SPRING JUMPERS VS POWER JUMPERS: ROLE OF THE ANKLE JOINT IN ELITE WUSHU PERFORMANCE AND INJURY RISK

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The purpose of this study was to characterize two jumping strategies observed in elite wushu athletes: power and spring jumping. Inverse dynamics analysis was conducted on 12 male wushu athletes performing squat jumps, drop jumps and wushu-specific acrobatic jumps. Ankle laxity and Achilles tendon elasticity were also measured. Spring jumpers showed lower ankle laxity and a bilinear evolution of overall ankle stiffness during the concentric phase of the stance, compared to power jumpers. They also showed higher peak valgus reaction moments at the knee joint. Tendon elasticity was similar between groups. As spring jumping strategy is more efficient in terms of energy expenditure and fatigue dependence, lower limb injury risk can be higher. Attention must be paid to athlete-specific jumping strategies for personalized conditioning and injury prevention.

KEY WORDS: jumping, stretch-shortening cycle, ankle, stiffness, acrobatics.

INTRODUCTION: Wushu, better known as kungfu, is the modern athletic form of Chinese martial arts, and consists of performing a routine of martial arts movements as well as acrobatic jumps. Since those acrobatic jumps are performed on a hard floor, vertical jump height plays a major role in elite performance. Wushu coaches often mention two different types of athletes: spring jumpers and power jumpers. From this empirical point of view, spring jumpers seem to jump more easily.

As in many sports, wushu jumps are performed with a run up followed by a stance phase with eccentric and concentric phases, often referred to as a "Stretch-Shortening Cycle" (SSC) in the literature. Vertical jump height in this case is the result of three main components acting during the concentric phase: muscle fiber shortening, coordination between joints and recoil of elastic energy stored during the eccentric phase. Whereas the Squat Jump exercise (SJ) is used to evaluate the first component, the Drop Jump (DJ) can be used as a standard exercise to analyze the whole SSC. The overall ability of an athlete to benefit from a previous eccentric phase can be evaluated by the ratio of DJ and SJ performances. This Pre-Stretch Augmentation (PSA) (Kubo et al., 2007) is one possible index to distinguish between types of jumper.

Storage and recoil of elastic energy in the lower limbs can be studied with a spring-mass model. However, it does not enable understanding of which joints are involved. Inverse dynamics methods enable estimation of joint torques, but cannot explain which part of these torques is due to muscle fiber shortening or to elastic energy recoil. Joint behavior can be characterized by the evolution of joint torque with respect to joint angle during the different phases of the support phase, with the slope being considered as overall joint stiffness.

The ankle joint has often been studied for its involvement in elastic energy storage and recoil during SSC. Ankle joint resistance to dorsiflexion can be seen as the sum of a muscle-tendon stiffness and an articular stiffness (bone contacts, ligaments…). The first of these has been largely studied through Achilles tendon stiffness, However there is currently no consensus on its link with the beneficial use of the eccentric phase (Kubo et al. 2007; Rabita, Couturier & Lambertz, 2008). The second of these can be neglected throughout most of the ankle range of motion, but can play an important role when the knee is flexed and the ankle dorsiflexion angle is close to its limit. These two conditions are verified at the transition between eccentric and concentric phases. This articular stiffness, linked with ankle laxity, can

be estimated by measuring maximum dorsiflexion angle, with body weight loading and knee flexed (Jones, Carter, Moore & Wills, 2005).
The aim of the present study was to characterize spring and power jumpers in elite wushu athletes in terms of PSA, ankle laxity, overall ankle stiffness during the concentric phase and Achilles tendon shear elastic modulus. The influence of the chosen jumping strategies on performance and injury risk will be also discussed.

METHODS: After standardized warm-up and maximal ankle dorsiflexion angle measures, 12 athletes of the French wushu team performed 3 repetitions of SJ and DJ, before performing 31 specific wushu jumps. 42 reflective markers were placed over skeletal landmarks. Kinematics were registered at 300 Hz with a 13 camera Vicon system and ground reaction forces with 2 AMTI force plates at 900 Hz. Marker positions were filtered with an adaptive filter and body segment inertial parameters were personalized. Ankle, knee and hip joint reaction moments, forces and powers, calculated using inverse dynamics, as well as ankle flexion angle were expressed between 0 and 100% of the support phase, and normalized by the body mass.
For SJ and DJ, performance was defined as the maximum height of the Center of Mass (CoM) during the flight phase minus the CoM height in the static position. Data of the best performance for each subject in SJ and DJ were kept for analysis. Pre-stretch augmentation (PSA) was defined as the ratio between the maximal performance in DJ and the maximal performance in SJ, minus 1. For the DJ, plantar flexion moments were plotted versus ankle flexion angles, and two linear regressions were performed for the two halves of the concentric phase. The two regression slopes were defined as the ankle dorsiflexion stiffness in the first half of the concentric phase (k_1) and the ankle dorsiflexion stiffness in the second half of the concentric phase (k_2) in Nm/°.
PSA results during DJ enabled the separation of the athletes into 3 groups of 4 subjects: power jumpers (low PSA), medium jumpers (medium PSA) and spring jumpers (high PSA).
Peak reaction moments, peak power, concentric work and eccentric work at ankle, knee and hip joint were calculated in the three groups for every jump performed (31 jumps).
Achilles tendon elasticity was measured with shear wave elastography using Aixplorer (Supersonic Imagine, Aix-en-Provence, France) coupled with an 8 MHz probe. Subjects were lying prone on a table, knee fully extended and feet out. A significant amount of gel was applied, and the shear elastic modulus was measured with the probe parallel to the fibers (Aubry et al., 2013).
Training experience and injury history were evaluated using a questionnaire. Wilcoxon tests were performed for statistical analysis, with spring jumpers as reference.

RESULTS: PSA was different between groups whereas performance, anthropometric data and training experience were similar. In power and medium jumpers, k_1 was lower than in spring jumpers ($p<0.05$). Maximal dorsiflexion angle was lower in power jumpers than in spring jumpers ($p<0.05$). Typical flexion moment vs. flexion angle curves for spring (a) and power (b) jumpers, and their respective k_1 and k_2 are presented in figure 1. Peak valgus reaction moments were higher in spring and medium jumpers ($p<0.01$). No significant differences were found between spring and power jumpers for concentric as well as eccentric power and work. Shear elastic modulus of the Achilles tendons was similar between groups. Main results are presented in table 1.

DISCUSSION: The bilinear evolution of ankle stiffness in spring jumpers can be interpreted as two different mechanisms predominating consecutively during the concentric phase. The first and higher slope could be mainly explained by the passive shortening of previously deformed articular structures, whereas the second and lower slope could be the effect of the active shortening of the triceps surae muscle fibers. In power jumpers, the second mechanism appears to be predominant.

Table 1: Main results for the 3 jumper types (*: p < 0.05; **: p < 0.01)

	Spring (n=4)	Medium (n=4)	Power (n=4)
DJ PSA (%)	19 ± 3	12 ± 2	7 ± 2
DJ performance (cm)	54 ± 7	46 ± 5	54 ± 6
DJ k_1 (Nm/°)	5.5 ± 2.6	3.0 ± 2.3 *	2.9 ± 1.2 *
DJ k_2 (Nm/°)	1.5 ± 0.3	1.5 ± 0.6	1.9 ± 0.4
Maximal Dorsiflexion Angle (°)	74 ± 3	74 ± 5	68 ± 6 *
Achilles Tendon Shear Elastic Modulus (kPa)	386 ± 98	405 ± 108	426 ± 67
Peak knee valgus reaction moment (31 jumps) (Nm/kg)	0,62 ± 0,1	0,67 ± 0,4	0,50 ± 0,1 **

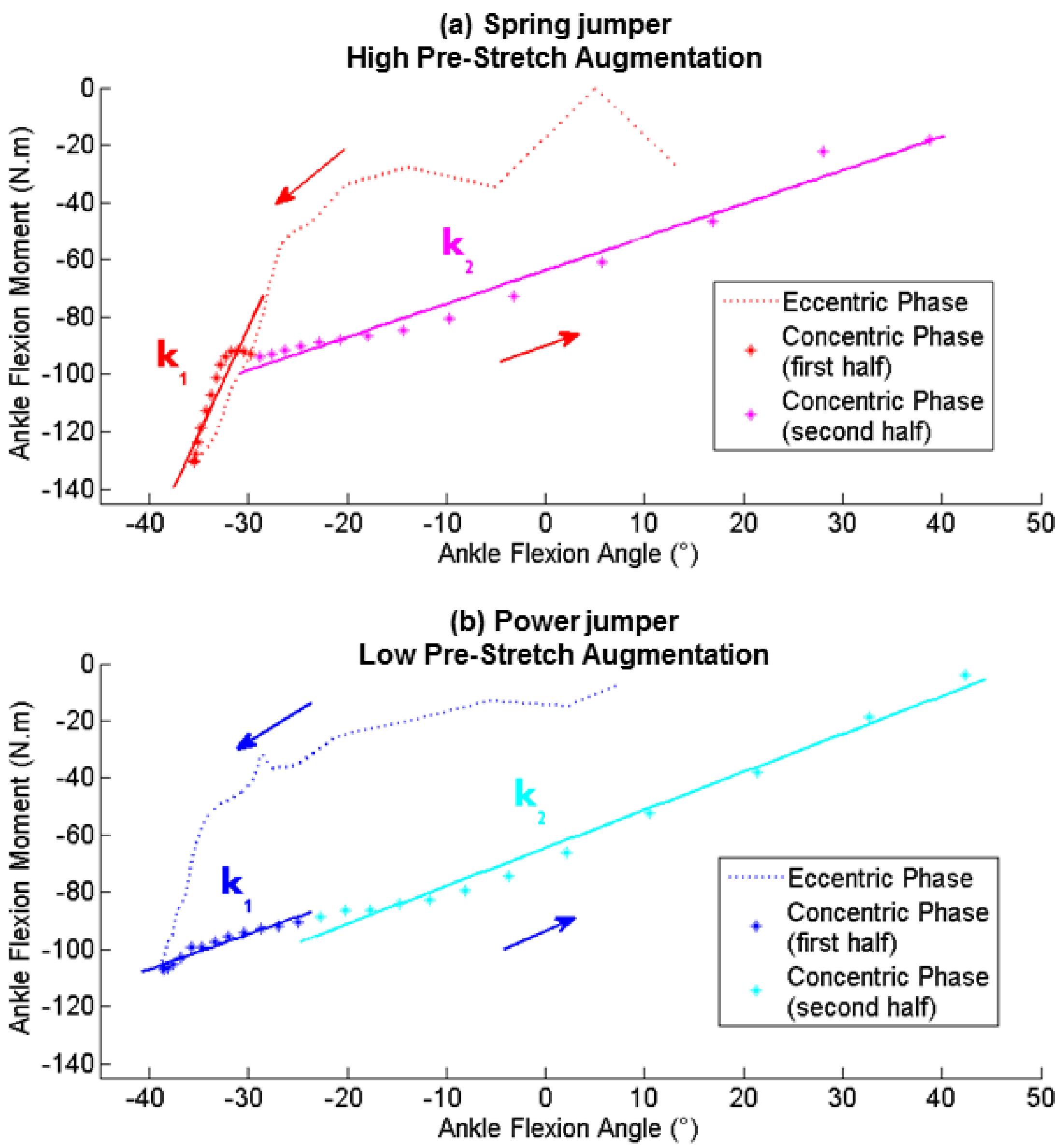

Figure 1: Ankle typical behavior in spring (a) and power jumpers (b) during the drop jump stance phase. Linear regressions (full line) represent overall ankle stiffness during the first (k1) and the second half (k2) of the concentric phase.

The higher maximal dorsiflexion angle observed in power jumpers could explain the difficulty for these athletes in the storage and recovery during recoil of elastic energy at the ankle joint, and their choice of a predominant ‘active strategy’ during the concentric phase, in contrast to the ‘combined active-passive strategy’ used by spring jumpers. Coaches sometimes call spring jumpers ‘calf jumpers’ (Wu, 2007), but in light of these results ‘ankle jumpers’ seems to be more appropriate.
Peak valgus reaction moment at the knee joint, in response to an external adduction moment, is often used as an index of knee osteoarthritis risk (Haim et al., 2012). In their injury history, the 4 spring jumpers were indeed more affected at knee level compared to power jumpers, but the small population does not allow statistical interpretation.
Although ankle laxity was higher in power jumpers, Achilles tendon shear elastic modulus didn’t show significant differences between groups. The differences between groups might have been smaller than measurement reproducibility, which has been reported as relatively low in tendon (Aubry et al., 2013). A standard procedure to accurately measure Achilles tendon mechanical properties using shear wave elastography still needs to be determined.
As PSA in the drop jump is not only dependent on the ankle joint, medium jumpers used both strategies at the ankle level without showing any characteristic ankle strategy.

CONCLUSION: Concerning performance, absolute jump height was similar between power and spring jumpers, so their performance for acrobatic jump heights in competition would be similar. On the one hand, spring jumpers are the most efficient in terms of energy expenditure. The active strategy of power jumpers requires both high activation input by the central nervous system and high energy expenditure for muscle fiber shortening. These athletes may be more subject to a decrease of performance with fatigue. On the other hand, their larger ankle range of motion helps them in performing wushu compulsory low stances with heels on the ground.
Concerning injury risk, spring jumpers seem to have a higher risk of knee injury when looking at knee loading. However, the dependence of power jumpers’ performance with motor control could also lead to injury in the case of loss of vigilance.
It is difficult to know why athletes choose one strategy rather than the other. It could be linked with genetic abilities (laxity, muscle typology) as well as training habits. Power jumpers seem to practice more weight training compared to spring jumpers who are more used to specific plyometric training. It is also possible that some athletes, particularly in the medium group, do not choose the technique that best fits their capacities, explaining their lower overall performance.
For personalized training optimization and injury prevention, the athlete’s jumping strategy should be taken into account, for instance by avoiding repetitive jump training with power jumpers or by focusing on knee safety with spring jumpers.

REFERENCES:

Aubry, S., Risson, J. R., Kastler, A., Barbier-Brion, B., Siliman, G., Runge, M., & Kastler, B. (2013). Biomechanical properties of the calcaneal tendon in vivo assessed by transient shear wave elastography. *Skeletal radiology*, *42*(8), 1143-1150.

Haim, A., Rubin, G., Rozen, N., Goryachev, Y., & Wolf, A. (2012). Reduction in knee adduction moment via non-invasive biomechanical training: a longitudinal gait analysis study. *Journal of biomechanics*, *45*(1), 41-45.

Jones, R. Carter, J. Moore, P. & Wills, A. (2005). A study to determine the reliability of an ankle dorsiflexion weight-bearing device. *Physiotherapy*, 91, 242-249.

Kubo, K., Morimoto, M., Komuro, T., Yata, H., Tsunoda, N., Kanehisa, H., & Fukunaga, T. (2007). Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Medicine & Science in Sports & Exercise*, 39, 1801-10.

Rabita, G. Couturier, A. & Lambertz, D. (2008). Influence of training background on the relationships between plantarflexor intrinsic stiffness and overall musculoskeletal stiffness during hopping. *European Journal of Applied Physiology*, 103, 163-171.

Wu, R. (2007). *Fundamentals of high performance wushu: taolu jumps and spins.* ISBN: 978-1-4303-1820-0