INTRODUCTION

Measuring relative muscle effort during a dynamic task is a challenge. This makes it difficult, in many clinical cases, to assess the muscular impairments that most limit an individual from being able to walk at a desirably fast speed. The data presented here from unimpaired individuals walking at multiple combinations of walking speeds and body-weight support levels show that different muscle groups exhibit different relative sensitivities to changes in each of these two factors. We envision that modulation of these and other variables during gait analysis could be used to develop a “biomechanical stress test” that would enable selective dynamic probing of how limited muscle strength may contribute to diminished walking ability in individuals with impairments.

METHODS

Motion capture and force platform data were collected from 8 unimpaired adult subjects as they walked on an instrumented, split-belt treadmill (Bertec Corp., Columbus, OH) while wearing a harness connected to a custom-designed, overhead body-weight support system (Intelligent Automation, Inc., Rockville, MD). The body-weight support system was specifically designed to maintain a constant support load throughout the gait cycle. Subjects walked with four different levels of body-weight support (0, 20, 40, and 60% of body weight) at each of three walking speeds (0.4, 0.6, and 0.8 statures/s, ranging on average from 0.7 to 1.4 m/s). Conditions were presented to subjects in a randomized order. Subjects were given 1.5 minutes to acclimate to each condition before data were collected for at least one minute.

Data were used to calculate hip, knee, and ankle net muscular moments for the left leg for all clean treadmill strides (i.e. neither foot fell on the opposite belt and the subject did not drift fore or aft.) Peak flexion and extension moments at the hip, knee, and ankle were averaged across trials within each condition for each subject. Average peak moments were scaled for each subject by the value measured when walking at 0.8 statures/s with zero body-weight support (i.e. after scaling, the peak moments for this condition had a value of 1.0). These scaled peak moment values were averaged across subjects for each condition. The relative sensitivity (S) of a muscle group to a change in walking speed (or body-weight support) was calculated at each body-weight support level (walking speed) as the difference in the scaled peak moment values at the lowest and highest walking speed (body-weight support level). Differences in sensitivities were evaluated using t-tests and the Holm-Bonferroni method for multiple comparisons with p < 0.05. These tests did not account for causal linkages across joints.

RESULTS AND DISCUSSION

As expected, in general, subjects’ peak joint moments decreased with decreasing walking speed and with increasing body-weight support. However, the relative sensitivities of the moments at the hip, knee, and ankle to changes in speed and body-weight support were variable across muscle groups.

For example, when subjects walked with 40% body-weight support over a range of speeds, the ankle extensors showed a low relative sensitivity to changes in walking speed (dropping from a scaled mean peak moment value of 0.67 to 0.50 {S = 0.17 ± 0.07} over a change in walking speed from 0.8 to 0.4 statures/s) as compared to the knee extensors (p < 0.05), which showed a high relative sensitivity to changes in speed (dropping from a scaled peak moment value of 0.80 to 0.34 {S = 0.47 ± 0.24} over a change in walking speed from 0.8 to 0.4 statures/s) (Fig. 1). This was observed at other levels of support, and suggests that an increase in supported walking speed poses more of a relative
challenge to the knee extensors than to the ankle extensors.

Conversely, when subjects walked at 0.6 statures/s, the knee extensor moment showed a much lower relative sensitivity to changes in body-weight support than all other muscle groups (p < 0.05), with the knee flexors showing a higher relative sensitivity to changes in body-weight support than all other muscle groups (p < 0.05) (Fig. 2).

Previous studies have examined the contribution of joint moments [1] or individual muscles [2,3] to support and forward progression. Our work complements these studies, but examines the data from a different vantage point and towards a different goal. As opposed to elucidating muscle function, we aim to identify how conditions could be altered to selectively challenge individual muscle groups. This goal is well-served by our choice to scale peak moments by those observed at a control condition. However it is important to recognize that this approach may mask which muscle groups showed the largest absolute changes in peak joint moment with changes in either walking speed or body-weight support levels.

By compiling these data for additional subjects over a broad range of walking speeds and support levels, we aim to provide a framework for selecting combinations of walking speed and body-weight support that could be used to effectively probe the biomechanical limits of an impaired gait strategy. Altering the level of body-weight support provided during sub-intervals of the gait cycle [4] could further differentiate the relative level of challenge provided to individual muscle groups.

REFERENCES

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**Figure 1**: Scaled peak joint moments averaged for 8 unimpaired subjects walking with 40% body-weight support at a range of speeds. Error bars indicate ±1 standard deviation. The ankle extensor moment shows less relative change with walking speed than the knee extensors (p < 0.05).

**Figure 2**: Scaled peak joint moments averaged for 8 unimpaired subjects walking at a speed of 0.6 statures/s at a range of body-weight support levels. Error bars indicate ±1 standard deviation. The knee extensor moment shows less relative change with body-weight support level than the other net muscle moments (p < 0.05), while the knee flexor moment shows more relative change (p < 0.05).