USE OF INDUCED POWER ANALYSIS TO UNDERSTAND RELATIVE JOINT MOMENT CONTRIBUTION IN A MARTIAL ARTS KICK

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SUMMARY
The purpose of this case study was to analyse the relative contributions of the lower limb net joint moments to the power generated at the kicking foot in a powerful martial arts kick (roundhouse kick), in order to provide a better understanding of the coordination and skill involved in such activities. This investigation was carried out using the induced power analysis, a method based on the dynamic coupling inherent to multiarticulated systems, and suggests that the power generated at the kicking foot is mostly achieved by the work done by the hip extensor and internal rotation moments and by the ankle dorsiflexor moment.

INTRODUCTION
Understanding the mechanism underlying the multijoint coordination required to generate a powerful kicking action, such as a martial art kick, may be of great interest to coaches as it may contribute to the development of strategies for the improvement of the kicking skill. However, the analysis of motion and the establishment of cause-effect relationships in a non-linear system such as a multiarticulated body are extremely complex [1].

In a multijoint rigid body system, forces applied to one segment instantaneously induce forces to all other segments in the system, through the joint intersegmental forces, thus affecting their motions. This phenomenon is known as dynamic coupling, which simply means that the equations of motion of all segments in a multiarticulated system are coupled. Accordingly, any one net joint muscular moment contributes to all joints’ intersegmental forces, and consequently to the power of all segments [2, 3]. Therefore, the power generated in the kicking foot is not only influenced by the muscular moment produced in its adjacent joint, but also by muscular moments produced at all joints in the system. Contrarily to the traditional inverse dynamics analysis, a segmental power analysis enables the measurement of the contribution of individual net joint moments to the power of individual segments, providing an insight to the mechanics and coordination used by athletes when performing a martial arts kick. The aim of this study was therefore to perform this type of analysis in a roundhouse kick.

METHODS
A male Karateka (22y; 59Kg; 1.73m), holder of various national medals, volunteered to participate in this study. After his warm-up routine, the subject performed several roundhouse kicks against a pad, held at chest height, of which the best four were selected for analysis. To perform the roundhouse kicks the subject stood with one foot on each of two force plates (models 9281B and 9283U014 Kistler Instruments Ltd, Winterthur, Switzerland). The motion was captured, at a frequency of 300Hz, with an optoelectronic system of 12 infrared cameras (Qualisys Oqus 300 and Qualisys Track Manager, Qualisys AB, Gothenburg, Sweden), synchronized in time and space with the force plates. Visual 3D (Version 4.75.36, C-Motion, Inc, Rockville, USA) was used to compute the kinetic and kinematic variables. The biomechanical model consisted of a linked rigid segment model composed by 15 segments – head, trunk, pelvis, bilateral feet, shanks, thighs, hands, forearms and upperarms – articulated by spherical joints. Thus, all joint rotations were allowed, but joint translation movements were constrained. The contributions of the net muscular moments at the ankles, knees and hips to the segmental power of the kicking foot were computed using the method described in Siege et al. [3]. Data was normalized to the subject’s body weight, and to a time period which began when the kicking foot left the ground and terminated at impact. The work done by the same net joint moments was calculated from the area under the normalized segmental power graphs for two intervals, to represent the energy transferred to the kicking foot. The first interval ran from 0 – 88% (0% being the instant after the kicking foot left the floor and 88% being the approximate instant when net muscular moments’ signal was inverted or its magnitude markedly increased), and the second interval ran from 88% to impact. The results are only presented for the kicking leg because the values obtained from the support leg were negligible.

RESULTS AND DISCUSSION
The results from the induced power analysis (Figure 1) show that, strangely, the hip internal rotation and the ankle dorsiflexor (very small) moments were the major contributors to the power achieved at the kicking foot during the roundhouse kick. On the other hand, the very same net muscular moments were inverted before impact (nearly at 90%) acting to remove a small amount of energy (less than 0.1J/kg each – Figure 2) from the distal segment. The high contribution of the ankle dorsiflexor moment could be unexpected, given the small net moment (0.11Nm/Kg). However, according to Putnam [4], a muscle acting isometrically can redistribute the energy among segments by accelerating some segments and decelerating others. Thus, the ankle dorsiflexor moment may have largely
contributed to the power induced at the foot by transferring energy from other segments to the foot, rather than by actually producing it.

Of great interest are the results obtained for the hip flexor/extensor moment. From 0% to approximately 88%, the athlete produced a hip flexor moment which, according to the induced power analysis, was responsible for removing power from the foot. From 88% up to impact, the hip net moment became extensor, adding energy to the foot (Figure 1). These results seem to be related to the proximal-distal sequential motion characteristic from kicking, throwing and striking activities, as they suggest the existence of a whip-like effect. As Putnam [4] advocated, the proximal-distal sequential motions may, to a large extend, be explained by the mechanics of multijoint systems and the dynamic coupling arising from their multiarticulated nature. The identification of a proximal-distal sequence is beyond the aims of this study. Nevertheless, the results obtained regarding the contribution of the hip moment seem to support this, by presenting a mechanism that may explain the benefit of the proximal-distal sequences in explosive/powerful movements.

The work done by the joint moments on the kicking foot was estimated in order to quantify the amount of energy added to or removed from the foot. However, if one only accounts for the amount of energy that was transferred to the foot throughout the roundhouse kick (Figure 2), it appears that, overall, the hip internal rotation is by far the most important factor in a powerful kick, and that the well known whip-like effect of the hip extension moment is much less important, which is unlikely. However, the maximum instantaneous power induced by the hip extensor moment was higher (2.5W/Kg; 147.5W in this case), and coincident with the instant of impact, than that induced by the hip internal rotation moment. Furthermore, the time intervals over which the work produced by the net muscular moments was calculated are very different, which may affect the results presented in Figure 2.

Figure 1: Kicking foot power induced by the net joint muscular moments of the corresponding leg, in the three orthogonal planes, normalized in time with movement duration.

Contrarily to what was expected, the knee moment, predominantly flexor throughout the movement, and eccentric approximately from the 60%, acted to absorb a high amount of energy from the kicking foot, particularly before impact. Also the hip adductor moment (from ~37%) contributed to the removal of energy from the kicking foot. This may be due to the passive resistance offered by the adductor muscles at amplitudes close to the end range of hip abduction, although joint amplitude assessment and tests using the dynamometer would be needed to confirm this speculation. Finally, neither gravity nor the ankle supinator/pronator (ankle - transverse) moment were found to contribute, positively or negatively, to the power achieved at the kicking foot.

CONCLUSIONS

The results from the segmental power analysis (Figure 1) show that the energy produced at or transmitted to the kicking foot results mainly from the work produced by the hip internal rotation and extensor moments as well as by the ankle dorsiflexor moment. This suggests that athletes should strive to improve their hip adductors flexibility and should explore the ability to quickly decelerate hip flexion just before impact, in order to potentiate the whip-like effect. This study also shows that the induced power analysis may potentially be an excellent tool used to understand and explain the mechanism behind the proximal-distal sequential motions. A more detailed analysis of energy transfer/flow among segments would enhance this type of analysis.

REFERENCES