Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

RELATIVE JOINT MOMENT CONTRIBUTION TO THE POWER GENERATED IN A MARTIAL ARTS KICK – INFLUENCE OF SKILL LEVEL

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The purpose of this study was to analyse whether athletes of different skill level present different relative joint moment contributions to the power generated in a martial arts kick. This investigation was carried out using the induced power analysis, a method based on the dynamic coupling inherent to multiarticulated systems. The comparison was done among three male karatekas, considered to be experienced, intermediate and novice. The results show that the hip extension moment was the major contributor in the production of mechanical energy in the kicking foot at impact. Similarly the hip internal rotation and ankle dorsiflexion moments worked to build up the foot's energy for most of movement. The experienced athlete seems to benefit more from these by potentiating the moments produced in these joints.

KEY WORDS: induced power analysis, roundhouse kick, karate, biomechanics.

INTRODUCTION: Sport movements involving collisions, such as a volleyball spike, a golf swing or a football kick, demand the production of maximum power at the distal end of a kinetic chain. Over the years, researchers have been studying martial art strikes and other related combat sports by measuring impact forces, segment velocities and electromyographic data, and comparing values obtained among athletes of different sports and different levels. For example, Neto et al. (2008) compared the force, power and efficiency of a Kung Fu palm strike performed by both experienced and novice Yau-Man practitioners. Bartfield et al. (2002) compared the kinematics of the instep kick performed by male and female soccer players. Nonetheless, this type of analysis does not discriminate possible differences in the mechanism and coordination required to generate a powerful movement. In order to explain the causes of such a coordinated motion, one must understand how mechanical energy is generated and channelled throughout the system. However, the motion analysis and the establishment of cause-effect relationships in a non-linear system such as a multiarticulated body are extremely complex (Zajac & Gordon, 1989).
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 the 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 (Zajac et al., 2002; Siegel et al., 2004). 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 performed by athletes of different skill levels, so as to analyse their differences or similarities in the relative joint moments contributions to the power generated.

METHODS: Three male karatekas (21 ± 3y; 67.0 ± 6.9Kg; 1.76 ± 0.03m) volunteered to participate in this study. The athletes were characterized as experienced, intermediate and novice, according to their coach. Following their warm-up routines, the participants performed several roundhouse kicks against a pad, held at chest height, of which the best four, from each performer, were selected for analysis. To perform the roundhouse kicks the participant 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 body 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 produced at the ankles, knees and hips to the segmental power of the kicking foot were computed using the method described in Siege et al. (2004). The data were normalized to the subject's mass, 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: All three athletes presented a fairly neutral ankle dorsi/plantar flexor and supinator/pronator moments throughout the execution of the roundhouse kick. The supinator/pronator moment did not contribute to the power of the kicking foot for any of the athletes, but the same did not happen for the dorsi/plantarflexor moment. The latter was a major contributor to the development of positive power on the foot, thus adding energy to the segment, in all three athletes. These results could be unexpected, given the small net moment (max=0.11Nm/Kg) and small joint amplitude (min - 32.91^{o} at 20%; max - 40.88^{o} at 86%). However, according to Putnam (1993), a muscle acting isometrically can redistribute the energy among segments by accelerating some segments and decelerating others. Thus, the almost null ankle dorsi/plantarflexor 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.

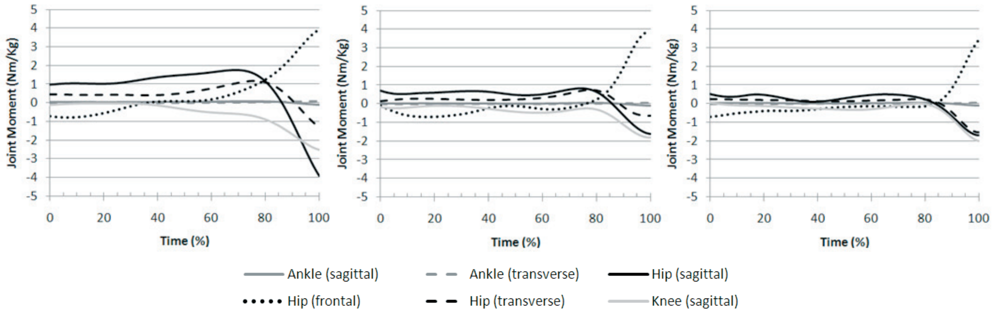

Figure 1: Joint muscular moments of the kicking leg. Time is normalized with movement duration. Athletes (A), (B) and (C) are, respectively, the experienced, intermediate and novice athletes.

Despite the similarities in the ankle dorsi/plantarflexion moment among athletes, and its parallel contribution to foot power, the amount of positive power induced by these moments

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and energy added to the foot (before the 88%) is substantially greater in the experienced athlete (A). The intermediate athlete was also able to induce more power than the novice athlete (C). On the other hand, before impact, the ankle dorsi/plantarflexor moment was responsible for removing approximately the same amount of energy in all three athletes.
Interesting were the results obtained for the hip flexor/extensor moment. From 0% to approximately 88%, all athletes 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 2). These results seem to be related to the proximal-distal sequential motion characteristic from kicking, throwing and stricking activities, as they suggest the existence of a whip-like effect. As Putnam (1993) advocated, the proximal-distal sequential motions may, to a large extent, 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 flexor/extensor moment seem to support this, by presenting a mechanism that may explain the benefit of the proximal-distal sequences in explosive/powerful movements. However, further research is needed to support this speculation, considering the small sample used in this study.

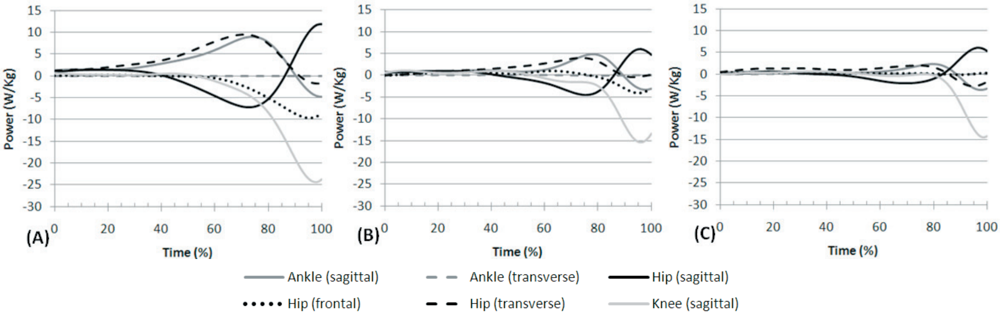

Figure 2: Kicking foot power induced by the net joint muscular moments of the corresponding leg, in the three orthogonal planes, normalized in time with movement duration. Athletes (A), (B) and (C) are, respectively, the experienced, intermediate and novice athletes.

Again, when comparing the three athletes, the energy removed from and added to the foot by the hip flexor/extensor moment were greater in the experienced athlete and lower in the novice athlete. These distinctions seem to be related to the parallel differences observed in the athletes' joint moments.

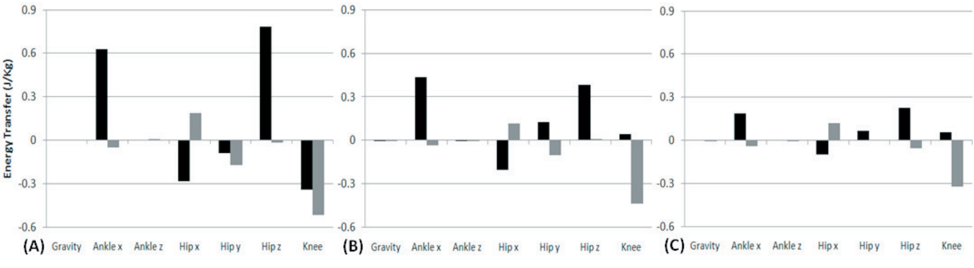

Figure 3: Energy transferred in (positive) and out (negative) of the kicking foot, during the principal phase of movement (black) – up to 88% – and the deceleration phase prior to impact (gray) – 88% to impact. Athletes (A), (B) and (C) are, respectively, the experienced, intermediate and novice athletes.

The results obtained for the hip adductor/abductor moment show that all athletes initiated movement with a small hip abductor moment that nearly had no effect on the power of the kicking foot. As this moment becomes adductor, which occurs latter in the intermediate and novice athletes, it gradually absorbs energy from the foot. This energy absorption is greater in the experienced athlete and inexistent in the novice athlete. This can be attributed to various factors, namely 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), as well as the variability in the kicking height and in maximum hip abduction angles. Surprisingly the intermediate and the novice athletes contacted the target at higher heights, and the intermediate athlete presented greater hip abduction amplitudes at impact.
The hip axial rotator moment was also a major contributor to the power of the kicking foot. All athletes presented a small external rotator moment for most of the execution of the roundhouse kick, which became internal rotator moment before impact. The external rotator moment was small in athlete (C) and larger in athlete (A), whereas the internal rotator moment was larger in the novice athlete in comparison with the experienced and intermediate athletes. These moments respectively worked to add energy to the kicking foot for most of the movement duration, particularly in athlete (A), and to remove a small amount of energy from the distal segment just before impact (no energy was removed in athlete (B)).
Contrarily to what was expected, the knee moment, predominantly flexor throughout the movement, and eccentric approximately from 60-70% up to impact, in all three athletes, acted to absorb a high amount of energy from the kicking foot, particularly before impact. This moment was larger in the experienced athlete and so was its effect on the power of the kicking foot.
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 3), 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 possibly caused by the hip extension moment is much less important, which is unlikely. However, the maximum instantaneous power induced by the hip extensor moment was higher, 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 3.

CONCLUSION: The results from this study show that the hip flexion/extension and internal/external rotation moments play a major role in the production of power in a martial arts kick, independently of the athlete's level. Furthermore, the results also suggest that the ankle dorsi/plantarflexor moment largely contributes to the same end by channelling the energy from other segments into the kicking foot. With regards to the athlete level, it appears that less trained athletes produced smaller joint moments, in general, which reflects in smaller contributions to the power of the kick.

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