manufactured in our laboratory), and the vertical force components from the force plates (natural frequency > 150 Hz, designed and manufactured in our laboratory) were stored simultaneously with the EMG recordings on the computer. The jumps were averaged in blocks of six jumps individually, condition by condition, using the steep rise of the vertical force as the trigger for the averaging. Threshold level was kept as low as possible (≤ 50 N).

For the SOL and VL muscles the eccentric and concentric phases were divided by the differentiated angle changes of the ankle and knee joints, respectively. The muscle length changes were used for the same determination of the GA muscle by the method of Frigo and Pedotti (1978). This method is based on the calculations from the angle displacement changes of the ankle and knee joints. However, while integrating the EMG patterns and relating them to the ground reaction forces, it is important that the electromechanical delay (EMD) is either negligible or constant. The problem of EMD has been widely studied by many authors (Cavanagh and Komi 1979; Grabiner 1986; Vos et al. 1991). It seems obvious that EMD may vary according to the muscle used, muscle action type and the

Table 1 The different types of jump and the modified impact parameters. For explanation of abbreviations see Methods

Jump	Dropping height (m)	Acceleration ($m \cdot s^{-2}$)	Impact velocity ($m \cdot s^{-1}$)	Mass (%)	Mean impact power ($N \cdot m \cdot s^{-1}$)
$g + 20$	0 38	11.77	3 0	100	2810.7
g	0 46	9.81	3.0	100	2342.6
$g - 20$	0.57	7.85	3.0	100	1874.6
DJ66	0.66	9.81	3.6	100	2810.7
DJ46	0.46	9.81	3.0	100	2342.6
DJ29	0.29	9.81	2.4	100	1874.6
SIJ + 20	0.96	4.68	3.0	120	2810.7
SIJ0	0.96	4.68	3.0	100	2342.6
SIJ − 20	0.96	4.68	3.0	80	1874.6

muscle action intensity. In the present study all the jumps were done with maximal effort and care was taken to ensure that the jumping technique did not change within the individual jumping exercise. Therefore, the differences in EMD were treated as systematic errors. The EMG values were time normalized and can be considered as average EMG.

Statistics

Descriptive statistical methods were employed to calculate mean and standard deviation values for the various parameters. A one-way ANOVA, with repeated measures, was used to detect statistical significance for selected variables. When a significant F-ratio occurred for the main effects, multiple comparison test (Scheffé) was used to locate the source of difference. A conventional correlation (Pearson) analysis with two-tailed significance was also employed to reveal the possible differences in the relationships of the variables among the different types of jumping exercise. Within an exercise, the three different jumping conditions were treated as equal conditions and as a method to obtain individual changes. Thus, the three values for one subject were analysed as three independent variables. It should be noticed that while doing so, some individual information was missing. However, the effect of the different conditions were tested with a dummy-regression analysis.

Results

The angular changes of the knee and ankle joints did not show statistically significant differences between the different conditions in the LBS exercises. The mean values for all conditions were 24.2 (SD 1.5)° and 20.9 (SD 1.8)° for the ankle and knee joints, respectively. In the DJ jump exercises significant differences ($P < 0.01$) could be observed both in the knee and ankle joint displacements among all the conditions. For the knee joint the angular changes increased with increasing stretch load from 18.9 (SD 4.0)° (DJ29) to 26.9 (SD 5.9)° (DJ66). The corresponding values for the ankle joint were from 19.8 (SD 5.8)° (DJ29) to 25.3 (SD 6.0)° (DJ66). This was also the case for the SlJ exercises, in which these changes increased significantly ($P < 0.01$) from 36.8 (SD 4.8)° (SlL − 20) to 51.5 (SD 5.8)° (SlL + 20) in the knee joint and from 26.1 (SD 5.0)° (SlJ − 20) to 29.9 (SD 5.9)° (SlJ + 20) in the ankle joint.

The results from the angular changes also indicate other performance differences (Table 2). In the LBS

Table 2 The take-off velocity, average eccentric time of the gastrocnemius, soleus and vastus lateralis muscles (*EccTime*), contact time, eccentric gross average force (*Eccentric F*) and the total gross average force (*Total F*). For explanation of other abbreviations see Methods

	Take-off velocity ($m \cdot s^{-1}$)		EccTime (ms)		Contact time (ms)		Eccentric F (N)		Total F (N)	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
$g - 20$	2.78	0.16	122	21	288	55	2109	267	1849	219
g	2.92	0.11**	102	20**	224	40**	2968	221***	2599	536**
$g + 20$	2.84	0.14*	111	22*	248	56*	2634	283**	2298	256**
DJ29	3.05	0.15	90	13	206	33	3027	253	2472	151
DJ46	3.11	0.15*	88	13	206	32	3286	357**	2656	182*
DJ66	3.14	0.15**	89	11	212	33	3659	343***	2832	334**
SlJ − 20	2.39	0.32	180	24	408	62	1453	125	1187	96
SlJ0	2.26	0.33	217	25**	486	66**	1551	151**	1274	140
SlJ + 20	1.95	0.21**	255	35***	596	94***	1596	137**	1259	78

Significantly different from the lowest impact condition of each exercise $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$

exercises the contact times increased in the added, as well as in the reduced load conditions compared to the *g* condition. This was due to the lengthening of both the eccentric and concentric phases. In the DJ exercises corresponding changes did not occur. In the SlJ exercises contact time changes were significant, revealing an increasing trend with increasing stretch load both in the eccentric and concentric phases. The absolute values were significantly higher ($P < 0.001$) than in the other two types of exercise. As expected, contradictory changes could be observed in the mean ground reaction forces. In the LBS exercises the highest values could be seen in the *g* condition. In the DJ exercises the highest mean ground reaction forces were measured from the highest load condition (DJ66). In the SlJ exercises the total mean reaction forces were lowest in the lowest stretch load conditions. As expected, however, the force values in the SlJ exercises were significantly smaller ($P < 0.001$) than in the other two exercises.

Figure 2 gives the eccentric mean and peak angular velocities of the ankle and knee joints in the different types of jumping exercise. In the DJ and SlJ exercises an increasing trend with increases in stretch load could be seen. The eccentric average and peak angular velocities for the ankle joint increased, respectively, by 1.43 rad $\cdot$ s^{-1} and 5.81 rad $\cdot$ s^{-1} from DJ29 to DJ66 condition. The corresponding values for the knee joint were 1.38 rad $\cdot$ s^{-1} and 3.23 rad $\cdot$ s^{-1}. In the SlJ exercise the eccentric peak angular velocity increased significantly by 1.29 rad $\cdot$ s^{-1} and 5.23 rad $\cdot$ s^{-1} from SlJ − 20 to SlJ + 20 condition for the ankle and knee joints, respectively. In the LBS exercise the *g* condition showed significantly higher eccentric mean and peak angular velocities compared to *g* + 20 and *g* − 20 conditions. The increments from the lowest value were 0.70 rad $\cdot$ s^{-1} and 1.10 rad $\cdot$ s^{-1} for the eccentric mean angular velocities and 6.21 rad $\cdot$ s^{-1} and 3.21 rad $\cdot$ s^{-1} for the eccentric peak angular velocities for the ankle and knee joints, respectively.

It was found that the eccentric peak angular velocity of the ankle joint was related to the various precontact and eccentric parameters in all the different types of jumping exercise (Fig. 3). The correlations were higher

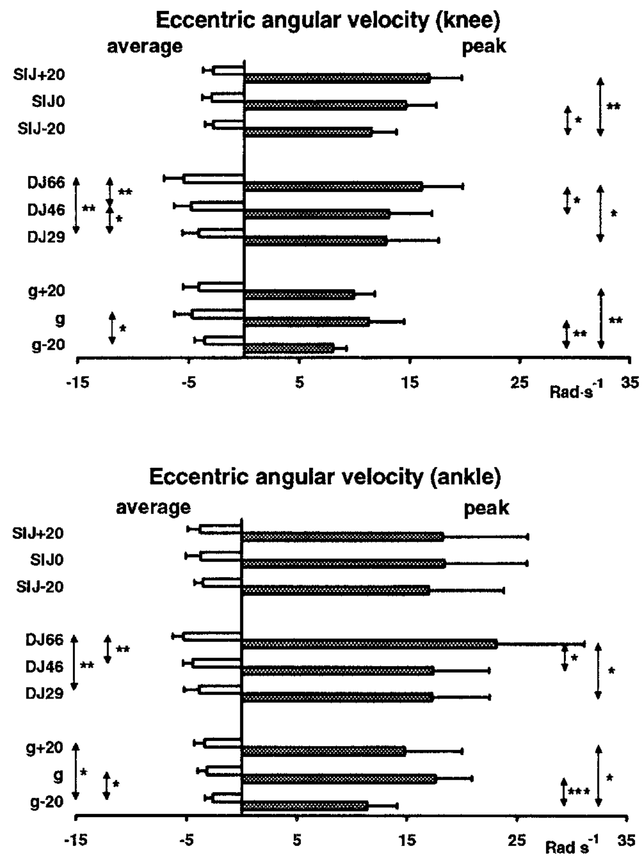

Fig. 2 The peak- and the mean angular velocities (rad $\cdot$ s^{-1}) of the ankle and knee joints during the eccentric phase of the contact (mean and SD) in all the types of jump ($n = 9$). $^{*}P < 0.05$, $^{**}P < 0.01$ and $^{***}P < 0.001$. *SlJ* Sledge jumps, *DJ* normal drop jumps, *g* gravity, for explanation of abbreviation see methods

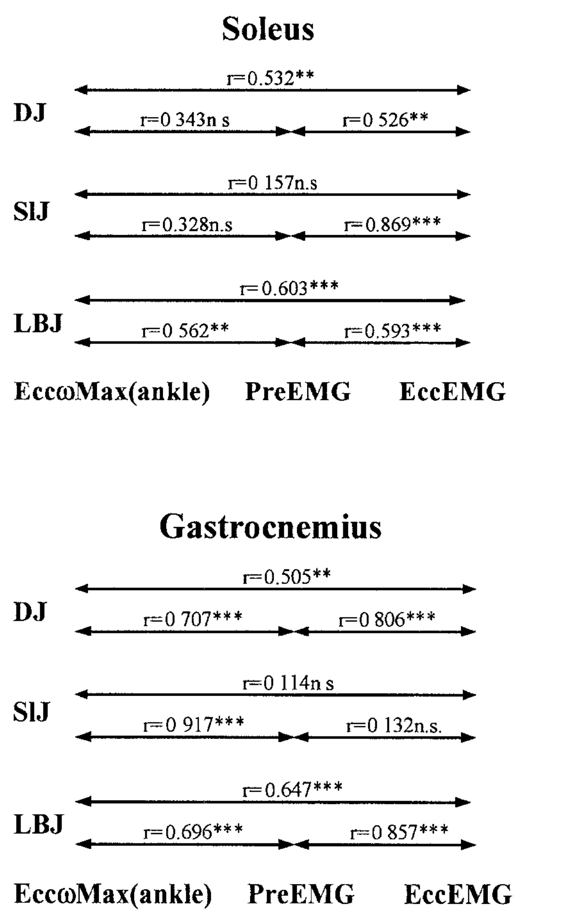

Fig. 3 Correlation coefficients (*r*, Pearsons) among the eccentric peak angular velocity of the ankle joint (*EccωMax ankle*), the average electromyogram activity in the pre-activation phase (*PreEMG*) and the amount of the average *EMG* in the eccentric phase (*EccEMG*) for the soleus and the gastrocnemius muscles ($n = 9 \times 3$). $^{*}P < 0.05$, $^{**}P < 0.01$ and $^{***}P < 0.001$. *DJ* Normal drop jump, *SlJ* sledge jumps, *LBJ* lifting block jumps

for the GA than for the SOL muscle. For the VL muscle a corresponding relationship was not observed.

In all the experimental conditions, the pre-activation of all the muscles measured started well before the impact of contact with the ground (Fig. 4). For the GA muscle it always started earlier than for the SOL and VL muscles in all the types of jumping exercise. The pre-activation times showed a linear increase with increasing stretching load for the GA and partly for the SOL muscles in the DJ and the SlJ exercise. For the VL muscle there was also a slight trend in this direction. In the LBS exercise pre-activation times were longest in the *g* condition in all the muscles measured. Figure 4 also shows the amount of the pre-activation EMG of these muscles. It can be observed that the amount of the pre-activation EMG followed almost identically the pre-activation times.

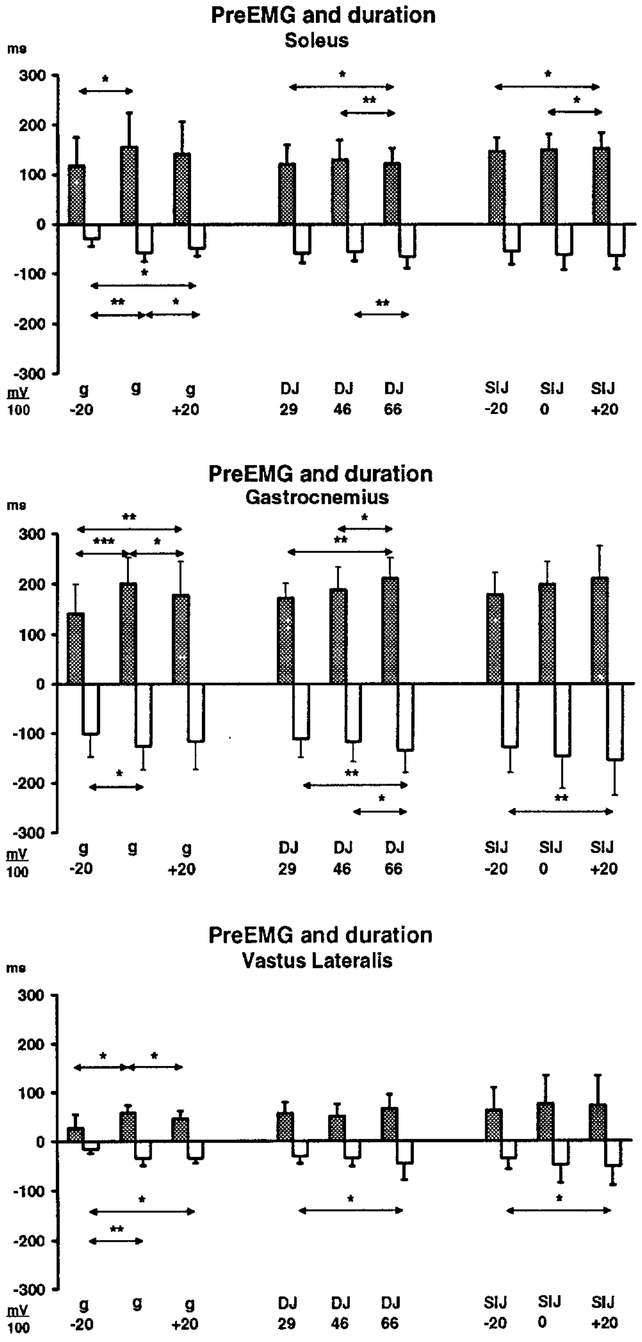

Fig. 4 The duration (ms) and the average electromyogram activity (mV) of the pre-activation phase (*PreEMG*) of the soleus, the gastrocnemius and the vastus lateralis muscles (mean and SD) ($n = 9$). $*P < 0.05$, $**P < 0.001$ and $***P < 0.001$. For definitions see Figs. 2 and 3

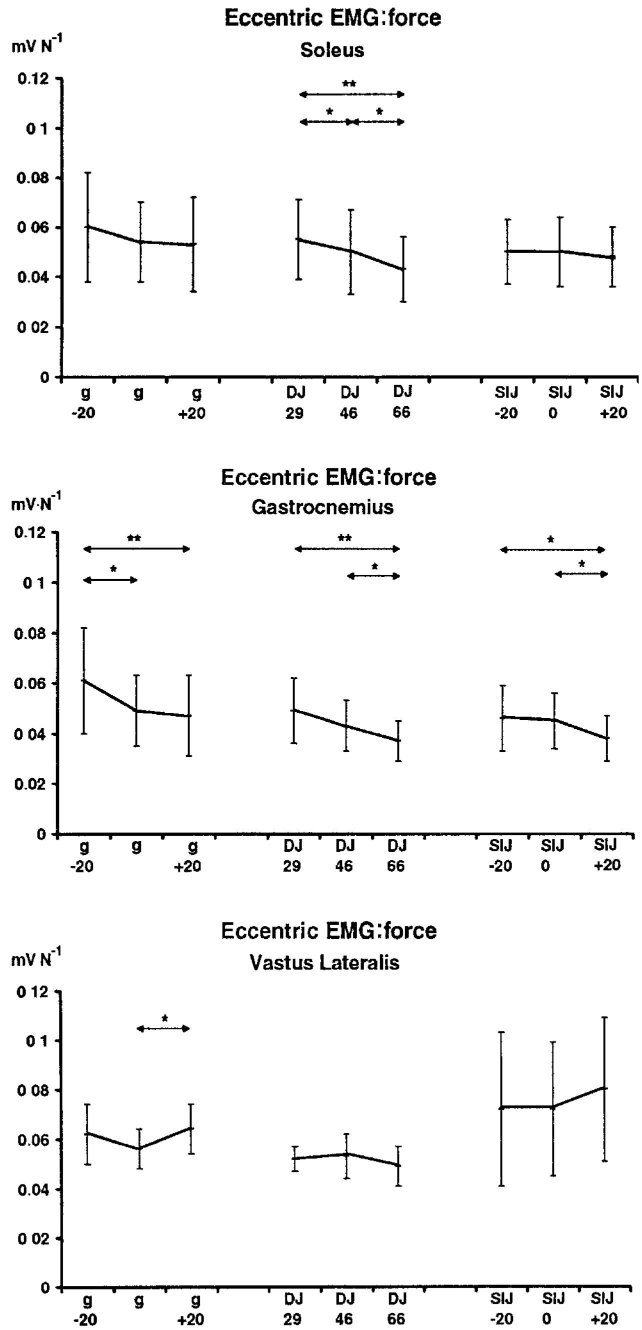

Fig. 5 *EMG*:force ratio curves (mean and SD) during the eccentric phase of contact from the soleus, the gastrocnemius and the vastus lateralis muscles ($n = 9$). $*P < 0.05$, $**P < 0.01$. For definitions see Figs. 2 and 3

Table 3 Electromyogram (EMG) values of the eccentric and the concentric phases for gastrocnemius (*GA*), soleus (*SOL*) and vastus lateralis (*VL*) muscles The EMG values are in arbitrary units. For explanation of other definitions see Methods

	Eccentric						Concentric					
	GA		SOL		VL		GA		SOL		VL	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
$g-20$	1.26	0.39	1.27	0.40	1.31	0.23	1.09	0.31	0.99	0.23	1.20	0.23
g	1.46	0.42*	1.60	0.48**	1.67	0.28*	1.34	0.36	1.16	0.23**	1.22	0.13
$g+20$	1.24	0.45	1.37	0.48	1.68	0.31*	1.36	0.38	1.14	0.28*	1.16	0.13
DJ29	1.36	0.41	1 56	0.48	1.57	0.22	1.31	0 45	1.02	0.27	1.03	0.12
DJ46	1.41	0.31	1 60	0.51	1.73	0.30	1.43	0.43*	1.08	0.29	1.05	0.14
DJ66	1.48	0.36	1.64	0.45	1.79	0.32*	1.35	0.32	1.09	0.18	1.04	0.11
SlJ − 20	0.74	0.17	0.76	0.24	1.02	0.39	1.21	0.23	1.09	0.29	1.08	0.30
SlJ0	0.74	0.17	0.79	0.27	1.10	0.37*	1.15	0.24	1.14	0.29	1.19	0 39
SlJ + 20	0.61	0.17*	0.77	0.22	1 26	0 39**	1.00	0.20**	1.01	0.20	1.20	0.49

Significantly different from the lowest impact condition of each exercise $^{*}P<0.05$, $^{**}P<0.01$

Table 3 gives the eccentric and the concentric activation characteristics of the muscles investigated in the different types of experimental exercise. For the concentric phase this analysis revealed only slight EMG amplitude differences among the different types of jump within the jumping exercise. The major significant differences in the eccentric phase can be observed for the VL muscle. The increasing stretching load resulted in increased EMG activation. However, in the LBS exercise differences in the eccentric phase appeared also for the GA and SOL muscles. Highest EMG values were measured in the g condition compared to the $g-20$ and $g+20$ conditions.

A strong relationship ($P<0.001$) between the amount of the pre-activation EMG and the eccentric EMG was found for the GA and SOL muscles in all the types of experimental jumping exercise. The only exception was the SOL muscle in the SlJ exercise. For VL muscle a corresponding relationship was not detected.

The eccentric EMG : force ratio was sensitive to changes in the jumping condition (Fig. 5). For the GA and SOL muscles clear decreases in the EMG : force ratio were observed with increases in the stretch load in all the types of jumping exercise. However, for the VL muscle these changes were more irregular. This was also the case in the concentric phase. Only in the SlJ exercise could a corresponding decreasing trend be detected for the GA and SOL muscles.

Discussion

The results of the jumping performance parameters can be summarized as follows. In LBJ the conditions with reduced as well as with added g, the duration of all phases of the total ground contact was increased compared to g. The mean ground reaction forces showed higher values in normal g, even higher than in added g. In the DJ there were no noticeable changes in the duration of the phases of the ground contact. However, the ground reaction forces were increased with increases in the dropping height. In SlJ the lower stretching loads were associated with the lower durations of the contact phase. Thus, lower duration resulted in lower ground reaction forces. The highest take-off velocities were different depending on the type of stretch exercise. In the LBS it was from the intermediate level (g), in DJ it was from the high level (DJ66) and in SlJ it was from the low level.

It can be assumed that the reasons for these contradictory results can be related to the overall control mechanisms of the neuromuscular system and to its functional responses to the different types of muscle stretching load or to the mechanical effect of the load to the contractile part of the muscle.

It has been well documented that the electrical activity prior to the ground contact is the primary sensitive feature with respect to the various load conditions (Avela et al. 1994; Dietz et al. 1981; Gollhofer and Kyröläinen 1991). This was also the case in the present study. Furthermore, the eccentric part of the contact showed similar mean EMG changes compared to the pre-activation phase. The only exception to this was in respect of the GA and SOL muscles in SlJ. However, there was a high correlation between these two phases, as well as between these phases and the eccentric peak angular velocity of the ankle joint in all the different types of jump. The peak angular velocity of the ankle joint can be considered as a rough estimation of the peak muscle stretching velocity changes of the triceps surae muscle. These variables have been found to be closely related to the function of the segmental stretch reflex. This is in an agreement with the results of Gottlieb and Agarwal (1979) who have found a linear relationship between the velocity of the imposed stretch and the magnitude of the spinal stretch reflex.

According also to Dietz et al. (1981) high stretch velocity as well as the existence of pre-activity at the moment of impact, might be responsible for the appearance of the spinal stretch reflexes. Thus, according to these interactions it can be assumed that the function of the pre-activation of the triceps surae muscle is

1. To trigger an adequate segmental reflex activity for producing a corresponding stiffness to support the body and
2. To buffer high initial force peaks (Gollhofer et al. 1984).

Figure 6 was constructed to demonstrate the presence of the short latency component of the reflex activation. As an example the averaged EMG of the SOL muscle of one subject has been drawn together with the instant of touchdown and the short latency reflex component. The latter has been based on the suggestion of Lee and Tatton (1978) for the M1 component of the

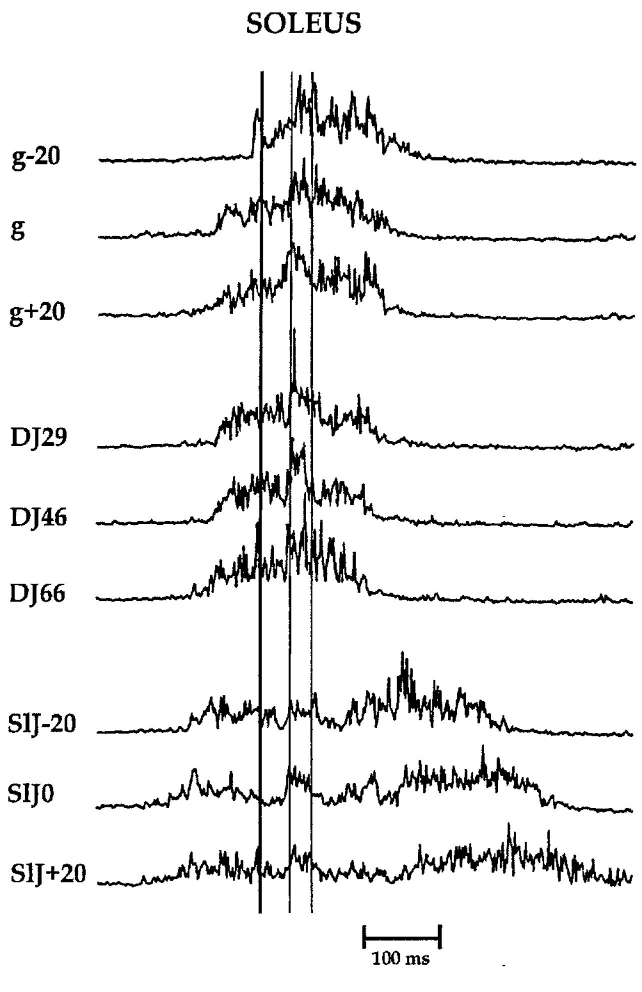

Fig. 6 Example of the electromyogram of the soleus muscle from one subject in all the types of jumping exercise and conditions. The *first vertical line* indicates the instant of touchdown and *the thin vertical lines* indicates the time for the M1 component of the stretch reflex activity as devised by Lee and Tatton (1978). For definitions see Figs. 2 and 3

human wrist extensors. The latency and the shape of the response in the EMG pattern match well the data presented in the literature. The M1 component is more obvious than expected in all the types of jump. The reason for this might be that the amplitude of the phasic M1 response was independent of the level of the background EMG activity as has been suggested by Toft et al. (1989). In addition, in all the types of jump the imposed stretch seemed to be strong enough to trigger the segmental reflex activity. However, there have been some other suggestions (Hunter and Kearney 1982; Matthews 1986) which have emphasized that the automatic gain principle should increase the M1 amplitude in proportion to the background EMG and also, in this case, in proportion to the increasing stretch load.

In the present study, the occurrence of the stretch reflex activity could be seen more clearly in the SOL muscle. The reported reduction of the EMG activity (Greenwood and Hopkins 1976) in the two joint muscle GA could have resulted in the M1 component not always being observed in this muscle. Therefore, it was note worthy that the mean EMG activity of the SOL muscle increased significantly from the preparatory phase to the eccentric phase and decreased again in the concentric phase in all the types of jump. Thus, it could have been that during the eccentric phase of the contact, while the GA EMG activity was reduced, strong background activity from the SOL muscle may have been essential. This is in an agreement with the study of Toft et al. (1991) who have found that the SOL muscle generates about two-thirds of the maximal torque of the triceps surae muscle with the subjects in a sitting position.

Nevertheless, it has been reported that the spinal stretch reflex can also contribute mechanically to active muscle shortening during the following push-off phase (Dietz et al. 1979). Therefore, for DJ and LBJ it would seem reasonable to suppose that the high pre-activation level also resulted in high eccentric activity, leading to powerful output of the muscles in the concentric phase by the reuse of the stored elastic energy as has been demonstrated by Asmussen and Bonde-Petersen (1974).

In LBS in $g + 20$ as well as in $g - 20$ the mean amount of EMG was reduced in both the pre-activation and eccentric phases. These results might imply adaptation of the neuromuscular system to natural g. Higher occurrence of the stretch reflex activity could also be expected as a consequence of the adaptation. Dietz et al. (1989) have reported decreased muscle proprioceptive reflex mechanisms on postural adjustments underwater simulating a (low gravity situation). It could be assumed that unexpected gravity conditions might reduce muscle spindle activity in low gravity situations. Thus, in $g + 20$ the increased acceleration might have led to a delay in central programming. However, in both cases the preparatory function to produce adequate stiffness for resisting high impact forces was weakened. This might also have led to an insufficient use of the elastic energy in the concentric phase (Komi 1984) and to a decreased ability to jump reactively.

As Melvill Jones and Watt (1971) have suggested, it seems that the control of landing is strongly pre-programmed from higher centres and at least in part, has been learned through previous experience. However, it has been suggested that adaptation of the neuromuscular control might occur faster to high g compared to low g (Avela et al. 1994). This idea would seem to be supported by the results from the eccentric integrated EMG-force relationship, which showed equal values in added g with respect to the g and clearly increased values in reduced g.

The other possible explanation for the lower results in the basic performance characteristics as well as for the lower EMG values in LBS in $g + 20$ could be the protection mechanism of the tendomuscular system to prevent high impact forces. However, this explanation would not be in an agreement with the results of DJ. In DJ the highest take-off velocity and EMG parameters were obtained from the highest load (DJ66) as expected for these subjects. This means that in $g + 20$ the artificial stretch load did not exceed the stretch load of an optimal dropping height for any of the subjects.

In SlJ the results from the eccentric and the concentric muscle output are not in agreement with the previous remarks. The highest take-off velocity should have been related to a higher muscle stiffness and better use of the elastic energy. This was not the case for SlJ. For methodological reasons the technique for performing SlJ differed from that of DJ and LBJ. In SlJ the extra loads could not be blocked-off at the moment of touchdown, in this way the extra mass loaded the neuromuscular apparatus during the whole contact period. This would mean that the muscles had to work against a greater body mass during the increased loads. Thus, the task of the movement was to produce preparatory functions to create adequate high stiffnesses to resist increase body masses. This might have caused changes to EMD as well, when comparing SlJ to the other jumping exercises. The increased force production time could have prolonged EMD. This could have led to a longer electromechanical coupling time between the eccentric and concentric phases. Therefore, the use of the elastic energy could have been reduced compared to the other types of jump. Furthermore, SlJ was performed in a sitting position, which reduced the use of the hip extensor muscles. However, the decreased performance ability with increased stretching velocity was a natural result of all of these possibilities.

Schmidtbleicher and Gollhofer (1982) have suggested, that muscle pre-activation is regulated by the expected muscle load, as a result of several years of learning. In the present study in all the types of jump the amount of PRE EMG of the GA and SOL muscles was strongly related to the peak muscle stretching velocity and the stretch load. Komi et al. (1987) have made a similar finding in running, where the pre-activation was related to the running velocity. Consequently, the expected high muscle stretch should result in a high pre-activation level. However, as in our earlier study (Avela et al. 1994), in LBJ both of these parameters were reduced even in $g - 20$ although these jumps were performed from a higher dropping level. According to Schmidtbleicher and Gollhofer (1982) higher dropping heights should result in a higher pre-activation time and EMG values. This was also the case in DJ in the present study. Therefore, it is possible to assume, as we have earlier stated (Avela et al. 1994), that the control of landing is not solely regulated by previous learning, but is also influenced by the relatively fast adaptation of the vestibular apparatus. The effect of visual control also should not be disregarded. The involvement of the visual system in locomotion has been reported form animal experiments to be connected to changes in neuronal activity in the motor cortex (Hancock 1985) and possibly to have excitatory actions mediated over the lateral vestibulospinal and reticulospinal tracks mainly on α-motoneurons.

In SlJ the subjects were unable to feel the effect of the extra mass in the starting position of the jump, while they were supported in the sledge track by an assistant. However, they did have knowledge of the expected muscle stretch load. It could be seen from the precontact activation parameters, that this earlier information, lacking knowledge from experience, could modify the central programme so that the increased stretch load resulted in higher pre-activation levels.

It has been reported by Dietz (1992) that the actual loading of proprioceptive, vestibular and visual inputs to the equilibrium control is context-dependent and profoundly modifies the central programme. This is in good agreement with the results of this study, and also in respect of more intensive SSC type of movement. Thus, information of the expected muscle load must also be emphasized from these results, even without earlier experience.

In conclusion, the pre-activation level of the muscles was strongly related to the peak muscle stretching velocity and to the eccentric muscle activation parameters. These did not necessarily result from the highest expected muscle load as those observed in LBJ. The results of LBJ showed considerable adaptation of the neuromuscluar system to the normal g, which has been fully discussed in our earlier paper (Avela et al. 1994). The observed results would also suggest a strong interaction between the pre-activation and the reflex-controlled muscle stiffness as well as the subsequent use of the stored elastic energy.

It seems reasonable to assume that there are many factors which affect preparatory muscle activation. It is obvious that the pre-activation part of landing is, at least inpart, preprogrammed. However, the total control mechanism may also depend on the proprioceptive, vestibular and visual inputs, which might modify even the earlier learned central programmes. Thus, the possibility of conscious modification of the expected muscle load, even without earlier experience must also be considered.

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