Posture Influences Ground Reaction Force: Implications for Crouch Gait

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1. INTRODUCTION

Crouch gait, a common condition among children with cerebral palsy, decreases walking efficiency due to the increased knee and hip flexion during the stance phase of gait [1]. Excessive knee flexion during walking deteriorates joints and leads to chronic knee pain [2], and if untreated, these symptoms can worsen over time [3]. Several factors have been linked with crouch gait, including muscle weakness, spasticity, tightness, and decreased motor control [4]. Despite being studied for decades, a cause and effect relationship between these factors and crouch gait remains unknown, due to the complexity of the musculoskeletal system [4].

Crouch gait is generally considered to be a negative symptom of patients with cerebral palsy; however, a crouched posture may afford biomechanical advantages that lead some patients to adopt a crouch gait. For example, an athlete gets lower to increase the ability to produce movement in all directions. Similarly, a standing passenger on a moving train gets lower to increase the ability to resist movement. In each case, the movement was produced or resisted by generating ground reaction forces in the transverse plane.

In this study, we used musculoskeletal modeling and optimization to evaluate one such possible advantage of crouch gait. The objective was to determine if posture influences the muscles' capacity to generate ground reaction forces in the transverse plane during midstance. We hypothesized that a crouched posture allows the largest average ground reaction force and area of the force profile among postures from upright to severe crouch (Fig. 1). The results of this study suggest an advantage to adopting a crouched posture is an increased capacity of ground reaction forces to compensate for impairments associated with cerebral palsy.

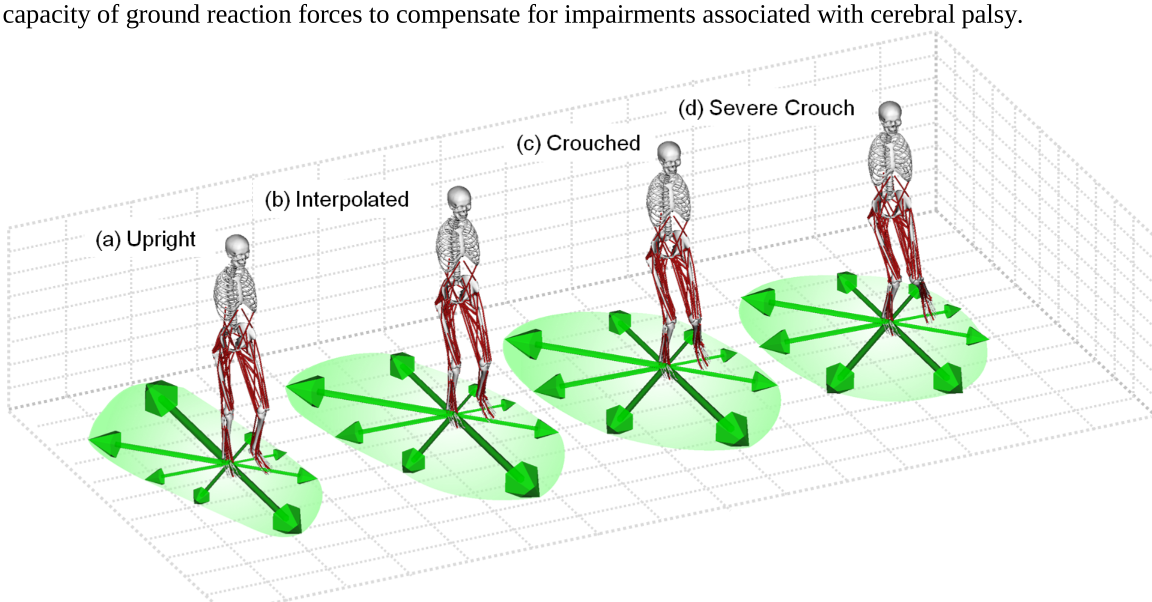

Figure 1. Three-dimensional musculoskeletal models placed in 4 (of 15 total) postures during midstance at 32% gait cycle shown with maximum ground reaction force profiles in the transverse plane: (a) experimental upright posture [5], (b) interpolated posture between experimental upright and crouch data, (c) experimental crouched posture [5], (d) and extrapolated posture from experimental upright and crouch data.

2. METHODS

A three-dimensional musculoskeletal model with 15 degrees-of-freedom and 92 muscles-tendon actuators was created in OpenSim [6]. The model consists of a head, trunk, pelvis, and a right and left femur, tibia, and foot segments. The stance foot (right foot in this simulation) was welded to the ground. The lower extremity joints were modeled as follows: the subtalar and ankle joint were revolute joints, each knee was a planar joint, and the hip was a ball-and-socket joint. The head and torso were included in the model and were articulated with the pelvis through a ball-and-socket joint.

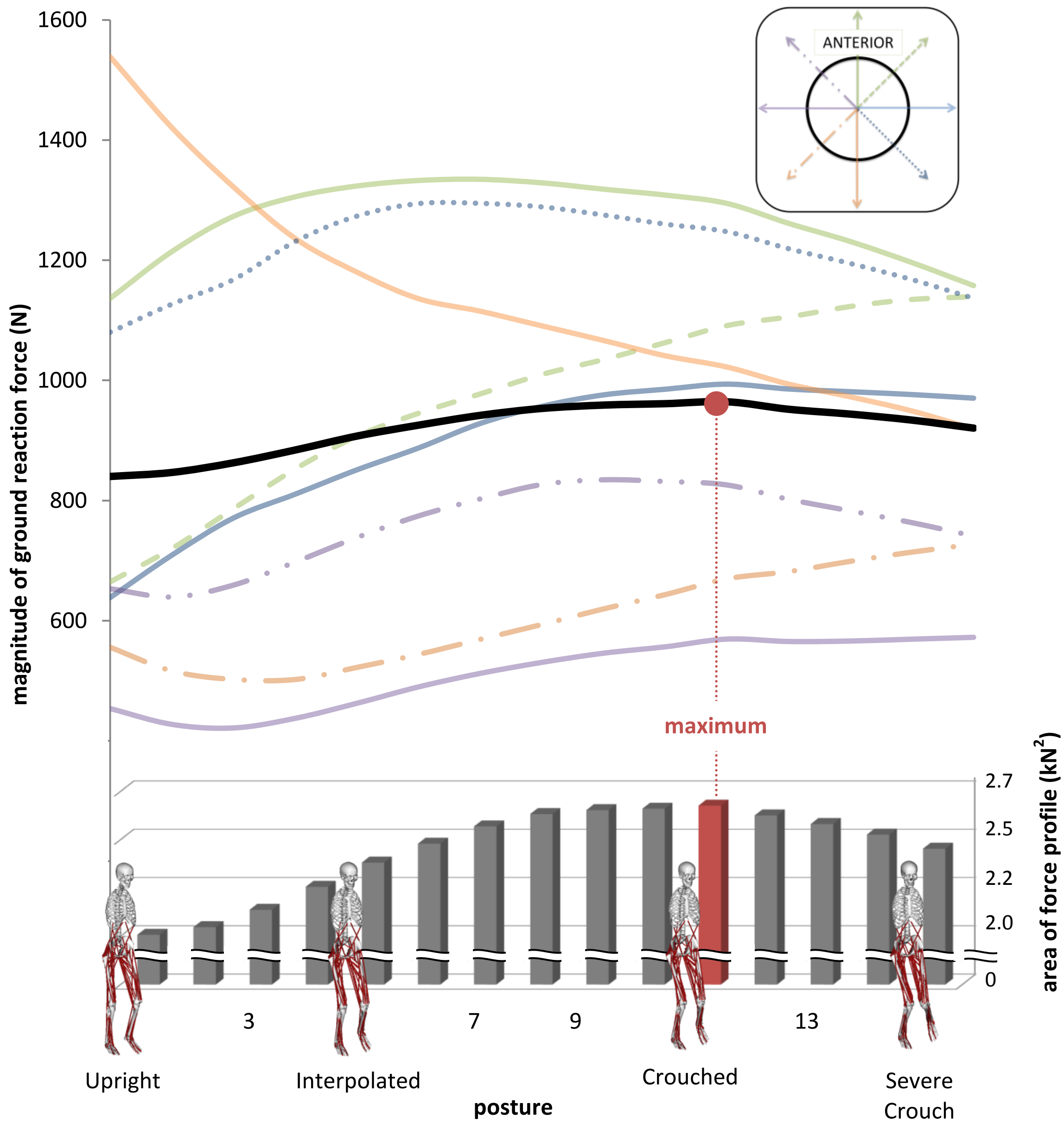

Figure 2. Individual (thin colored lines) and average (thick black line) magnitudes of ground reaction forces and areas of force profiles (bars) for 15 postures during midstance at 32% gait cycle. Individual ground reaction forces were maximized for the 8 compass directions in the transverse plane. The 15 postures were interpolated or extrapolated from experimental upright (posture 1) and crouched (posture 11). The maximum average ground reaction force and area of force profile are shown in red.

The musculoskeletal model was placed in 15 different postures from upright to severe crouch during midstance at 32% of the gait cycle (Fig. 1). Upright posture was defined from the average gait data of 83 able-bodied subjects [5]. Crouch was defined from the average gait data of 100 subjects with cerebral palsy and crouch gait [5]. Using this experimental data, we linearly interpolated nine postures between upright and crouch. We extrapolated four additional postures with knee flexions greater than crouch.

For each of the 15 different postures, a series of optimizations were performed. The optimizer maximized ground reaction forces for the 8 compass directions in the transverse plane by modifying muscle forces acting on the model. Each optimization was subject to a set of constraints requiring the center of pressure to be under the stance foot and the vertical ground reaction force to be greater than or equal to zero.

Our hypothesis was evaluated by comparing the magnitude of maximum ground reaction force in each direction, the average force in all directions, and the area of the force profile for each posture (Fig. 2).

3. RESULTS

The crouched posture allowed the largest ground reaction force averaged over all 8 directions (Fig. 2). The average force of crouch (posture 11) was 12% larger than upright (posture 1) and 4% larger than severe crouch (posture 15). The average force of crouch was only slightly larger (<1%) than posture 10. Upright postures (1 - 5) allowed the largest ground reaction forces in the anterior and posterior directions.

The force profile area of crouch was 24% larger than upright and 8% larger than severe crouch (Fig. 3). Crouch force profile was only slightly larger (<2%) than postures 8, 9, 10, and 12.

4. DISCUSSION

This study examined how posture influences ground reaction forces generated by muscles. We found that average ground reaction force and area of force profile increased as postures change from upright to crouch and decreased as postures move beyond crouch to severe crouch.

Our study is fundamentally different from Hicks et al. [5] which examined the effect of crouched postures on the capacity of muscles to extend the hip and knee joints. They used induced acceleration analysis to determine the joint angular accelerations towards extension resulting from the application of 1 N muscle force to the model. Their study showed almost all the major hip and knee extensors' capacities were reduced in crouch gait. This finding suggests a reduction in the ability to generate vertical ground reaction force. In our case, we used optimization, rather than induced acceleration, to maximize ground reaction forces in the transverse plane without regard for the vertical ground reaction force. Our finding suggests an increase in the ability to generate these forces.

The overall ability to generate larger ground reaction forces and areas of force profiles represents a mechanical advantage of a crouched posture. This advantage results from increased capacity of muscles to generate ground reaction force. This increase in muscle capacity while in a crouched posture may allow a patient to generate new movements to compensate for impairments associated with cerebral palsy, such as motor control deficits.

5. ACKNOWLEDGMENT

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6. References

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