

JOINT WORK OF THE TAKE-OFF LEG DURING ELITE HIGH JUMP

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The purpose of the study was to evaluate kinematics and kinetics in elite high jumpers and to estimate joint work of the lower extremity with a custom-modified full-body model. Motions of seven male athletes (personal best 2.24 ± 0.06 m) during jumping were filmed with 19 Infrared-Highspeed-Cameras and ground reaction forces were captured with a force plate. The results show that knee joint energy absorption is twice as much as at the ankle joint ($p < 0.05$). There was no significant difference ($p > 0.05$) in energy generation between the knee and ankle joint, but the ankle joint generates more energy than it absorbs ($p < 0.05$). The problem-solving approach to raise the center of mass to 2.10 m was different between the jumpers.

KEY WORDS: metatarsophalangeal joint, ankle joint, knee joint, energy, elite high jump.

INTRODUCTION: The mechanical aim of a high jump is vertical displacement of the body's center of mass (COM). Therefore the athlete produces upward forces in order to produce upward velocity. The upward velocity and the height to which the COM has to be raised depend amongst others (e.g. energy of the COM) on the energy output at the joints of the lower extremities. In principle, the muscle-tendon work performed during movement can be estimated from the integration of the mechanical power over a period of time at a joint. Estimations of joint work during high jump might help to control training and to enhance performance. Detailed studies exist about the kinematics of the high jump (e.g. Dapena & Chung, 1988, Brüggemann & Glad, 1989; Alexander 1990; Arampatzis & Brüggemann, 1999; Isolehto, Virmavirta, Kyröläinen, & Komi, 2007), but kinetic analyses are rare in the current literature (Deporte & Van Gheluwe, 1989; Coh 2010). To the best of our knowledge, there is no inverse-dynamic approach available about joint kinetics during elite high jump. Therefore the purpose of this study was to investigate lower leg joint work within a homogeneous group of highly trained high jumpers.

METHODS: Motions of seven male athletes (personal best 2.24 ± 0.06 m) during jumping were filmed with 19 Infrared-Highspeed-Cameras (300 Hz, Vicon, Oxford, UK) and ground reaction forces were captured with a force plate (1200 Hz, Kistler, Winterthur, Switzerland). Kinematics of the full body were determined using 69 retro-reflective, spherical markers. For estimation of mechanical work done in the sagittal plane at the metatarsophalangeal joint (MPJ), ankle joint and knee joint, a custom-modified full-body model (Alaska, Chemnitz, Germany) was used. A Wilcoxon signed-rank test was used to identify significant differences in energy absorption and generation. The level of significance was defined as $\alpha = 0.05$.

RESULTS: Five of seven jumpers crossed the bar at 2.10 m, one at 2.05 m and one at 2.00 m. Run-up velocities ranged between 6.0 and 7.5 ms^{-1} . Maximum vertical ground reaction forces attained 56.5 to 78.3 N kg^{-1} and horizontal forces 35.6 to 46.8 N kg^{-1} . The energy loss

of the seven jumpers during take-off differed between 6.9 and 10.2 J kg⁻¹ (8.6 ± 1.0 J kg⁻¹). Interestingly, energy input at the knee was higher than energy output ($\Delta W = -1.21 \text{ J kg}^{-1}$, $p < 0.05$). In contrast, energy output at the ankle was higher than energy input ($\Delta W = 0.51 \text{ J kg}^{-1}$, $p < 0.05$) (table 1). Energy input at the knee joint was twice as much as at the ankle joint ($p < 0.05$), but energy output differed not significantly between the two joints ($p > 0.05$). Compared to the ankle and knee joint, energy input (0.07 ± 0.05 J kg⁻¹) and output (0.03 ± 0.01 J kg⁻¹) at the MPJ was small.

Table 1
Energy input (-) and output (+) at the metatarsophalangeal (MPJ), ankle, and knee joint (J kg⁻¹) during take-off of the seven athletes and mean ± SD.

athlete	MPJ (-)	MPJ (+)	ankle (-)	ankle (+)	knee (-)	knee (+)
A01	0.10	0.02	1.34	1.62	1.98	1.33
A02	0.06	0.04	0.79	1.45	3.20	1.53
A03	0.17	0.03	1.16	1.61	2.58	1.53
A04	0.04	0.03	0.73	1.44	2.36	1.40
A05	0.04	0.02	0.73	1.23	2.11	0.97
A06	0.06	0.03	0.76	1.35	2.21	0.78
A07	0.01	0.06	1.00	1.39	2.65	1.10
mean	0.07	0.03	0.93	1.44*	2.44*	1.23[#]
SD	0.05	0.01	0.24	0.14	0.41	0.29

*sig. different ($p < 0.05$) to ankle (-), [#]sig. different ($p < 0.05$) to knee (-).

DISCUSSION: The only source of mechanical energy generation in the human body is the muscle. But the patterns of energy generation, absorption, storage and release by muscles and tendons and through the joints are quite complex. However, energy absorption and storage during jumping occur when the plantarflexor muscle-tendon unit of the ankle or the extensor muscle-tendon unit of the knee are lengthened during ankle dorsiflexion or knee flexion. Energy is generated when the large extensor muscles (triceps surae and quadriceps femoris) do positive work by concentric contraction. In this case, the extensor muscles do work on the foot or shank segment. During high jump, the energy output at the ankle and knee was 1.44 J kg⁻¹ and 1.23 J kg⁻¹, respectively. Lees, Vanrenterghem, and de Clercq (2004) also showed that during maximal vertical jumps the energy output at the ankle (2.06 J kg⁻¹) was a little higher than at the knee (1.94 J kg⁻¹). Bobbert, de Graaf, Jonk, and Casius, (2006) found positive joint work during one-leg squat jumps of 1.29 J kg⁻¹ for the ankle and 1.06 J kg⁻¹ for the knee joint. In comparison to the toe flexors at the MPJ, it is evident that the major contributors at take-off are the plantarflexors of the ankle and the extensors of the knee. The MPJ is more or less irrelevant for energy output. One should consider that joint work at the hip was not estimated in this study.

CONCLUSION: It can be concluded that the ankle and its spanning structures do positive net joint work and therefore produce energy output during the take-off of high jump. In contrast, the knee and its spanning structures do negative net joint work during the take-off of high jump. Further, it was found that different joint work at the take-off leg enables the same jumping height (2.10 m). It seems that jumpers with different physical characteristics and techniques have the possibility to compete successfully at the highest international level. Information about muscle and tendon properties would provide more insight into the energy generating capacities of the athletes.

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