KINETIC ENERGY OF BODY SEGMENTS IN DROP JUMP EXERCISES

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INTRODUCTION

In sport movements, such as sprinting and jumping, where the ability to produce explosive movement is extremely important, the elastic characteristics of the muscle-skeletal system are decisive (Alexander & Ker, 1990) (Anderson & Pandy, 1993). Drop jump (DJ) exercises are often used as a training method to develop the mechanical and control capabilities of the neuromuscular system (Bobbert et al. 1987). DJ have also been used to obtain very important data about the degree of adaptability of the locomotor system to tolerate high mechanical loads, using different dropping heights (Gollhofer et al. 1992). The purpose of this study was to analyse the changes of the kinetic energy of body segments (KE) induced by different mechanical loads, both in the stretching and push-off phases. These changes were related to the angular kinematics of joints and to the relative length changes of some leg extensor muscles.

METHODS

Four elite sprinters (height 178±5 cm, body mass 69.3±4.5 kg) performed 6 DJ from 25, 40, 55 and 70 cm. Ground reaction forces were recorded at 500Hz and the vertical peak and vertical net impulse were calculated. Simultaneously, angular kinematic data of the ankle, knee and hip joints were calculated using a video analysis system (120 Hz). Joint landmarks co-ordinates were filtered with a 15 Hz Hamming low pass filter and the co-ordinates were combined with anthropometric data from Winter (1992) to obtain positions of mass centres of segments as well as the position of the total body mass centre. Grieve (Grieve et al., 1978) and Visser (Visser et al.,1990) models were used to calculate the relative length changes (%L) of gastrocnemius (GAS), rectus femoris (RF) and biceps femoris (BF) muscles. The joint angular velocity (ω) and relative muscle length changes velocity (%L.s^{-1}) were also calculated. The KE energy of the foot, lower leg, thigh and upper body mass centres were calculated from the kinematic data. Kinematic and force platform data were synchronised. After time normalisation force, position angle and the percentage of muscle length signals were averaged for each jumping condition. Statistical analysis of the differences between jumping heights were tested for significance using a Student's T-test for paired comparisons, and a 5% level of confidence was accepted.

RESULTS

Table 1 summarise the results for the mechanical work and net impulse during the downward movement and during the push-off phase, for each of the four jumping heights. The value of the vertical force peak is also presented on table 1.

The jumping performance did not show statistically differences among the four conditions, considering the net impulse and mechanical work variables. Nevertheless, the higher net impulse and total mechanical energy at the end of push-off phase, was obtained during the DJ40 trials and DJ55 trials.

The amount of negative work increased with the increase of jumping height. During SP25 and SP40 the difference between the work done during the lengthening phase and the work done during the push-off phase was positive. When jumping from a height of 55 cm the subjects produced the same amount of mechanical work during both phases while at SP70 a negative energy balance was present, between lengthening phase and the push-off phase. These results and the higher initial vertical force peak values obtained during the jumps from 55 and 70 cm suggested that a considerable amount of energy was transferred to the bone and other passive structures of the body and was dissipated (Cole et. al.).

Table 1 - Kinetic energy, vertical net impulse and vertical force peak.

Downward Movement

		SP25	SP40	SP55	SP70
KE	Foot	5.4 ±0.4	5.4 ±0.2	8.0 ±0.8	8.2 ±0.6
joule	L.leg	20.6 ±2	22.7 ±1.2	29.7 ±1.2	37.7 ±2
	Thigh	58 ±12	66 ±4.2	91 ±9.8	104 ±7.9
	Up.body	175 ±9.6	226 ±20	286 ±14 *	373 ±16 *†‡
	Total body	254 ±13	318 ±17	408 ±21 *	523 ±24 *†‡
N.s.kg^{-1}	Net Imp.	2.3 ±0.2	3.2 ±0.3	3.6 ±0.5 *	4.2 ±0.4 *†‡
		Push-off Phase			
KE	Foot	1.4 ±0.4	2.12 ±0.6	3.17 ±0.3	2.6 ±0.3
joule	L.leg	14 ±3	18.0 ±1.9	21 ±2.1	18.5 ±0.8
	Thigh	55 ±7	54.8 ±6.5	64 ±3.2	57.8 ±4.6
	Up.body	265 ±32	291 ±14	280 ±11	273 ±10
	Total body	342 ±17	358 ±12	385 ±23	340 ±17
N.s.kg^{-1}	Net Imp.	2.7 ±0.6	3.4 ±0.7	3.2 ±0.2	3.0 ±0.4
N	Fz Peak	3660 ±143	3800 ±125	4929 ±163	5570 ±148 †‡

* The value of DJ70 and DJ55 differs from the value of DJ25
† The value of DJ70 differs from the value of DJ40 and DJ25
‡ The value of DJ70 differs from the value of DJ25

The variables that characterise joint movement and muscle length variation are presented on table 2. Considering all three joints, the initial and final angular positions as well as total angular movement presented similar values when the subjects performed from the four different jumping highs. In the same way, no differences were detected on hip angular velocity among the four conditions. Whoever, negative peak value of angular velocity increased for both ankle and knee joints as dropping height increased (table 2).

During the push-off phase ankle and knee angular velocities attained higher values at DJ40 and DJ55

The total length change of gastrocnemius increased, slightly from 4.07% at DJ25 to 7.5% at DJ70, during the lengthening phase. A similar behaviour was observed on the rectus femoris with average values increasing from 4.7% at DJ25 to 7.8% at DJ70. The values attained by the total length change of biceps femoris were substantially higher when compared with the length changes obtained from GAS and RF. Total %L change on BF, during the lengthening phase, varied from 5.0% at DJ25 to 18.2% at DJ70. Gollhofer et al. (1992) discussed the elastic behaviour of the muscle tendon complex as function of the short range elastic stiffness. The range of imposed muscle length changes play a major role determining the limits of these elastic properties, apparently when length changes attained values near 8% of resting length the stretch load is excessive and the muscle tendon complex tends to present a reverse energy balance. The muscles length changes values obtained from DJ70 during the lengthening phase on GAS and RF, and particularly on BF, suggested that the stretch load limits were exceeded, explaining the negative kinetic energy balance illustrated on table 1.

Table 2 - Joint and muscle length change variables

Downward Movement

		SP25	SP40	SP55	SP70
max. ω rad.s^{-1}	Ankle	-14.2 ±1.2	-15.8 ±1.3	-17.8 ±2.3*	-21.6 ±2.1*†
	Knee	-11.4 ±1.4	-12 ±3.2	-12.6 ±1.3	-14.9 ±1.3‡
	Hip	-4.6 ±0.7	-5.3 ±1.6	-5.4 ±0.3	-8.3 ±0.4‡
%L .s^{-1}	GAS	122 ±19	142 ±7.5	167 ±12*	207 ±5.7*†
	RF	79.9 ±14	89.3 ±5.9	98.3 ±8.1	106 ±8.3 ‡
	BF	182 ±25	274 ±13	234 ±12 *	361 ±13 *†
		Push-off Phase			
max. ω rad.s^{-1}	Ankle	10.5 ±0.6	15.8 ±3	15.1 ±0.9	16 ±1.7
	Knee	11.5 ±1.1	15.7 ±2.3	15.6 ±1.0	16.6 ±2 1
	Hip	7.8 ±0.5	10 ±1.3	10.6 ±1.5	10 ±3
%L .s^{-1}	GAS	-100 ±7	-157 ±19	-147 ±7.9	-152 ±12
	RF	-112 ±4.5	-120 ±7.5	-118 ±9.0	-120 ±14
	BF	-426 ±20	-436 ±35	-406 ±23	-420±17

* The value of DJ70 and DJ55 differs from the value of DJ25

† The value of DJ70 differs from the value of DJ40 and DJ25

‡ The value of DJ70 differs from the value of DJ25

Table 2 shows peak lengthening velocity values from GAS, RF and BF. These values increase with the increase of dropping height for the three muscles studied. For GAS the lengthening velocity ranged from 122 %Ls^{-1} at DJ 25 to 207 %Ls^{-1} at DJ70. On RF, lengthening velocity varied from 79.9 %Ls^{-1} at DJ25 to 106 %Ls^{-1} at DJ70, finally BF presented lengthening velocity increase from 182 %Ls^{-1} at DJ25 to 361 %Ls^{-1} at DJ70. During the shortening phase no differences were found with the increase of dropping height both in length changes as well as in shortening velocity values. The values obtained for the RF shortening velocity are in agreement with those presented by Visser et. al. (1990).

Considering the temporal muscle co-ordination between RF and BF our data shows that BF begins is shortening action 40 to 50 ms before RF. When BF is contracting concentrically, delivering energy for the elevation of the upper body, RF is contracting eccentrically taking up part of these energy produce by BF, as illustrated by Figure 1. This mechanism explains one of the ways of energy transfer done by bi-articular muscles as suggested by Bobbert & Van Ingen Schenau (1988). The raise of RF contracting velocity at the end of push-off phase probably leading to a decrease of the contracting force due to the force-velocity relationship of the muscle tendon complex suggest that elastic energy will be delivered by the delivered by the elastic structures of the muscle. The work can be produced by the muscle as well as elastic energy is released by tendinous tissues in the concentric phase of the contraction

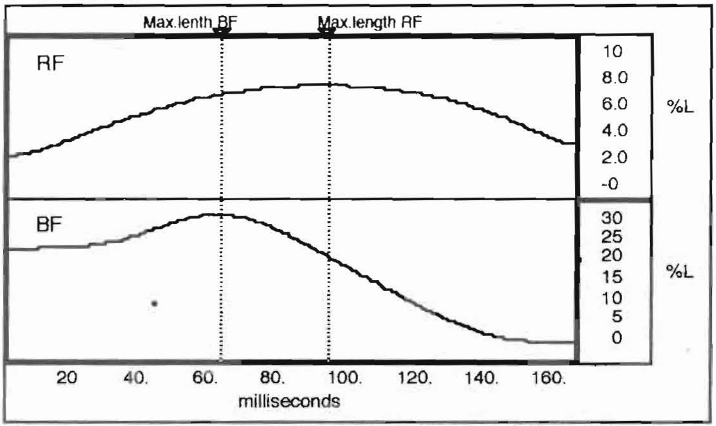

Figure 1- Percentage of length change for RF and BF during DJ40. Average signal for the 4 subjects.

CONCLUSION - The KE of the body segments at the end of push-off was higher on DJ25 and DJ40, when compared with the KE at touchdown, presenting a positive energetic balance. At DJ55, the energetic balance was null and at DJ70 was negative. This results suggested that for the highest stretch loads the elastic stiffness of the muscles was exceeded. The stretching velocities increased in all muscles with the increase of DJ height. Nevertheless, no differences were found on vertical jumping achievement between DJ executed from different heights. The subjects were able to reduce the increasing stretching load producing higher vertical net impulses during the downward movement.

REFERENCES

Alexander, R M., & Ker, R.F. (1990). The architecture of leg muscles. In J.M. Winters & S.L. Woo (Eds.), *Multiple muscles systems, biomechanics and movement organisation* (pp. 568-577). New York: Springer -Verlag.

Anderson, R.M. & Pandy, M.G. (1993). Storage and utilisation of elastic strain energy during jumping. *Journal of Biomechanics*, 26, 1413-1427.

Bobbert, M. F. , Huijing, P.A., & Van Ingen Schenau, G.J., (1987). Drop jumping II. The influence of dropping height on the biomechanics of drop jumping *Medicine and Science in Sports and Exercise*, 19, 4: 339-346

Bobbert, M. F. & Van Ingen Schenau, G.J., (1988) Coordination on vertical jumping. *Journal of Biomechanics* , 21:249-262.

Gollhofer, A., Strijnick, V., Rapp, W., & Schweizer, L. (1992). Behaviour of triceps surae muscle-tendon complex in different jump conditions. *Eur J Appl Physiol*, 64: 283-291

Grieve, D.W., Cavanagh, P.R., & Pheasant, S. (1978). Prediction of gastrocnemius length from knee and ankle joint posture. In Asmussen E. , Jorgensen K. (eds) *Biomechanics, international series on biomechanics VI-A* , (pp. 405-412) University Park Press, Baltimore.

Visser J.J., Hoogkamer, J., Bobbert, M.F. & Huijing, P.A. (1990). Length and moment arm of human leg muscles as a function of knee and hip-joint angles *Eur J Appl Physiol*, 61: 453-460