INTRODUCTION

Children with Down syndrome (DS) display poorer kinematic and kinetic patterns of walking than children with typical development (TD). It is generally suggested that low muscle tone and joint laxity contribute to motor deficits in children with DS. However, little is known about 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. Clinically, this ratio was previously used to show 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 while walking overground and on a treadmill.

METHODS

Participants: Twenty six children with and without DS aged 7-10 years completed overground walking at lab visit #1, and 20 children completed treadmill walking at lab 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 the first visit, participants walked barefoot overground at two speeds: normal (NS) and the fastest speed (FS). At the second visit, participants walked barefoot on a treadmill at 75% (NS) and 100% (FS) of the preferred overground speed. Two load conditions were manipulated at both visits: no load (NL) and ankle load (AL) that was 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:
A total of four conditions (2 treadmill speed by 2 ankle load) were tested at both lab visits. The order of condition presentation was mostly randomized across the two groups. 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: Customized Matlab programs were used to determine gait events such as heel contact and toe off for overground and treadmill walking trials. 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:

\[ \tau = 2\pi \sqrt{\frac{mL^2}{mLg + kb^2}} \]

where \( \tau \) is stride time, \( m \) is the mass, \( L \) is equivalent leg length of the system, \( g \) is gravitational acceleration \( (9.81 \text{ m/s}^2) \), \( mL^2 \) 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. This equation can be reduced as below:

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

**Statistical analysis:** Two 3-way (2 group x 2 speed x 2 load) ANOVA with repeated measures on the last two factors 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. In other words, 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). There was a speed effect on the $K/G$ ratio ($p<0.001$) such that both groups increased the $K/G$ ratio from the NS to the FS condition.

![Overground K/G ratio](image)

During treadmill walking, the $K/G$ ratio across the two groups was 0.85 in the NS condition regardless of external ankle load. 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). There was a speed effect on the $K/G$ ratio ($p<0.001$) such that both groups increased this ratio from the NS to the FS condition. Also, there was a group by load interaction on the $K/G$ ratio ($p=0.007$). No difference in the $K/G$ ratio was observed in the NS condition between the two groups. However, 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. The DS group produced a lower $K/G$ ratio at the fast speed of treadmill walking without ankle load, but the inclusion of ankle load helped children with DS produce a similar $K/G$ ratio as their healthy peers.

![Treadmill K/G ratio](image)

Although no specific muscle was identified, the FDHO model demonstrates that children with DS are able to produce a similar general muscular activation as their healthy peers while walking overground, an important daily motor activity. However, children with DS may have difficulty in performing a novel task such as walking on a treadmill at a fast speed due to the limitations of their physical characteristics.

**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 protocol to improve motor function in children with DS.

**REFERENCES**


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