POWERING THE KNEED PASSIVE WALKER WITH BIARTICULAR SPRINGS

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INTRODUCTION

Passive dynamic walking can be powered by push-off impulses applied along the trailing leg. This form of powering is possible in both straight-legged models [3, 4] and following the addition of knees [1]. In the kneed model, the addition of torsional springs at the hip and knee—as an analogue for muscular torque generation—allows for a wider range of stable gaits. These springs also can reduce energetic losses associated with redirecting the body center of mass during step-to-step transitions [3]. The hip spring helps to generate human-like step frequencies, and the knee spring facilitates proper knee lock timing. Here we show that similar effects can be achieved with a single biarticular spring crossing the hip and knee joints of the swing leg. The spring produces forces similar in phase to those expected from the biarticular muscle activity seen in humans. It appears to be theoretically advantageous to produce higher torques about the hip than the knee, because a human-like gait can be achieved with the lowest spring forces.

METHODS

While torsional springs can be used to model the torques produced about the joints, the human leg also has biarticular muscles which cross both the hip and knee joints. Of particular interest in gait are the rectus femoris, which can produce hip flexion and knee extension, and the long head of the biceps femoris, which generates hip extension and knee flexion. Biarticular springs with attachments above the hip and below the knee can model the action of these two muscles. We used dynamical simulations to determine the effect of a biarticular spring on the kinematics, energetic costs, and stability of the kneed walking model.

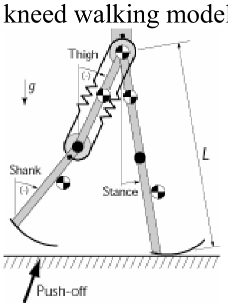

Figure 1. Side view of the walking model. The stance leg is actuated by an impulsive push applied along the leg prior to heel strike, and the joints are actuated by biarticular springs on the anterior and posterior sides of the swing leg. Stance, swing thigh, and swing shank angles are measured counter-clockwise with respect to vertical.

Our planar kneed walking model was similar to McGeer's [4], consisting of four segments with anthropometrically distributed mass, and curved feet offset forward from the legs (Fig 1). Hyperextension of each knee was prevented by a passive mechanical stop. We added a push-off impulse applied at the ground contact point of the stance leg and directed toward the hip, and a variable stiffness spring with one attachment point directly above the hip, and the other on the shank below the knee. The moment arms about the hip and the knee, as controlled by the attachment points, were variable. The model was made non-dimensional by normalizing by body mass (M), leg length (L), and gravity (g).

The periodic gait was powered solely by push-off. During a gait cycle, knee lock and heel strike, modeled as impulsive inelastic collisions, produced instantaneous changes in segment speeds with accompanying energy losses.

RESULTS AND DISCUSSION

As found in the model with torsional springs, step length was predominantly governed by push-off impulse. Step frequency was controlled by the biarticular spring stiffness and the moment arm about the hip. At higher speeds, a minimum spring stiffness is required for stability, and to generate high step frequencies. For a given spring stiffness and hip moment arm, there is a minimum knee moment arm required to ensure that knee lock occurs before foot touchdown.

The configuration of the biarticular spring on the swing leg causes hip flexion and knee extension torques early in the swing phase, and hip extension and knee flexion torques late. This pattern is similar to the torques expected from rectus femoris and biceps femoris muscle activity [2].

Stable gaits at the preferred human speed and step frequency (1.2 m/s, 1.8 Hz) can be generated by appropriate choice of parameters. Push-off is approximately constant across the possible range, but the peak forces or torques produced by the springs, representing muscular forces, can be minimized by producing more torque about the hip than the knee. This may be accomplished by choosing a weak spring about the knee in the torsional spring model (Fig 2a), or springs with a smaller moment arm about the knee than the hip in the biarticular model (Fig 2b).

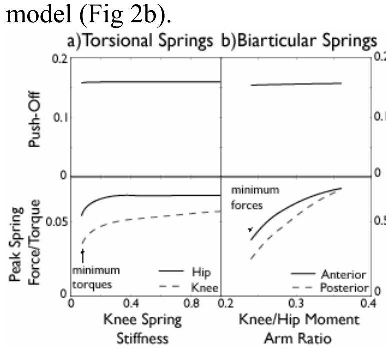

Figure 2. Human-like gaits can be generated using (a) torsional or (b) biarticular springs. In both models, spring forces or torques are minimized by generating less torque across the knee than the hip.

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