Estimation of power transfer by biarticular leg extensors on the acceleration phase of the sprint

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Introduction:
In sport movements, such as sprinting and jumping, the ability to produce explosive leg extension movements is extremely important. Values for maximal knee extension moment of force, calculated by inverse dynamics, are higher than the maximal isometric and isokinetic moments of force values obtained with tests performed on Isokinetic machines. Values of maximal knee extensor moments of force could reach 310 Nm on sub maximal running (Jacobs, et all, 1993) and around 500 Nm in drop jump exercises (Bobbert, et all, 1987a). These values exceed the values for maximal isometric knee extension, around 200 Nm obtained on the classical studies of Wickiewicz, et all (1984). The same discrepant behaviour was found for plantar flexion (Bobbert, 1988).

One of the mechanisms that might explain these discrepancies is the fact that the biarticular muscles perform differently during actual sports movements than they do on Isokinetic testing. The major difference concerns the length variations of the biarticular muscles. These length changes are dependent on the simultaneous movement of the two joints crossed by the muscle. This means that the force-length and the force-velocity relationships of biarticular leg extensors are different from those obtained during isometric testing, where the adjacent limb is in a fixed position. Another potential influence of biarticular muscles is the transfer of mechanical power from one joint to the adjacent one, considering where the two joints they cross (Prilutsky et all, 1994).

The purpose of this study was to estimate the transport of mechanical power from hip to knee and from knee to ankle, performed by rectus femoris (RF) and gastrocnemius (GAS) muscles, during the acceleration phase of sprinting. This power transport action partially explained the difference found on the moment of force between maximal isometric testing and the value obtained by inverse dynamic on this explosive leg extension movement.

Methods:
Ten elite sprinters (height 1.76±0.04 m, body mass 73.7± 5.1 kg, thigh length 0.433±0.020 m and shank length 0.395±0.018 m) performed 6 sprint starts from blocks. The second stage following the start was performed over a kistler force platform, and ground reaction forces (GRF) were recorded at 1KHz. The trial where the maximal net horizontal impulse was achieved was selected for analysis. Simultaneously, linear and angular kinematic data from the transversal plane of the ankle, knee, hip and shoulder joints were calculated using a 2D video analysis system (120 Hz) (extension angular movement was defined as positive). After a residual analysis of joint landmarks (Winter, 1990) co-ordinates were filtered with a 10 Hz Hamming window, Butterworth 2 order, 0 phase lag low pass filter. A four-segment rigid body link system was constructed with foot, shank, thigh and HAT (head, arms and trunk). Using an inverse dynamics approach, the net joint forces and moments of force at ankle, knee and hip were calculated (extensor moments of force were defined as positive). GRF were filtered with a 12 Hz low pass filter in order to remove the passive force peaks (van den Bogert et all, 1996).

The length variation behaviour of thigh and shank muscles was estimated using Visser, et all (1991) and Spoor, et all (1990) polynomials curves fit and the joint angular position. Using an inverse dynamics approach, the net joint forces and moments of force at ankle, knee and hip were calculated (extensor moments of force were defined as positive). GRF were filtered with a 12 Hz low pass filter in order to remove the passive force peaks (van den Bogert et all, 1996).

The length variation behaviour of thigh and shank muscles was estimated using Visser, et all (1991) and Spoor, et all (1990) polynomials curves fit and the joint angular position. These results were combined with the observed length of thigh and shank of the athletes, estimated using dual frequency x-ray (DXA) images, to obtain the muscle-tendon length variation (Loi) for each athlete. Velocity from origin to insertion (Voi) was calculated by differentiation (dLoi/dt) (concentric velocity was defined as positive). For the same muscles, the effective moment arm equals the derivative of tendon travel with respect to joint angulations (Spoor, et all, 1990):

These calculations were performed for the following muscles, Gluteus (GM), semi tendinosus (ST), biceps femoris (long) (BF), vastus lateralis (VL), rectus femoris, (RF) gastrocnemius (GAS) and soleus
A physiological criteria was used to estimate force distribution among muscles, the physiological cross-sectional area (PCSA) values presented by Roy & Edgerton, (1993) were used to calculate specific dynamic muscles tension for the studied muscles. Assuming that: muscle tension is proportional to PCSA and that mono-articular antagonists are inactive, dynamic muscle tension was calculated (Winter, 1990): Individual muscle force was calculated by multiplying dynamic tension of a muscle, or muscle group and the PCSA of this muscle or muscle group (Winter, 1990). Muscle power was obtained multiplying muscle force by the instantaneous rate of change of its length (V_o). Mechanical power transferred from hip to knee by RF (P_{transp,RF}) equals the difference between knee net power and the knee extensors muscles power, the same occurs for knee to ankle joint. The amount of power transported by GAS (P_{transp,GAS}) from knee to ankle (or the opposite) equals the difference between ankle net joint power and the plantar flexor (Prilutsky et all, 1994). It is important to note that this algorithm leads to an absence of co-activation of hamstrings (HA) and rectus femoris. This model does not predict the hamstrings knee moment of force. Other limitations of the model are that muscle composition is not accounted for. As GAS presents a higher percentage of fast twitch fibers in comparison with SOL, probably this model tends to overestimate SOL contribution for triceps surae force and underestimate GAS.

Results and Discussion
The transfer action or tendon action of biarticular rectus femoris and gastrocnemius was estimated comparing the net joint power for each joint and the muscle power (the product of instantaneous muscle force by the instantaneous contraction velocity). The difference obtained for each joint represents the amount of energy transferred by the biarticular muscles from a joint to the adjacent. The method used presents the advantage of allowing internal verification, because the total net joint power should be of the same amount as the total muscle power. On the top graph of figure 10 it can be observed that the to curves are very similar indicating that the energy balance was obtained. The transfer action of the biarticular muscles is seen clearly on Figure 1 for hip to the knee joint and from the knee joint to the ankle joint (on both knee and ankle joints joint power exceeds muscle power while on the hip joint muscle power exceeds joint power). The transfer action of RF and GAS during the early phase of support is small indicating that during the early sprint acceleration the absorption phase characteristic of running is absent, except for the ankle, and apparently with no power transfer from ankle to knee. After 45% of support phase, where leg extension is predominant RF and Gas are able to transfer energy from the hip extensors to the knee and from the knee extensors to the ankle joint. The mechanical energy transferred was calculated integrating over time the transfer power curves showed on Figure. 1. The energy transferred by RF from Hip to knee, present a mean value of 35.63 J, which represents 21.2 % of the Knee energy. The transfer of energy from knee to ankle performed by GAS achieves a mean value of 22 J being 23.6 % of the total work performed on this joint. These results are in close agreement with those presented by (Jacobs, et all, 1996), (Bobbert, et all, 1987b) for sprint start and vertical jumping. They used a direct dynamics model. The present results are similar to the values presented by Prilutsky & Zatsiorsky, (1994) for vertical jumping using a model similar to the one used in the present study.

Conclusion:
The musculo-skeletal model proposed allowed the estimation of the behaviour of the muscle-tendon complex on a actual sport movement performed characterized by the generation of maximal leg extension power, the second stance period after sprint start from blocks. The similarity between the total sum of joint net powers at the lower extremity and the sum of the total power of all the muscles of the lower limb indicates the adequacy of the model.
The biarticular muscles appear to have an important role in transferring energy from the proximal joint, where the muscles with larger volume are located, to the distal joints. The distal limbs have muscles with shorter fibres and larger tendons that are suitable for fast contracting velocities that are associated with the transfer mechanism of the biarticular muscles allowing for an efficient high power output at the distal joints. This transfer action could be partially responsible for the discrepancy between max isometric moment of force registered on dynamometer and the net moment of force values calculated by inverse dynamics on actual sport movements. These findings should be taking into consideration when isometric or isokinetic tests are used to evaluate power athletes.

References

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