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The association between altered hip extension and kinetic gait variables: A brief report

Elizabeth Carr Wonsetler, PT, DPT¹, Ellie Louise Miller, PT, DPT², Katherine Leigh Huey, PT, DPT², Sarah Elizabeth Frye, PT, DPT², and Mark Goodman Bowden, PhD, PT^{1,2,3}

¹Department of Health Sciences and Research, Medical University of South Carolina, Charleston, SC

²Division of Physical Therapy, Medical University of South Carolina, Charleston, SC

³Ralph H. Johnson VA Medical Center, Charleston, SC

Abstract

Kinematic and kinetic outcome measures are tightly linked in walking. While altering motor output is a major goal of gait rehabilitation, little is understood regarding the relationship between altering a single kinematic variable and kinetic outcome changes. We designed a strategy to isolate hip extension alterations during walking on a treadmill to assess the change in kinetic outcomes. Ten healthy individuals walked on an instrumented split-belt treadmill with motion capture to calculate hip extension and kinetic outcomes at 5 different randomized cadences: self-selected cadence; self-selected $\pm 10\%$, and self-selected $\pm 20\%$. The treadmill speed was held constant at the individual's self-selected walking speed, forcing cadence changes to result in successful alterations to hip extension, varying 8.3 degrees from the self-selected - 20% to + 20% cadence conditions. Kinetic outcomes demonstrated similar alterations. Hip extension changes at each cadence significantly correlated with kinetic changes in propulsive impulse ($r=0.852$, $P<0.001$), peak ankle power ($r=0.473$, $P=0.002$), and ankle plantarflexion work ($r=0.762$, $P<0.001$). These results demonstrate that kinetic outcomes are highly alterable in response to a kinematic gait change. This clinically relevant finding highlights the potential to improve motor output in individuals during rehabilitation by altering gait patterns to achieve more optimal limb positions.

Keywords

Gait; Kinematics; Kinetics; Rehabilitation

Corresponding Author: Elizabeth C. Wonsetler, PT, DPT, Doctoral Student, Health and Rehabilitation Science, Graduate Assistant, Health Sciences and Research, Medical University of South Carolina, College of Health Professions, 77 President St., MSC 700 Charleston, SC, USA 29425-7000, Office: 843-792-3477, Fax: 843-792-1358, wonsetle@musc.edu.

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Introduction

Measuring kinematic and kinetic parameters is important in understanding and assessing the quality of human locomotion, and these parameters are tightly linked within the investigation and rehabilitation of walking. Specifically, hip extension is required for adequate loading of the ankle at terminal stance/pre-swing, the phases of the gait cycle that are necessary for energy storage and transfer during propulsion.¹ Generation of these propulsive forces is required to propel the body forward during walking, and is defined as an essential requirement of locomotion.² Kinematically, hip extension increases the anteriorly directed force and is a significant positive predictor of the amount of propulsion generated by the paretic leg, as well as a critical determinant of walking endurance, after stroke.^{3,4} In addition, loading in extension has long been hypothesized as a precursor to flexion⁵ and is critical in contemporary strategies to normalize sensory input in the goal of aiding walking recovery.⁶⁻⁸

Hip extension is a challenging kinematic factor to control during gait. Robotic gait trainers are often used to control kinematic parameters,⁹ but isolating kinematics is difficult without external constraint. These robotic gait trainers are often expensive, time consuming, and prone to mechanical difficulties, and results obtained are not translatable to over-ground conditions in which the robotic support is removed. We designed a strategy to manipulate step length (with the ultimate goal of altering hip extension) by controlling for both walking speed and cadence during treadmill walking. If walking speed is kept constant, alterations in cadence must be accompanied by changes in step length, as speed is the product of cadence and step length.

While altering motor output is a major goal of gait rehabilitation, little is understood regarding the association between altering a single kinematic variable, without external constraint, and kinetic outcome changes. This is particularly problematic in those variables proven to be crucial in the production of effective gait patterns after neurologic injury, such as spinal cord injury or stroke. In order to build a foundational knowledge base, it is essential to first evaluate the effectiveness of this novel method of altering hip extension and to understand the relationship between hip extension manipulation and kinetic outcomes in healthy controls. Having an understanding of the critical role of hip extension modification in healthy controls during gait will allow for greater understanding in the investigation of these parameters in disabled populations. Therefore, the purposes of this study are as follows: 1. to assess the effectiveness of altering hip extension by manipulating step length via controlling walking speed and cadence, and 2. to assess the association between altering hip extension and a battery of kinetic outcome measures including propulsive impulse, peak ankle power, and ankle plantarflexion work. We hypothesized that changes in hip extension would have a strong direct relationship with changes in kinetic outcome measures.

Methods

Subjects

Subjects from a convenience sample who met the following criteria were included in this study: (a) Adult participants, defined as >18 years of age; (b) Able to provide informed

consent; and (c) Have no preexisting diseases or conditions that would pose increased medical risk during or following ambulation. Informed written consent, approved by the Institutional Review Board at the Medical University of South Carolina (MUSC IRB Pro28941, Contributions to Impaired Walking), was obtained from each participant.

Procedures

During this single session, cross-sectional study, participants walked on an instrumented split-belt treadmill with bilateral force plates (Bertec Corp., Columbus, OH, USA), with motion capture (PhaseSpace Inc., San Leandro, CA, USA) using a modified Helen Hayes marker set to calculate hip extension and kinetic outcomes at 5 different cadences: self-selected (SS) cadence; SS cadence $\pm 10\%$, and SS cadence $\pm 20\%$. First, SS cadence was recorded while the participant walked at their SS walking speed, and the cadence for each walking cadence condition was then calculated. The treadmill speed was then held constant at the individual's SS walking speed, while a metronome produced an audible beep at each of the randomized cadence conditions to assist the participant in staying on rhythm, forcing cadence changes to result in alterations to stride length with the goal of simultaneously altering hip extension. Kinetic variables (propulsive impulse, peak ankle power, and ankle plantarflexion work) were collected during the five walking trials per participant. Number of gait cycles was not standardized, but rather time was constant with each trial at 30 seconds.

Data Analysis

Bilateral step length and peak hip extension of the dominant lower extremity were recorded during each step and averaged for each trial. Differences in step length and hip extension were taken between SS cadence and SS cadence $\pm 10\%$ and $\pm 20\%$ for each participant. Difference scores from baseline SS cadence were also calculated for each kinetic variable. Pearson correlation coefficients assessed the relationship between the change in hip extension and the change in kinetic outcomes.

Results

Ten healthy subjects completed this study: 7 female/3 male; mean age 31.3 years old (SD 7.5); mean height 172.7 cm (SD 10.6); and mean weight 70.4 kg (SD 14.5).

SS cadence averaged 112.40 steps/min (SD 7.24).

Step length was effectively altered bilaterally, varying an average of 0.284 m for the left step and 0.293 m for the right step from the SS -20% to the +20% cadence conditions (Fig. 1).

In turn, hip extension was successfully manipulated, varying an average of 8.3 degrees from the SS - 20% to + 20% cadence conditions (Fig. 2).

Kinetic outcomes demonstrated similar alterations and can be seen in Table 1. Hip extension changes at each cadence significantly correlated with changes in each kinetic outcome: propulsive impulse ($r=0.852$, $P<0.001$), peak ankle power ($r=0.473$, $P=0.002$), and ankle plantarflexion work ($r=0.762$, $P<0.001$).

Discussion

The results of this study demonstrate that hip extension can be successfully manipulated by altering cadence, consequently changing stride length, when a participant's walking speed is kept constant. In turn, the kinetic outcome measures, propulsive impulse, peak ankle power, and ankle plantarflexion work, are highly alterable in response to those changes in hip extension. To our knowledge, no one has been able to isolate hip extension from other kinetic and kinematic variables in this manner in order to investigate this complex gait issue. Our novel approach to manipulating hip extension, and thus, kinetic outcome measures, not only expands upon the literature supporting the importance of hip extension in neurologic rehabilitation, but potentially provides a more clinically applicable and feasible method to alter gait mechanics.

Our findings align well with other studies that have shown that trailing limb angle is a major contributor to propulsion during gait in both the healthy¹⁰ and the post stroke population.^{3,11} Since achieving adequate hip extension is critical in preparing for transition from stance to swing,³ by successfully facilitating an increase in step length (and thus greater hip extension), production of anterior propulsion and force during gait is improved. In addition, hip extension more appropriately loads the ankle in dorsiflexion, creating better muscular and mechanical energy, essential for stance to swing transition and thus forward propulsion.¹² Adequate hip extension and ankle loading is critical to coordination from the various components of the neuromotor system contributing to gait, as recent work by Palmer et al. in the stroke population demonstrates that the ankle plantarflexion moment is strongly related to descending corticomotor excitability.¹³

Understanding the influence of kinematic variables on kinetic variables and the control mechanisms of these influences expands upon the increasing knowledge of motor control of human gait. The cadence component of this experiment adds a cortically driven aspect to the gait pattern, as the participant is having to actively think about and control stepping to the beat of the metronome. This component emphasizes the concept that the motor cortex plays an imperative role in human locomotion.¹⁴ However, these results also illustrate the capability of the nervous system to interpret cadence and kinematic input into spinal modulatory systems. While it is beyond the scope of this project to examine spinal neurophysiology, these findings support recent evidence that kinematic and kinetic alterations to gait patterns may be spinally modulated.¹⁵ Loading in hip extension has neural importance via the activation of peripheral sensory input into spinal modulation, therefore allowing neurorehabilitation therapy to take advantage of the sub-cortical control of walking.

Clinically, therapists may potentially improve the force output of impaired limbs by increasing the amount of hip extension in terminal stance. Contemporary walking rehabilitation strategies, including the use of walkers and other assistive devices, can not only limit hip extension training by hindering the ability for a clinician to assist with hip extension, but also because they often place patients in trunk and hip flexion. The results of this study advocate for not only potentially introducing cadence as a training parameter, but also incorporating permissive training environments. These permissive environments, like overhead body-weight support systems, will provide greater opportunity for gait training

into hip extension, which will allow for greater kinematic and kinetic alterations. It will be necessary to duplicate this study in an impaired population, as our method of hip extension manipulation may not be as effective in those with neurologic gait impairments, for example post-stroke. However, this study provides proof of concept regarding gait adaptations secondary to kinematic manipulation.

There are limitations within in this study that should be considered. The sample size was small and the male to female ratio was not equal. This reflects a limitation of the convenience sampling method used in this study, and potentially affects inverse dynamics calculations that rely on anthropometric assumptions. However, the effect of anthropometric variance should be minimized as the design utilized repeated measures with a constant control of both gait speed and cadence.

In conclusion, these results demonstrate that kinetic outcome measures are highly alterable in response to kinematic hip extension changes in the gait pattern. This clinically relevant finding suggests that therapists may potentially improve motor output and the neuromechanics of gait in individuals undergoing rehabilitation by simply altering hip extension in terminal stance.

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Abbreviations

SS self-selected

Fig. 1. Step Length Change
Average of 10 participants at each condition.

Fig. 2. Hip Extension Change
Average of 10 participants at each condition.

Table 1
Hip extension and kinetic variable change scores from SS cadence condition

Change Scores	Hip Extension (°)	Propulsive Impulse (Ns)	Peak Ankle Power (W)	Ankle Plantarflexion Work (J)
20% less cadence	4.770	16.440	23.059	10.067
10% less cadence	3.091	9.580	10.441	5.845
10% more cadence	-0.901	0.051	1.806	-0.271
20% more cadence	-3.577	-4.408	-8.388	-1.667