Influence of Step Length and Cadence on the Sharing of the Total Support Moments Between the Lower Limbs During Level Walking

Chien-Chung Kuo[1], Shih-Wun Hong[1], Jia-Da Li[2] and Tung-Wu Lu[2,3]

Department of Orthopaedics, China Medical University Hospital, Taichung, Taiwan, R.O.C[1]
Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan, R.O.C [2]
Department of Orthopaedic Surgery, School of Medicine, National Taiwan University, Taiwan, R.O.C [3]

The current study aimed to investigate the effects of walking speed on the inter-limb sharing of whole body support in terms of total support moments (Ms) during walking. A multiple linear regression model was conducted to explore the relationship between gait speed in terms of step length and cadence, and the difference of the first and second peaks of the Ms (DMs) during walking. The DMs were found to increase with either increased step length or cadence. Walking with greater speed relied more on the leading limb to provide support for the forward progression of the body. In addition, variations of gait speed parameters affected the load-sharing pattern between the lower limbs during weight transfer of walking. Gait speed parameters have to be taken as covariates when analysing the coordination of the kinetics between lower limbs.

KEY WORDS: Gait analysis, Walking speed, Support moment.

INTRODUCTION: Gait analysis has been used to detect subtle differences in persons with pathology in the locomotor system. For some gait studies, whether the changes of gait variables are affected by the pathology or the compensatory strategies such as reduced walking speed is an existing issue (Mrozowski J & Awrejcewicz J, 2011). During Gait, proper combinations of joint moments with respect to a specific kinematic pattern are necessary to support the body weight (BW) and to prevent collapse of the lower limbs while balancing and supporting the body (Winter DA. 1980). It has been shown that gait speed affects joint moments. However, whether gait speed would also affect the effort for body support remains unclear. Therefore, a quantitative characterization of the coordination of the joint kinetics between lower limbs is needed. The coordination is associated with the multitude of combinations of moments at the hip, knee and ankle that could be used to support the upper body. Such coordination could be described using the total support moment (Ms), defined as the numerical sum of the extensor moments at the hip and knee, and the plantarflexor moment at the ankle (Winter DA. 1980). The current study thus aimed to investigate the effects of walking speed (in terms of step length and cadence) on the inter-limb sharing of whole body support in terms of total support moments (Ms) during walking.

METHODS: Thirty-six healthy subjects were recruited and asked to walk at self-selected speed while their kinematic and kinetic data were measured with a 7-camera motion analysis system (Vicon, Oxford Metrics, U.K.) and two force plates (AMTI, U.S.A.). Twenty-eight infrared retro-reflected markers were placed on specific landmarks of the lower limbs to track the motion of the segments. With the measured GRF and kinematic data, internal moments at the lower limb joints were calculated using inverse dynamics analysis. All the calculated joint moments were normalized to body weight (BW) and leg length (LL). The total support moment (Ms) of a limb was calculated as the sum of the net joint moments at the hip, knee and ankle joints, which showed a characteristic double peak pattern. For studying the load-sharing between the lower limbs during walking, differences between the first and second peaks of the Ms (DMs) were then calculated (Fig. 1). Parameters of walking speed including step length (cm) and cadence (steps/min) were also calculated.

A multiple linear regression model was conducted to analyze the relationship between step length and cadence, and DMs. An analysis of variance (ANOVA) was used to test the performance of the model. The value of coefficient of determination (R2) was calculated to illustrate the goodness of the fit. All significance levels were set at α=0.05. All statistical analyses were performed using SAS version 9.1.3 (SAS Institute Inc., NC, USA)

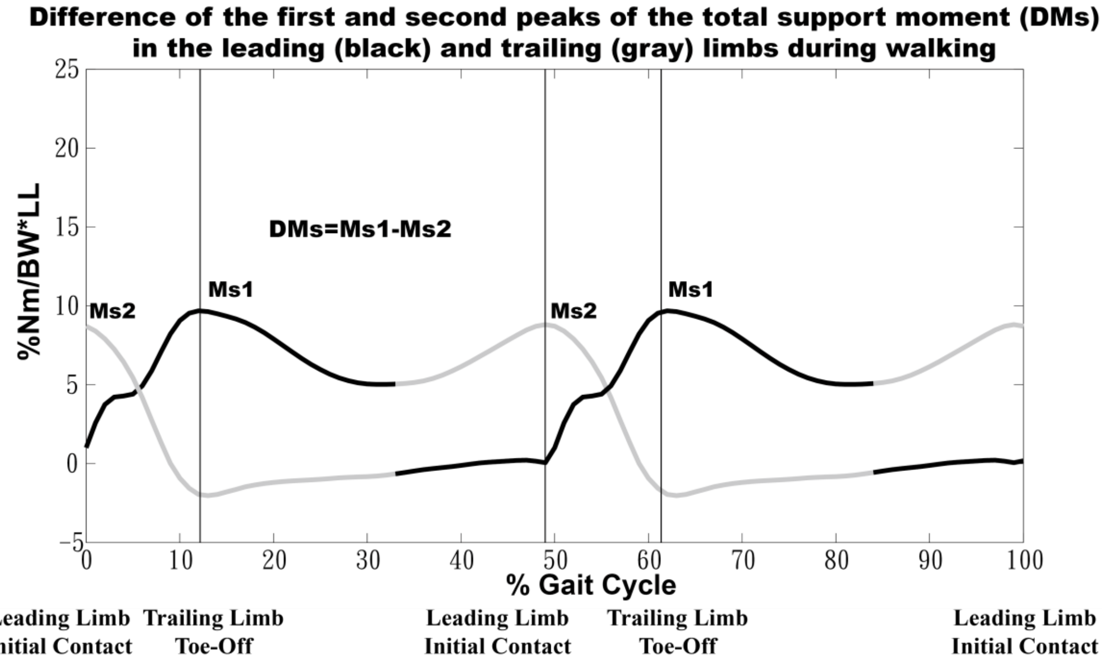

Figure 1: The difference of the first and second peaks of the total support moment (DMs) in the leading (black) and trailing (grey) limbs

RESULTS: Data for walking speed, step length, cadence, first and second peaks of Ms, and DMs are summarized in Table 1. DMs were significantly associated with gait speed parameters in the multiple linear regression analysis (R^2=0.74, F=46.56, p<0.0001). In addition, DMs were associated with step length (βs=0.15, p_s=0.02) and cadence (βc=0.23, p_c<0.0001). The regression model was then written as

$$DMs=\beta_0+\beta_s*\text{Step length}+\beta_c*\text{Cadence} \quad (1)$$

where β_0= -34.09, β_s=0.15, β_c=0.23

Table 1 Means, standard deviations (SD), and 95% confidence intervals (95% CI) of the gait speed and kinetic parameters (LL: Leg Length; BW: Body Weight)

Variables	Mean	SD	95% CI
Speed (cm/s)	108.0	15.7	103.0 - 113.0
Step length (cm)	58.4	5.3	56.6 - 60.2
Cadence (steps/min)	111.2	13.4	106.7 - 115.8
Ms1 (% LL*BW)	9.9	4.6	8.3 - 11.4
Ms2 (% LL*BW)	9.2	2.1	8.4 - 9.9
DMs (% LL*BW)	0.69	3.6	-5.1 - 1.9

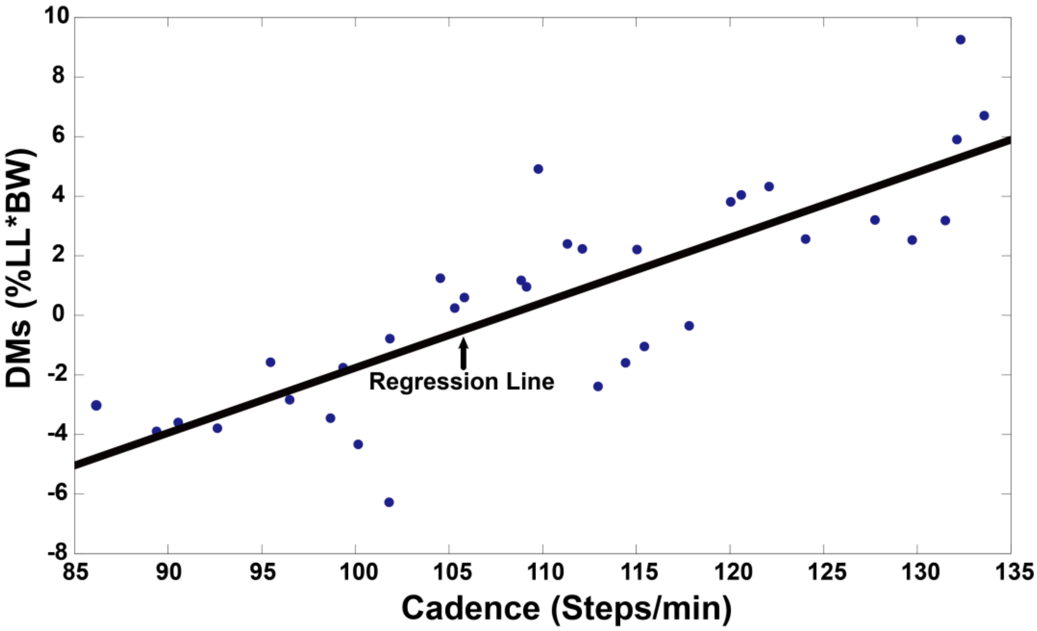

Figure 2: The scatter plot and regression line of cadence (step/min) against difference of the first and second peaks of the Ms (DMs, LL*BW) for all subjects. LL: Leg Length; BW: Body Weight

DISCUSSION: During walking, the first peak of the total support moment (Ms1) occurred during early stance when the limb was leading, and the second peak (Ms2) occurred during late stance when the limb was trailing. As the DMs is the difference of the first and second peaks of the Ms, greater DMs indicate that the peak total support moment was greater during early stance. In the current study, the DMs were found to increase with either increasing step length or cadence (Figure 2). This suggests that walking with greater speed relied more on the leading limb to provide support for the forward progression of the body. This is in contrast to walking slowly where the second peak of the support moment tended to be greater than the first peak (Figure 2).

According to the regression model, the DMs would be increased for 0.15 units of the joint moments (%LL*BW) with an increase of 1 cm in step length and be increased for 0.23 units with an increase of 1 steps/min in cadence. Thus, variations of gait speed parameters affect the load-sharing patterns between the lower limbs during weight transfer of walking. It is suggested that gait speed parameters have to be taken as covariates when analysing the coordination of the kinetics between lower limbs to detect the subtle differences in the persons with pathology.

CONCLUSION: The walking speed (step length and cadence) was found to affect the inter-limb sharing of the total support moments during walking. A multiple linear regression model has been conducted to explore the relationship between gait speed parameters and differences between the first and second peaks of the total support moment (DMs). The DMs would be increased with either increasing step length or cadence. It is suggested that gait speed parameters have to be taken as covariates when analysing the coordination of the kinetics between lower limbs during level walking.

REFERENCES:

Mrozowski J & Awrejcewicz J (2011). Changes in the gait characteristics caused by external load, ground slope and velocity variation. *Communications in Nonlinear Science and Numerical Simulation*, 16, 2313-2318.

Winter DA. (1980) Overall principle of lower limb support during stance phase of gait. *Journal of Biomechanics* 13, 923-927.