SIMULATION OF EFFECTS OF POSITIVE AND NEGATIVE LOADING ON POWER OUTPUT IN JUMPING.

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SUMMARY
In the literature it has been claimed that a subject's own body mass provides the optimal load for producing maximum mechanical output in vertical jumping. The purpose of the present study was to determine how positive and negative loading affect the mechanical output of a forward simulation model if control is optimized for each loading condition. According to the simulation results, peak power output of contractile elements in squat jumping is higher when upward external forces are exerted than when no external forces or downward forces are exerted. This result is in contrast to results of experiments in subjects. Presumably subjects are unable to quickly tune their control to changed loading conditions, and inadvertently perform submaximally in negative loading conditions.

INTRODUCTION
In order to jump higher, an athlete needs to achieve a higher takeoff velocity and hence more kinetic energy. To achieve more kinetic energy, more muscle work must be produced during the push-off. Increased work production leads to a reduction of the time available for work production, because the limited push-off distance will be traveled at higher speed. Hence, mean power output is an important factor for performance in jumping. Furthermore, to avoid premature takeoff and therewith premature termination of work production, power output must continue to increase during the push-off [3], and therefore peak power output is also an important performance-determining factor in jumping.

According to the literature on long-term improvement of power output, it is most effective to train at the load at which muscle power is maximized [4,8]. It has been shown that peak power output in jumping becomes less with positive loading, either applied by a bar at the shoulders [4] or by elastic cords pulling upwards on the body [7]. It has also been shown that peak power output becomes less with negative loading, applied by elastic cords pulling upwards on the body [7]. These findings have led to the idea that a subject's own body mass provides the optimal load for producing maximum mechanical output in vertical jumping [6,7], with the implication that it also provides the optimal load for jump training.

The theoretical maximal output in jumping depends on the properties of the musculoskeletal system, but in order to achieve this maximal output a subject needs to find optimal control [2]. The question may be raised whether the results of positive and negative loading experiments could be inadvertently affected by the inability of subjects to quickly tune their control to changed loading conditions. The purpose of the present study was to determine how positive and negative loading affect the mechanical output of a forward simulation model if control is optimized for each loading condition.

METHODS
Maximum height squat jumps were simulated with a forward dynamic model of the musculoskeletal system consisting of four rigid segments (feet, shanks, thighs and a head-arms-trunk segment) actuated by six muscle-tendon complexes: m. gluteus maximus, biarticular heads of the hamstrings, m. rectus femoris, mm. vasti, m. gastrocnemius and m. soleus [10]. Each muscle-tendon complex was represented by a Hill-type unit. The model calculated the segmental motions corresponding to stimulation (STIM) input to the muscle-tendon complexes. Following Hatze [5] the relationship between STIM and active state was modeled as a first order process. For simulation of a maximum height squat jump, the model was put in the average preferred position observed in human subjects [1]. Initial STIM-levels were set such that the model maintained equilibrium. STIM of each muscle was allowed to change once towards its maximum of 1.0. A change towards 1.0 occurred at a rate of 5/s, a value previously used to match simulated and experimental curves in maximum height squat jumping [1]. STIM-onset times were optimized using height of the center of mass at the apex of the jump as criterion. For optimization, a genetic algorithm was used [9]. To simulate negative and positive loading, we added an extra external force (F_{ext}) at the mass center of the head-arms-trunk segment, ranging from -0.6 to 0.6 times body weight (BW), and after optimization of STIM-onset times for each condition we calculated power output of the contractile elements (P_{CE}).

RESULTS AND DISCUSSION
Figure 1 shows time histories of P_{CE} for maximum height jumps with an upward F_{ext} of -0.6 BW, with zero F_{ext}, and with a downward F_{ext} of 0.6 BW. Table 1 shows for F_{ext} ranging from -0.6 to 0.6 BW the duration of the push-off, vertical velocity at takeoff, peak P_{CE} and mean P_{CE}. Not surprisingly, vertical takeoff velocity increased with negative loading and decreased with positive loading. Peak

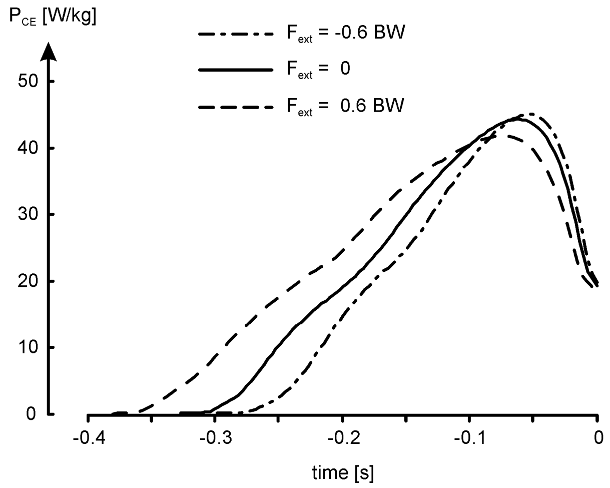

Figure 1: Time histories of power output of contractile elements (P_{CE}) for simulated maximum height squat jumps with different positive and negative external forces (F_{ext}) acting on the body. F_{ext} is given in terms of body weight (BW), with negative values indicating that the body is pulled upwards. Time is expressed relative to take-off (t=0).

P_{CE} did not reach its highest value at zero F_{ext} but increased as the negative loading increased, in contrast to what has been reported for experiments on subjects [7]. However, the variation in peak P_{CE} was small compared to the variation in vertical takeoff velocity. Moreover, mean P_{CE} was almost independent of loading, because the increases in peak P_{CE} with negative load were accompanied by a reduction in push-off duration.

CONCLUSIONS

According to the results of this simulation study, peak power output of contractile elements in squat jumping is higher when upward external forces are exerted than when no external forces or downward forces are exerted. This result is in contrast with results of experiments in subjects, which show that peak power output is highest when no loading is applied and decreases with negative loading [7]. Presumably subjects are unable to quickly tune their control to changed loading conditions, and inadvertently perform submaximally in external loading conditions. This should be taken into account when designing training programs involving external loading with the purpose of achieving long-term improvement of power output.

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Table 1: Results of simulated maximum height squat jumps with different positive and negative external forces (F_{ext}) acting on the body. F_{ext} is given in terms of body weight (BW), with negative values indicating that the body is pulled upwards.

F_{ext} [BW]	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6
t_{po} [ms]	298	303	307	311	318	322	327	334	340	348	356	364	380
v_{to} [m/s]	3.07	2.98	2.90	2.81	2.72	2.62	2.53	2.44	2.33	2.22	2.12	2.00	1.89
$P_{CE,peak}$ [W/kg]	45.0	45.0	45.0	44.8	44.6	44.5	44.2	43.9	43.6	43.2	42.8	42.3	41.7
$P_{CE,mean}$ [W/kg]	23.0	23.1	23.3	23.4	23.4	23.6	23.7	23.6	23.7	23.6	23.6	23.6	23.1

t_{po} is push-off duration, v_{to} is vertical takeoff velocity, $P_{CE,peak}$ is peak power output of contractile elements, and $P_{CE,mean}$ is mean power output of contractile elements.