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Effects of cadence on energy generation and absorption at lower extremity joints during gait

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Abstract

Background. Information regarding kinetic changes associated with walking speed is important for identifying alterations in locomotor disorders caused by pathological processes, as opposed to those arising solely from altered speeds.

Methods. Fourteen healthy subjects were assessed walking at both natural and imposed cadences of 60, 80, and 120 steps/min. A 3D motion analysis system, force platforms, and related software were used to obtain kinematic and kinetic data. Net joint powers were calculated across cycles and the area under the positive and negative phases of the power curves provided the mechanical work generated and absorbed at the hip, knee, and ankle. The relative contributions to the total positive and negative work across the four cadences were calculated for each joint. ANOVAs followed by planned contrasts were used to assess the effects of laterality, joint, and cadence.

Findings. Power and mechanical work, as well as the contributions of individual joints to the total energy generated and absorbed, were shown to be influenced by walking cadence, independent of laterality. The ankle, knee, and hip contributions to the total limb generation and absorption at the lowest cadence were 53%, 21%, and 26%, and at the highest cadence, the corresponding values were 34%, 33%, and 33%, respectively.

Interpretation. Power and mechanical work, as well as the contributions of individual joints to the total energy generated and absorbed, were shown to be influenced by the walking cadence, independent of laterality. These findings will be helpful for identifying walking strategies and adaptations in populations with gait disorders.

Keywords: Gait analysis; Biomechanics; Mechanical work; Energy; Walking speed

1. Introduction

It is well known in the study of normal human gait, that muscles are the main sources of energy generation and absorption. When walking, the ability to adjust the speed is an important mechanism that requires different levels of muscular activities for appropriate adaptations to changes in the task demands. In general, muscle activity tends to increase at faster walking speeds, resulting in a larger muscular force output (Den Otter et al., 2004). One of the main roles of the muscles is the control of the magnitude and duration of acceleration and deceleration of individual body segments to permit safe forward progression (Bishop et al., 2004; Neptune et al., 2004).

Self-selected walking speed is a well-known indicator of overall gait performance and is commonly used to assess locomotor ability. However, gait speed alone does not contribute substantially to the understanding of the nature of gait deficiencies nor to guide intervention protocols. By the same token, kinematic analyses yield little information

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about the mechanisms underlying normal and abnormal movement patterns. On the other hand, kinetic analyses provide a better understanding of normal motor patterns and result in new directions for diagnosing the causes of abnormal motor patterns observed in pathological gait profiles (Olney et al., 1991, 1994).

Several kinetic parameters have been proposed to evaluate gait. The moment of force parameter provides insights about the predominant muscle groups at a given joint and about the level of the mechanical effort that is produced when relatively expressed to the maximal force capabilities (Milot et al., 2006; Requião et al., 2005). The assessment of the joint power parameter is more sensitive to instantaneous muscle effects to generate or absorb energy, but does not take into account the duration of force application. Work parameters, on the other hand, integrate the power curve over time and provide, in some cases, additional meaningful measures (Winter, 1991) to understand normal (Chen et al., 1997; Siegel et al., 2004; Winter, 1983a) and abnormal walking patterns (Mansour et al., 1982; McGibbon et al., 2001; Olney et al., 1991, 1994; Teixeira-Salmela et al., 2001). Positive work performed during concentric contractions, results in energy flow from muscles to the segments to accelerate the body, whereas negative work, originating from eccentric contractions, produces energy flow from the segments to the muscles to decelerate the body. The interplay between these energy sources facilitates successful progression during walking (Chen et al., 1997; Winter, 1983).

When walking on level surfaces, the ankle plantarflexors, hip flexors, and hip extensors are the main muscle groups that contribute to energy generation in the sagittal plane (Chen et al., 1997; Olney et al., 1994; Winter, 1983, 1991). Previous studies have shown high correlations between positive power bursts of these muscle groups and gait velocity or cadence both with normal (Sadeghi et al., 2001), low-performing elderly (Graf et al., 2005), and pathological subjects (Mueller et al., 1994a, 1994b; Olney and Richards, 1996; Teixeira-Salmela et al., 2001). The knee joint muscles act mainly eccentrically and the rate of absorption of energy is greater with increases in walking speed (Olney et al., 1994; Teixeira-Salmela et al., 2001; Winter, 1983), while negative work at the hip and ankle also results in increases at higher walking speeds.

Because decreasing gait speed or cadence is commonly observed in locomotor disorders, information on kinetic changes with gait speed or cadence in normal subjects is important to pinpoint specific modifications related to the pathology. The study of variations in positive and negative energy contributions would provide baseline data and yield information that would be useful in understanding and treating gait deviations. Moreover, the interaction between different muscle groups in generating and absorbing power is relevant for the understanding the compensatory mechanisms in pathological conditions. For example, patients with diabetic peripheral neuropathy were able to attenuate the decreased push-off by emphasizing hip flexor muscles (Mueller et al., 1994a, 1994b), whereas higher power generation by the hip extensors in early stance was a typical, specific adaptation of above (Seroussi et al., 1996) and below-knee amputees (Gitter et al., 1991; Hermodsson et al., 1994).

In this context, the relative contributions of each muscle group to the total energy generation or absorption should be studied. In normal children, Chen et al. (1997) investigated the influences of walking speed on mechanical joint power during gait and demonstrated that the relative contributions to mechanical work of muscles about the knee and hip were positively correlated with speed, while negatively correlated with ankle muscles. Nadeau et al. (2001) investigated the relative contributions to energy generation for stroke and healthy subjects walking at similar speeds and observed that for the former, they were greater when originated from the hip flexors, whereas for the later, the plantarflexors predominated. Thus, the estimation of the relative contribution of each joint to the total energy generated and absorbed during gait at different speeds seems to be a useful approach to understand the nature, extent, and degree of compensation across joints and to suggest more efficient methods of correction. Moreover, information which is related to kinetic changes to walking speed is important for identifying alterations in locomotor disorders caused by pathological processes, as opposed to those arising solely from altered speeds.

Therefore, the purpose of the present study was to employ an analytical model to estimate the effects of walking cadence and laterality on the positive and negative mechanical work performed by the hip, knee, and ankle muscles in the sagittal plane. According to Winter (1983b), cadence does not affect the energy generation and absorption pattern shapes over a stride and it is largely controlled by the mechanical power generation and absorption. Therefore, it was decided to use cadence as the controlling parameter in the present study.

2. Methods

2.1. Participants

Fourteen healthy volunteers participated in the study, recruited from the community, who had no previous history of lower limb injuries and showed no obvious gait abnormalities. All participants provided consent prior to their evaluation, based on ethical approval from the local research review board. Data related to the mechanical level of effort during gait at different cadences have been published in a previous study for this group of participants (Requião et al., 2005) and used as comparative data in another study (Milot et al., 2006).

2.2. Gait assessment

Participants walked with their own low-heeled shoes along a nine-m walkway over three embedded force plat-