

Effects of Speed and Cadence on the lower Extremity Joint Reaction Forces and Torques During Walking

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ABSTRACT

Inverse dynamics is a process by which kinematic and kinetic data are synchronized to estimate the interior forces and torques in a human joint during movement. By this approach, the reaction forces and torques provide insight to the potential causes of injury. The purpose of this study was to examine the effect of speed and cadence on the lower extremity joint reaction forces and torques during walking. Five different combinations of walking speeds and cadences were analyzed utilizing a repeated measures protocol of fifteen females. Reflective markers, tracking position in time, were placed on the subjects prior to testing. Subjects were tracked by a three-dimensional motion analysis system as they walked down a 15-meter walkway 5 times at each speed and cadence. Photocells monitored walking speed and a digital metronome was used to specify walking cadence. During each walking trial subjects were required to contact a force platform located flush with the walkway surface to obtain ground reaction force data. Modeling software was used to create the link segment model and generate the joint reaction forces and torques at the hip, knee and ankle. Differences were found in joint kinematics and joint kinetics between the different walking conditions ($p < 0.05$).

INTRODUCTION

The process of inverse dynamics uses kinematic (position, velocity and acceleration of body segments and joints) and kinetic (ground reaction forces) data to estimate interior forces and torques of a human joint during movement. This is accomplished by capturing external data through motion analysis and a force platform as a person performs a skill. This technique is a large part of what makes biomechanical analysis useful to scientists. For example, Devita et al. (1997) studied individuals' post ACL injury and reported that there were improvements in knee extensor torques of the injured knee after rehabilitation. Biomechanical analysis may serve to further develop, provide evidence for or even improve rehabilitation protocols.

Lower extremity modeling may also be useful in reducing the occurrence of injury and in prevention (Novacheck 1999; Winter 1992). The speed of walking affects the ground reaction forces that may affect joint kinetics. Devita and Hortobagyi (2000) reported that the lower extremity joint torques change as a result of aging. Further more, Devita (2000) stated that elderly adults select a slower gait velocity with a shorter step length.

The purpose of this study was to examine the effect of speed and cadence on the lower extremity joint reaction forces and torques during walking of healthy females. Relatively, lit-

tle is known about making specific changes in walking speed and cadence and their effect on loads on the lower extremities. This information is important for preserving and maintaining joint health during walking.

METHOD

Subject

We used a repeated measures research design of fifteen healthy females. The females' age ranged from 20 to 25 years. All were free from injury that would alter lower extremity motion during walking.

Instrumentation

Five different combinations of walking speeds and cadences were analyzed: (normal speed-cadence, normal cadence-speed 15% above, normal cadence-speed 15% below, normal speed-cadence 15% above, and normal speed-cadence 15% below). Reflective markers placed on the subjects prior to testing using the Helen Hayes marker set (Kadaba et al.1990). These markers were tracked by a three-dimensional motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) at 60 Hz. Before performing the walking trials, a static data trial was taken to establish hip, knee and ankle joint centers. The position of the reflective markers was tracked as the subject walked down a 15-meter walkway (5 trials at each combination of speed and cadence for a total of 25 trials). Photocells were used to monitor walking speed and a digital metronome provided auditory feedback on the specified walking cadence. During each walking trial, subjects were required to contact a force platform (Bertec, Columbus, OH) located flush with the walkway surface. These ground reaction force data were captured at 1200 Hz. OrthoTrak modeling software (Motion Analysis Corporation, Santa Rosa, CA) was used to create the link segment model and calculate the joint reaction forces and torques at the right hip, knee and ankle. The data was time normalized and the five trials for each condition were averaged.

Procedure

Subjects wore tight fitting clothing and their own pair of athletic shoes. Standing heights and weights were recorded, along with the length of both their right and left foot that was used in the lower extremity model. The subject's normal walking speed was measured through the use of photocells by averaging the speed of ten normal walking trials. Normal walking cadence of the subject was matched to a digital metronome. Reflective markers were placed on the lower extremities of the subject. These reflective markers were used by the three-dimensional motion analysis system to measure the position of the body while moving in space. A static trial was measured first to determine joint centers.

Each subject was instructed to walk at a certain speed while matching their step to the specified cadence on the metronome down a 15 meter walk way. The subject was also required to contact a force platform with her right foot. A few practice trials were provided to allow the participant to match the designated speed and cadence within five percent. After five successful trials, the subject performed the trials at the next specified speed and cadence. During the first set of trails, the subjects walked at her normal walking speed and cadence. The other sets of trials were performed in a random order: cadence kept the same as normal and increased the speed by fifteen percent, speed that was decreased by fifteen percent while

the cadence was kept normal, normal walking speed while cadence was increased by fifteen percent and normal walking speed while cadence was decreased by fifteen percent. Each subject walked a total of twenty-five successful trials.

Data Analysis

Different walking speeds and cadences were analyzed utilizing a repeated measures experimental protocol of the 15 healthy women. The independent variable in this study was the cadence and speed combination. The dependent variables were the kinematic and kinetic data. Statistical analysis was performed using a 2-way ANOVA with repeated measures ($\alpha = 0.05$).

RESULTS

Data analysis indicated that there were differences in the joint reaction forces and torques of the lower extremities when manipulating speed and cadence. The greatest differences occurred when the subjects reduced their walking speed by 15%. There were also reductions in joint reaction forces and torques with increased cadence.

Range of Motion during Walking

The lowest amount of range of motion in the ankle was found when the subject walked at a normal cadence when the walking speed was reduced by 15%. Similar findings were observed at the hip. The knee exhibited the greatest range of motion at a walking speed of 15% below normal and the least at a walking speed of 15% above normal.

Joint Compression Forces during Support

The smallest amount of ankle joint compression force was observed at a walking speed of 15% below normal. Increasing cadence while walking at a normal speed reduced the joint compression force at the ankle. The knee showed similar results as the ankle with a reduced joint compression force at a walking speed of 15% below normal (see Figure 1). Increasing the cadence reduced the joint compression force at the knee. The results at the hip were similar. This indicates a shorter walking stride reduces joint compression forces of the lower extremities during the stance phase of walking.

Anterior Shear

Joint Forces during Support

The least anterior joint force was found at the ankle when the subject was walking at a speed 15% below normal. Similar data were found for the knee and hip.

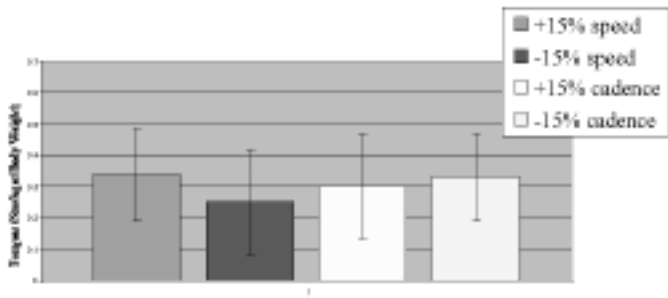


Figure 1. Compression at the Knee during Support

Posterior Joint Forces during Support

Reducing either walking speed or cadence by 15% resulted in a reduction in the posterior joint forces of the ankle. The knee posterior joint force was least when the subject walked at a cadence reduced by 15%. The posterior joint force at the hip was largely reduced when the subject walked at a speed 15% below normal.

Moments during Support

The lowest peak flexor and extensor moments that were produced at the ankle, knee, and hip were exhibited when the subject was walking at a speed that was 15% below normal (see Figure 2).

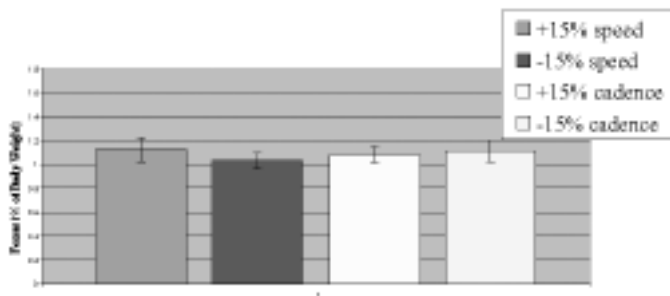


Figure 2. Knee Extension Moment during Support

CONCLUSIONS

The greatest change in joint reaction forces and torques of the lower extremities occurred when subjects walked at a speed that was 15% below normal. We also found lower extremity compressive force reductions when the subject walked at a faster cadence compared to normal. The combined effects of reducing walking speed and increasing cadence results in a shorter stride length. Overall, reducing walking speed has a slightly greater effect on reducing joint compression and peak muscle moments during walking than altering cadence.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Thomas W. Kernozek, for his help, time and guidance on this project. I would also like to acknowledge the College of Science and Allied Health Dean's Summer Fellowship for funding and supplies.

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