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# Walking pattern in children with and without Down syndrome via a Force-Driven Harmonic Oscillator Model

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## Introduction

Children with Down syndrome (DS) display poorer kinematic and kinetic patterns of walking than typically developing (TD) children. However, little is known on neuromuscular control in children with DS during locomotion.

A force-driven harmonic oscillator (FDHO) model sheds light on general muscular activation with respect to the gravitational load of the thigh-shank-foot system. The K/G ratio derived from this model represents a scaling between the elastic restoring torque from muscles and soft tissues and the gravitational torque from the weight of the leg during walking.

The K/G ratio has shown different muscular function in infant walkers [1] and children with cerebral palsy [2]. This study aimed to compare the K/G ratio between children with and without DS during walking.

## Method

**Participants:** 26 children with and without DS aged 7-10 years completed overground walking at visit #1, and 20 children completed treadmill walking at visit #2. Of the 26 subjects, the DS group was 9.0±1.3 years in age, 1.24±0.08 m in height, and 30.6±5.6 kg in body mass; the TD group was 9.1±1.4 years in age, 1.33±0.07 m in height, and 29.6±5.1 kg in body mass.

**Experimental design:** At visit #1, participants walked barefoot overground at two speeds: normal (NS) and the fastest speed (FS). At visit #2, participants walked barefoot on a treadmill at 75% (NS) and 100% (FS) of the preferred overground speed. Two loads were manipulated at both visits: no load (NL) and ankle load (AL) equal to 2% of body weight on each side. Average AL condition was 6.0 N in the DS group and 5.9 N in the TD group.

**Data collection:** Four conditions (2 speed x 2 load) were tested at each visit. A 7-camera Vicon motion capture system was used to register reflective markers attached bilaterally to the subjects. Four trials were collected for each condition during overground walking. A Zebris FDM-T instrumented treadmill was used to register vertical ground reaction force during treadmill walking. Two 60-second trials were collected for each condition.

**Data analysis:** An FDHO model [3] represents a hybrid pendulum-spring system that consists of a single pendulum and a spring attached to the pendulum. The simple pendulum represents the gravitational contribution of the thigh-shank-foot system facilitating the passive dynamics of the system, and the spring represents the contribution of muscles and soft tissues facilitating the active dynamics of the system during walking. When ankle load is added, it becomes the thigh-shank-foot-ankle load system.

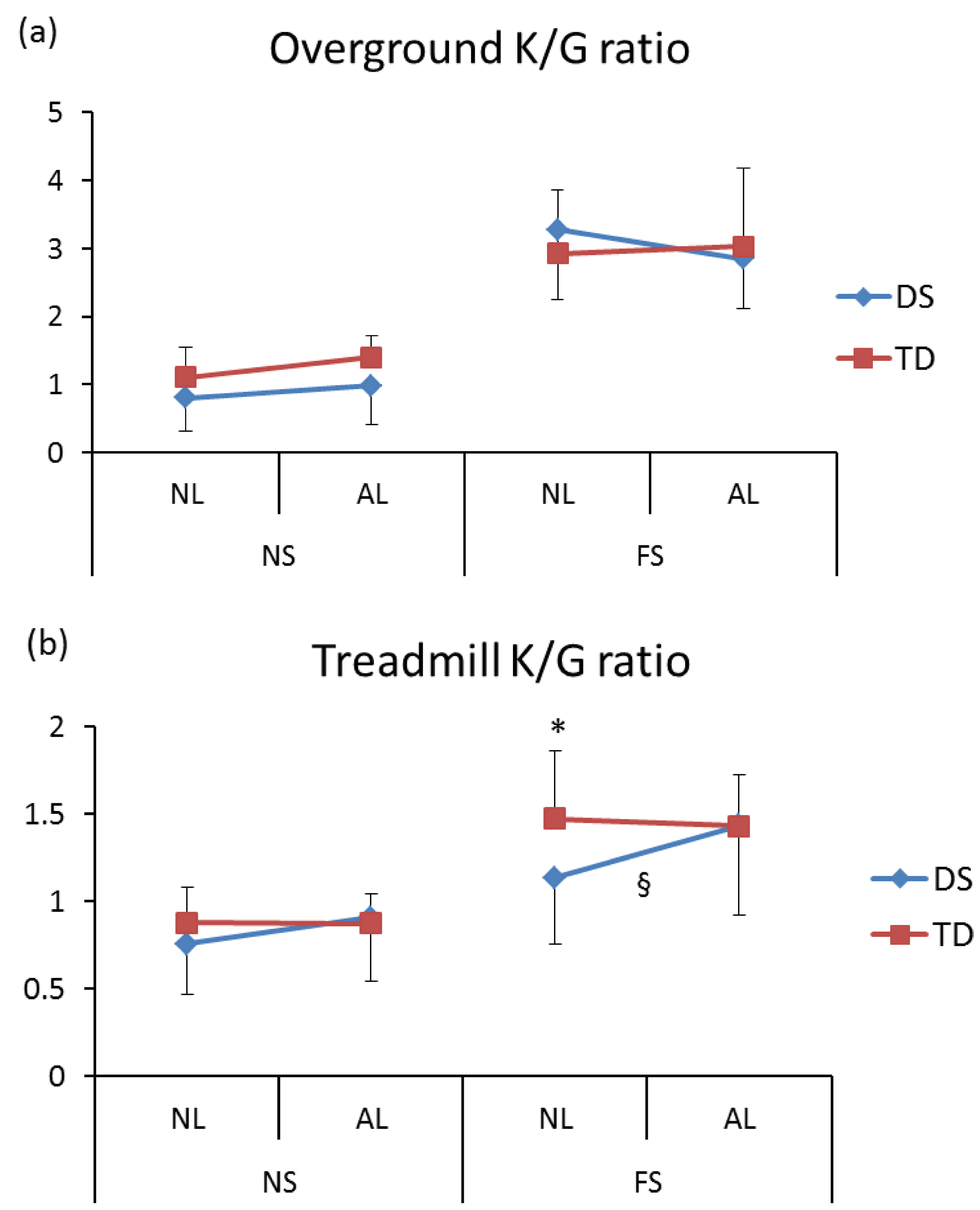
For small amplitude of oscillation during walking, the periodic duration (i.e., stride time) can be predicted as below:

$$\tau = 2\pi\sqrt{\frac{mL^2}{mLg + kb^2}} = 2\pi\sqrt{\frac{L}{g + \frac{kb^2}{mL}}} = 2\pi\sqrt{\frac{L}{(1 + {}^{K}/_{G})g}}$$

where $\tau$ is stride time, $m$ is the mass, $L$ is equivalent leg length of the system, $g$ is gravitational acceleration (9.81 m/s$^2$), $mL^2$ is the moment of inertia of the system about the hip joint, $mLg$ is the gravitational restoring torque associated with the size and mass of the system, and $kb^2$ is the elastic restoring torque from muscles and soft tissues.

**Statistical analysis:** Two 3-way (2 group x 2 speed x 2 load) ANOVAs with repeated measures were conducted on the K/G ratio for overground and treadmill walking separately. Post hoc pair-wise comparisons with Bonferroni adjustments were conducted when appropriate. Statistical significance was set at $p<0.05$.

## Results and Discussion




During overground walking, the K/G ratio across the two groups was 1.07 in the NS condition and 3.02 in the FS condition.

The ratio between the elastic and gravitational torques was about 1:1 in the NS condition and 3:1 in the FS condition for the two groups regardless of external ankle load (Fig. a).

Both groups increased the K/G ratio from the NS to the FS condition ($p<0.001$).

During treadmill walking, the K/G ratio was 0.85 across the two groups in the NS condition. In the FS condition, the DS group produced a lower K/G ratio of 1.14 compared to 1.47 in the TD group without ankle load, but a similar K/G ratio of 1.44 compared to 1.43 in the TD group with ankle load (Fig. b).

Both groups increased this ratio from the NS to the FS ($p<0.001$). Also, there was a group by load interaction on the K/G ratio ($p=0.007$). In the FS condition, the DS group increased the K/G ratio from the NL to the AL condition while the TD group maintained the K/G ratio regardless of external ankle load.

## Conclusions

The inclusion of external ankle load appears to improve general muscle activation in children with DS, and it may be a promising training component when designing an intervention to improve motor function in children with DS.

## References

1. Holt KG, et al. Phys Ther 87, 1458-1467, 2007.
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