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RESIDUAL FORCE ENHANCEMENT IN CONTEXT OF EVERYDAY HUMAN MOVEMENT

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SUMMARY

When an active muscle is stretched, the resulting post-eccentric steady-state force is known to be greater than the isometric force at the corresponding muscle length. The aim of our research was to clarify if residual force enhancement (RFE) is relevant for voluntary human muscle action in everyday like scenarios.
Therefore 13 healthy subjects participated in our study and had to perform bilateral leg extensions using a motor-driven leg press dynamometer, measuring external reaction forces (F_{ext}) as well as activity of 9 lower extremity muscles. In addition, ankle (M_a) and knee (M_k) joint torque were calculated using inverse dynamics. Subjects performed isometric and isometric-eccentric-isometric contractions (20° stretch, ω=60°/s) at 30% of maximum voluntary activation. Visual feedback of VL muscle activation was given to control submaximal muscle action.
We did not find differences in VL activation level between contraction conditions and time points. Mean VL activity ranged between 29.1 ± 2.2% and 29.8±2.5% MVA. We found significantly enhanced F_{ext} ($p < 0.002$) as well as joint torques in knee ($p < 0.002$) and ankle joint ($p < 0.033$) for all instances in time. In summary RFE seems to be relevant in everyday like human motion.

INTRODUCTION

Residual force enhancement has been constantly observed in *in vitro* as well as in *in vivo* experiments over the last decades [1, 2]. Nevertheless, although RFE is also shown in voluntarily activated human muscles [5], its relevance for everyday human movement has to be discussed. Characterization of human motion includes coordination of different voluntarily activated muscles in multi-joint movements, mainly working at a submaximal level of activation. Thus, the aim of our research was to model this scenario.

We assumed that both, enhanced force as well as joint torques are present after eccentric multi-joint leg extension in relation to isometric reference contractions at the same joint-angle configuration during sub-maximal experimental assembly.

METHODS

13 healthy subjects (10♂, 3♀) with no history of ankle, knee, or hip joint injury or neurological disorder participated in the study. Bilateral leg extensions were performed using a motor-driven leg press dynamometer (IsoMed2000, D&R Ferstl GmbH, Germany) (Figure 1).

Stretches with a mean amplitude of 18,8°±2.3 were performed at an angular velocity of 60°/s from the initial start position of 78.8°±5.2 to the end position of 97.1°±4.1 knee flexion. External reaction forces (F_{ext}) were measured by 3d-force plates (Kistler, Germany) mounted to the leg press footrest. Muscle activation of 9 muscles of the lower limb were measured using wireless surface electromyography (EMG) (myon RFTD, Myon AG, CH). Lower extremity kinematics and kinetics were calculated by inverse dynamics. A sample rate of 1000Hz was used for forces and EMG signals and 250Hz for kinematic data. Visual feedback of vastus lateralis (VL) muscle activation was given to control submaximal muscle action.

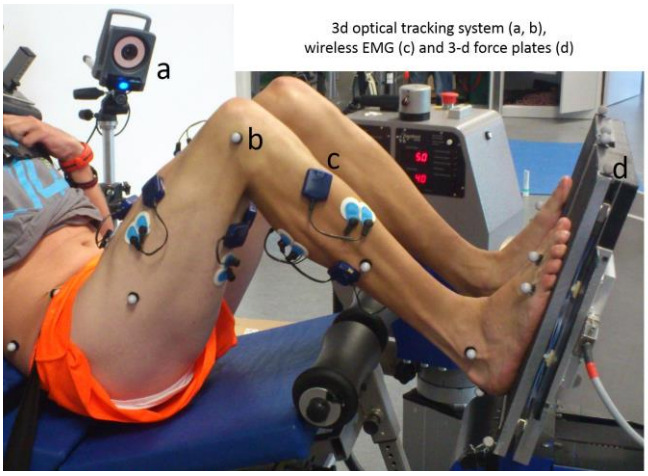

Figure 1: Experimental setting in the leg press dynamometer.

Data of F_{ext}, M_a and M_k were analyzed from the right leg only. EMG data was band-pass filtered (Butterworth, 10-500Hz), smoothed by root-mean-square (500ms) and normalized to MVA, calculated as the mean activation of MVC trials. Parameters for statistics (F_{ext}, torques, EMG, kinematics) were defined as means of a 2s interval at 4-6, 8-10 and 20-22s after stretch (AS1-3). RFE is presented as percentage difference between dynamic and isometric force and torque.

RESULTS AND DISCUSSION

We did not find any differences in VL activation level between contraction conditions and time points. Mean VL activity ranged between 29.1±2.2% and 29.8±2.5% MVA. We obtained a significant increase between post-eccentric (97.1 to 97.3±4°) and isometric (97.7 to 97.8±4°) knee-angle setting, resultant in a mean increase of 0.53°. There were no differences between analyzed muscles at contraction conditions, except TA, having increased activation 4-6s after stretch (19.4±24.4% MVA) compared to purely isometric (8.0±10.2% MVA) trials.

In submaximal stretch-contraction trials, F_{ext} as well as M_k and M_a were always significantly enhanced compared to isometric references ($p < 0.033$) (Figure 2).

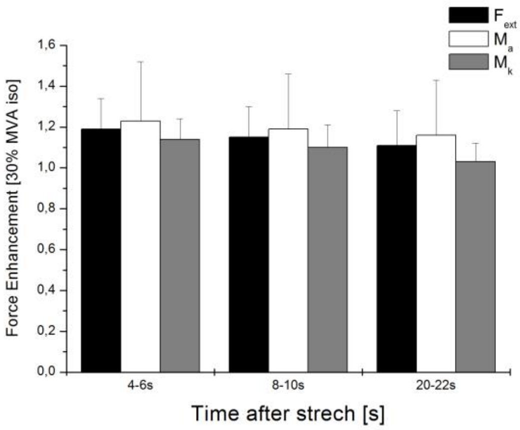

Figure 2: Residual force enhancement

VL activity was almost exactly 30% MVA, whereas analyzed uncontrolled muscles resulted in activation intensities from 8% to 43% MVA. This represents motor redundancy phenomenon, as there is an infinite number of solutions to perform a given motor task, like leg-extension. Contribution to overall force differs among involved muscles. Notwithstanding, we could not find differences between contraction conditions nor time.

With RFE values of 13% to 3%, data of M_k, are in good agreement with directly measured data of single-joint experiments at the same level of activation [4]. M_a however was about twice the values (up to 22% RFE) which are reported for single-joint studies [3].
Analogous to enhanced forces, literature also reports data of reduced activation after stretch compared to pure isometric contractions [4]. Assuming activation reduction and RFE to originate from the same mechanism, which is more than likely, we speculated that RFE is beneficial in saving metabolic energy while executing a given task.

CONCLUSIONS

In this work we were able to show that RFE is present in submaximal multi-joint muscle action. Thus, RFE seems to play a role in daily locomotion. Enhanced force or torque of submaximal leg-extensions at 30% MVA ranged between 3 to 22% and was present for up to 22s post stretch. Maybe RFE is an evolutionary optimization mechanism to reduce energetic effort in history relevant muscle action. Future work in the fields of physiology, energy consumption during long term muscle action and time to failure tasks after active muscle stretch may help to get a more detailed view on the relevance of RFE in natural muscle function.

ACKNOWLEDGEMENTS

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