INTERDEPENDENCE OF TORQUE, ANGULAR VELOCITY, AND JOINT ANGLE DURING LEG EXTENSION

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INTRODUCTION

Although critisised by several authors [e.g. 1] in most cases human muscle kinetics are still presented as a function of joint angle or as a function of velocity at optimum joint angle. According to this, data from literature is strongly limited and mostly deals with single joint knee extension. Moreover, these studies [e.g. 2] concentrated on concentric but only little on eccentric muscle action. In this context to our knowledge this is the first study that aimed to determine the interdependence of torque, angular velocity, and joint angle for multi-joint leg extension.

METHODS

Experiments were carried out in a seated leg press dynamometer on 18 moderately active male subjects (30 ± 6.3 years of age) without any neuromuscular disorders or injuries at the lower extremity. To assess their muscular capacity in a first session subjects performed 3 sets of 8 maximum voluntary isometric contractions, each at different joint angles. Measurements were done in steps of 10° knee joint angle over a ROM from 30°-100° knee flexion. In a second session, separated by at least 2 days rest, subjects performed 5 sets of 3 concentric contractions as well as 4 sets of 3 eccentric contractions both over the full ROM. Contractions of each set were performed at different mean angular velocities of 30, 60, 120, 180, and 240°s^{-1} (the latter only for concentric muscle action). Dynamic contractions were initiated only when subjects reached at least 95% of their angle specific isometric external reaction force.

External reaction forces exerted on the leg press were measured separately for each leg by a custom build force plate with 3-component force sensors (KISTLER, CH), and a VICON MX-3 Motion-System (Oxford Metrics, UK) served for measuring lower extremity kinematics. Capturing frequency and sampling rate for analogue data was 240 Hz. Kinematic measurements and force recordings were synchronised by software. Joint moments in knee and ankle joint were calculated by the methods of inverse dynamics. To account for inertial properties an anthropometrical model was scaled individually to weight and body height by linear regression [3] and was adjusted according to [4].

RESULTS AND DISCUSSION

According to the test protocol consisting of isometric and dynamic muscle action, the data allowed to create 3D-plots, which represent the resulting human muscle strength of multi-joint leg extension. These plots clearly demonstrate that joint angle and angular velocity are not independent factors determining resulting forces and joint torques.

Moreover, there are several novelties that are in conflict with findings from single joint experiments: For example, the concentric part of the torque-joint angle-velocity plot does not fit the classical Hill-curve very well, especially when muscles are not operating at optimum length. According to this, we found an almost linear torque-velocity relationship for a knee flexion angle of 90°. In addition, with increasing shortening velocity we found a shift in optimum knee joint angle from 52.2±6.6° (isometric contraction) to 63.8±3.8° (concentric contraction at mean angular velocity of 180°s^{-1}).

Concerning eccentric muscle action there are two main findings: First, force potentiation showed a clear length dependence ranging from relative isometric torques of 1.09 M_{iso} around optimum joint angles up to 1.32 M_{iso} at 90° knee flexion. Second, with increasing knee flexion angles eccentric forces and torques were strongly affected by angular velocity, which is in contrast to the largely accepted opinion on eccentric muscle action and to commonly used models of human muscle function.

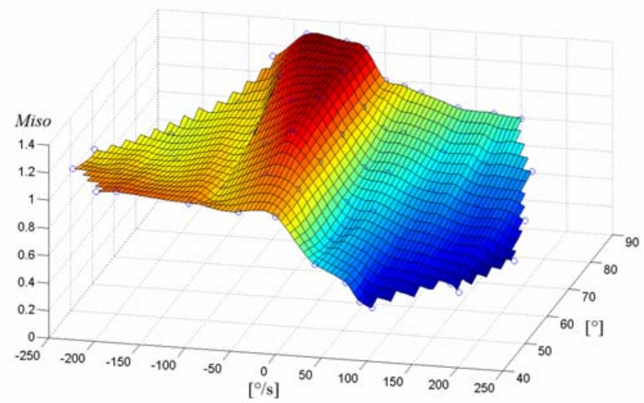

Figure 1: 3D-plot representing relative knee joint torques during multi-joint leg extension. X-Axis represents angular velocity [°s^{-1}], y-axis relative isometric torque M_{iso}, and z-axis knee joint flexion [°].

CONCLUSIONS

Our findings clearly demonstrate the interdependence between the mechanical factors joint angle, angular velocity, and human torque generation capacity during multi-joint leg extension. This interdependence should be considered when trying to optimize sports performance or when modeling human movement. In order to incorporate this dependence into models of the human musculoskeletal system additional research is needed, which concentrates on the mechanisms behind these results. Moreover, important factors like activation level and fatigue also need further investigation, so that it is possible to account for the complexity of human muscle kinetics.

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