PRESCRIBING SKELETAL MOTION CAN SUBSTANTIALLY ENHANCE MECHANICAL POWER OUTPUT; A SIMULATION STUDY

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INTRODUCTION

Average mechanical power output (referred to as "power output" in what follows) is a key factor in determining performance in high-intensity periodic movements like cycling and rowing. We have recently investigated how power output is affected by adding/removing kinematic constraints on skeletal motion using a modelling/simulation approach. We have predicted that the power output of rowers may be limited by the fact that they must prevent "shooting the slide", and that strapping the rower to the sliding seat (i.e. adding a kinematic constraint) may thus improve power output [1]. In the context of FES cycling we have predicted that releasing the customarily fixed ankle joint and stimulating triceps surae and tibialis anterior, does not necessarily improve power output; removing the kinematic constraint at the ankle introduces a degree of freedom that has to be controlled through muscle actions, which counteracts the power gained by the extra muscle mass [2]. Regarding isokinetic sprint cycling we have predicted that prescribing the optimal leg kinematics for unconstrained conditions (i.e. adding a kinematic constraint), and thus removing the need to coordinate leg motion, does improve power output, albeit only marginally [3]. While the latter study confirmed that upon prescription of the optimal unconstrained kinematics power output can only improve, it did not answer the question to what extent power output of the leg muscles can theoretically be improved relative to the natural sprint cycling setup when the fully prescribed leg motion is optimized. The goal of this modelling/simulation study is to find the maximal power output that can be achieved when prescribing a periodic motion of hip, knee and ankle joint in a sagittal plane model.

METHODS

For comparability we adopt a model that was used previously in a study of isokinetic sprint cycling [4], where the highest power output occurred at a pedalling rate of 120 RPM. In this study we investigate 120 "RPM" prescribed sinusoidal movements of hip, knee and ankle, parameterized by average joint angle and joint angle amplitude for each of the three joints, and phase shifts between hip, knee and ankle joints. These parameters are optimized collectively with the stimulation pattern of 8 Hill-type muscles with realistic activation and contraction dynamics. The muscles are assumed to be maximally stimulated for one part of the period time and to receive no stimulation for the remaining part. The optimization is carried out using a genetic algorithm [5], with power output as the optimization criterion.

RESULTS AND DISCUSSION

The optimal leg motion found is characterized by almost simultaneous extension (and flexion) of hip, knee and ankle joints. The hip joint range of motion is much larger than during cycling, resulting in a leg motion (Fig. 1) that is quite different from that allowed by the circular path of the MTP joint as imposed during cycling. As expected for any setup where muscles are effectively decoupled, stimulation of each muscle is tightly tuned to maximization of its power output, i.e. full stimulation during shortening and none during lengthening. Most importantly, power output was found to be 1441 W., which is 135% of the optimal power output for the natural sprint cycling setup.

It must be expected that the theoretical maximal power output of the leg muscles is even higher than that calculated here, as neither the period time nor the form of the motion has been varied. It remains to be investigated if a mechanism that enforces the optimal lower extremity motion can be built, and if subjects are able to exploit the advantages of such a mechanism. It also remains to be established if such a mechanism has advantages during prolonged exercise, where central physiological processes may be performance-limiting. Irrespective of issues of practical implementability, this study illustrates the potential of a modelling/simulation approach for preliminary evaluation of hypotheses on the mechanics and energetics of human motion.

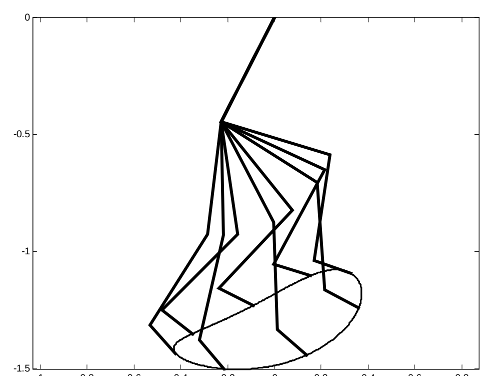

Figure 1: Optimal motion of foot, shank and thigh, plotted at regular time intervals, with fixed upper body. To facilitate comparison to the kinematics of cycling the complete path of the MTP joint is also plotted.

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