Walking Easier by Attaching a Spring-Mass to the Body: A Preliminary Simulation

When carrying or pushing a load, more force is needed to accelerate and decelerate the additional mass, increasing Ground Reaction Force (GRF). However, this can be reduced by synchronizing the object's movement with the individual's Center of Mass (COM) using antiphase acceleration and deceleration. Past studies have shown this can decrease muscle work and metabolic costs. This study aimed to determine optimal spring parameters to minimize horizontal GRF (GRFh) when pushing a cart by connecting the human to the cart with a spring and damper system.

Three walking conditions were simulated in MATLAB: 1) Normal walking; 2) Walking with a heavy cart (45 kg) attached to the person's waist by a rigid bar, causing the person and cart to accelerate and decelerate in phase; and 3) Walking with the cart attached to the person's waist by a spring with varying stiffness and damping, allowing for antiphase acceleration.

The simulation results indicated that the greatest decrease in GRFh happens when the stiffness constant of the spring is 4360 N/m and the damping constant is 33 Ns/m. The most important finding of this simulation is that any spring with a constant below 5106 N/m leads to a reduction in GRFh, predicting that reducing the GRFh in human experiments will be feasible by starting with a soft spring and replacing it with higher stiffnesses if the constants stay below the optimum. Damping constants of up to 23230 Ns/m still allow reducing GRFh. These constants fall well within the range of existing springs and dampers, supporting the feasibility of lowering GRF with an actual prototype.

High spring stiffnesses (> 5106 N/m) rapidly increase the GRFh above the level of normal walking and even above the level experienced if the person were connected to a rigid bar. In this range of stiffness, even a low acceleration of the person leads to a high amplitude of cart acceleration. Additionally, High damping causes a delay in cart acceleration leading to unsynchronized acceleration of the person and cart. Low damping increases the cart's acceleration fluctuation and results in inconsistent acceleration.

The simulation results show that reducing GRFh while pushing an object is possible by attaching it to the waist with a soft spring. This could lead to designing a device to lower the energy cost of pushing an object while walking.