The Cost and Spring-like Behavior of Walking: Are Children Scaled Down Adults?

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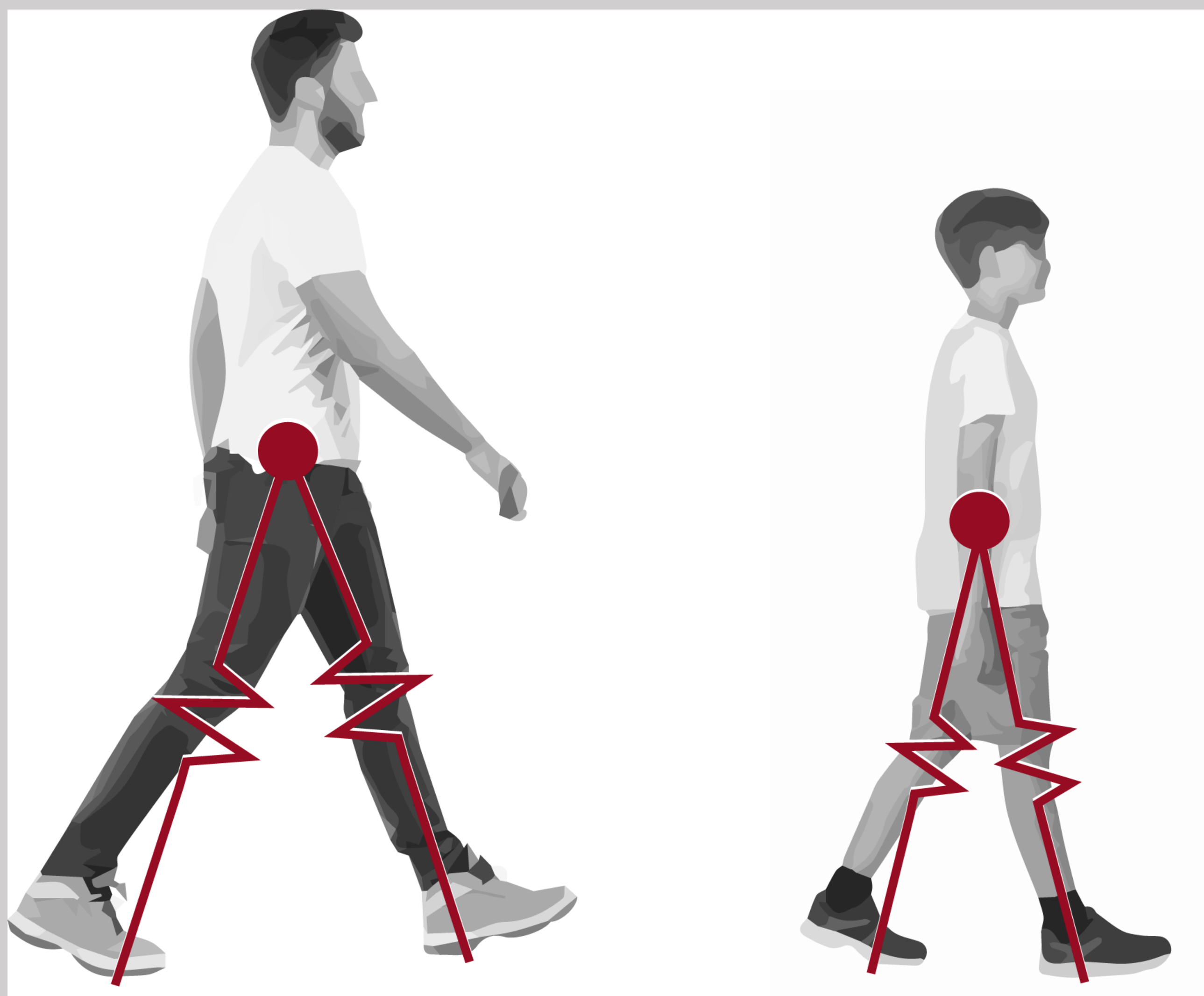
INTRODUCTION Evidence from walking experiments suggests that adults operate and exploit the leg's ability to behave as a spring to save metabolic energy[1-2]. Children demand a higher net cost of transport (CoT) compared with adults—they use more energy to move one kilogram of their body mass a unit meter[3]. Using a simple spring-based walking model[4], we explored the following question:



Eight adults and eight children walked at a comfortable speed on an instrumented treadmill (Bertec) for 5 minutes at 3 step frequencies (75%, 100%, 125% of preferred) while recording metabolic rate (Parvo Medics) and kinematics (Vicon).

Table 1: Subject Characteristics

	Children (n=8)	Adults (n=8)
Sex (F)	3	4
Age (y)	5.43 (.53)	26.38 (4.4)
Height (m)	1.22 (.04)	1.72 (.08)
Weight (kg)	24.77 (5.6)	75.0 (17.4)
Spring length (m)	0.70 (.06)	1.03 (.06)
Speed (m/s)	0.52 (.13)	1.13 (.18)

Values are mean (SD)

METHODS We defined a vector from the center of mass to the center of pressure to represent a 2D spring in the sagittal plane during single support, and then calculated *k* from the best fit slope of the 2D GRF vs. spring length curve. Spring constant *k* was scaled to a non-dimensional $\check{k}$, where $\check{k} = kl_0/mg$. Separate repeated measures ANOVAs ($\alpha<0.05$) and *t*-tests were used to compare net COT, $\check{k}$, and touchdown angle.

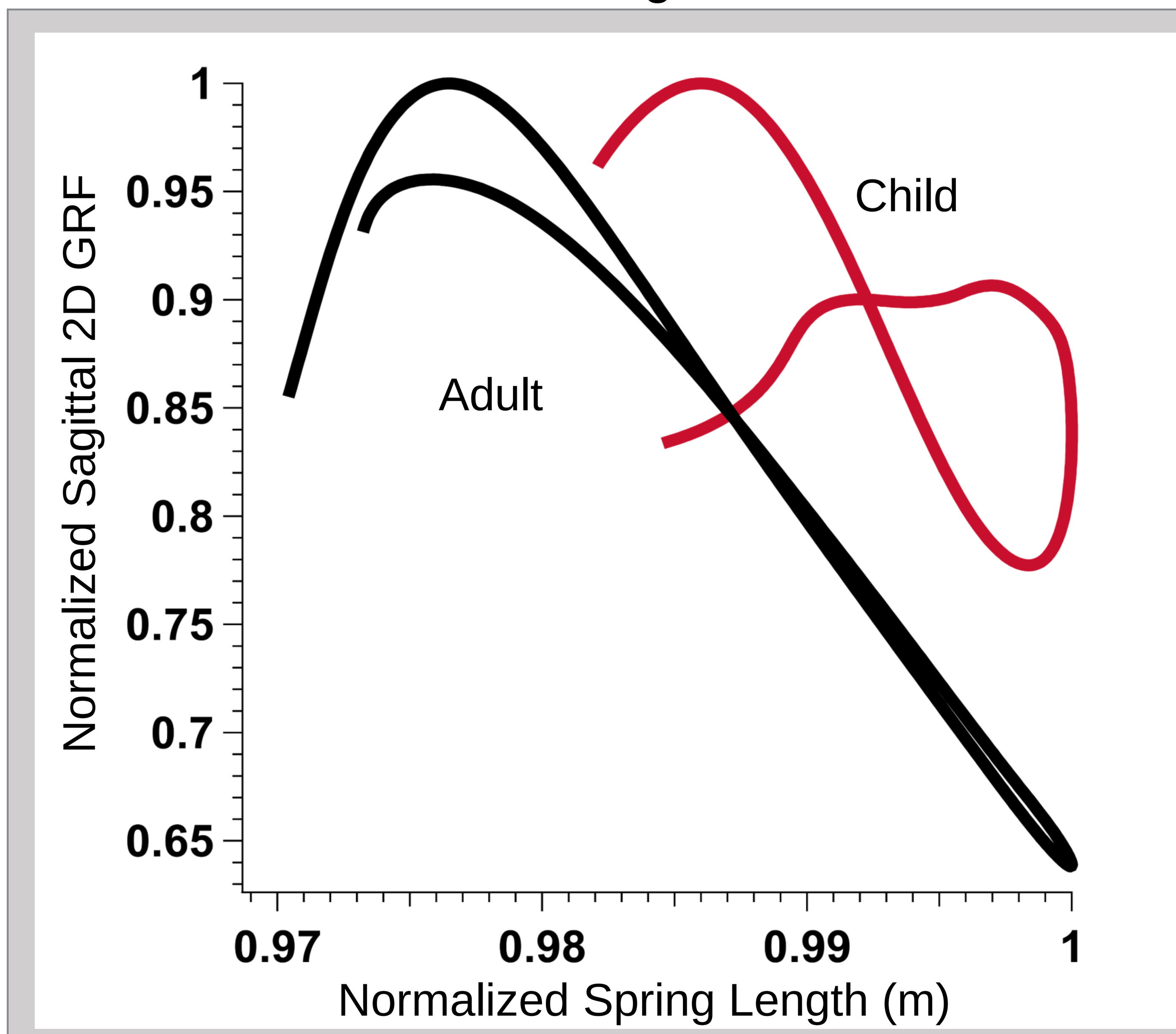


Figure 1. Representative child and adult force-displacement curves normalized to peak values during a single support phase. Note that slope equals *k*. Child trajectories are more variable and exhibit more hysteresis.

Might the higher net cost of transport in children be a consequence of how well children operate the spring-like behavior of their leg?

1. **Is scaled leg spring stiffness, $\check{k}$, similar in children?**
2. **How is $\check{k}$ modulated across step frequency?**
3. **Can $\check{k}$ can serve as a mechanical correlate to CoT?**

We find a child's leg "spring" to be more compliant, which is linked to a higher net CoT

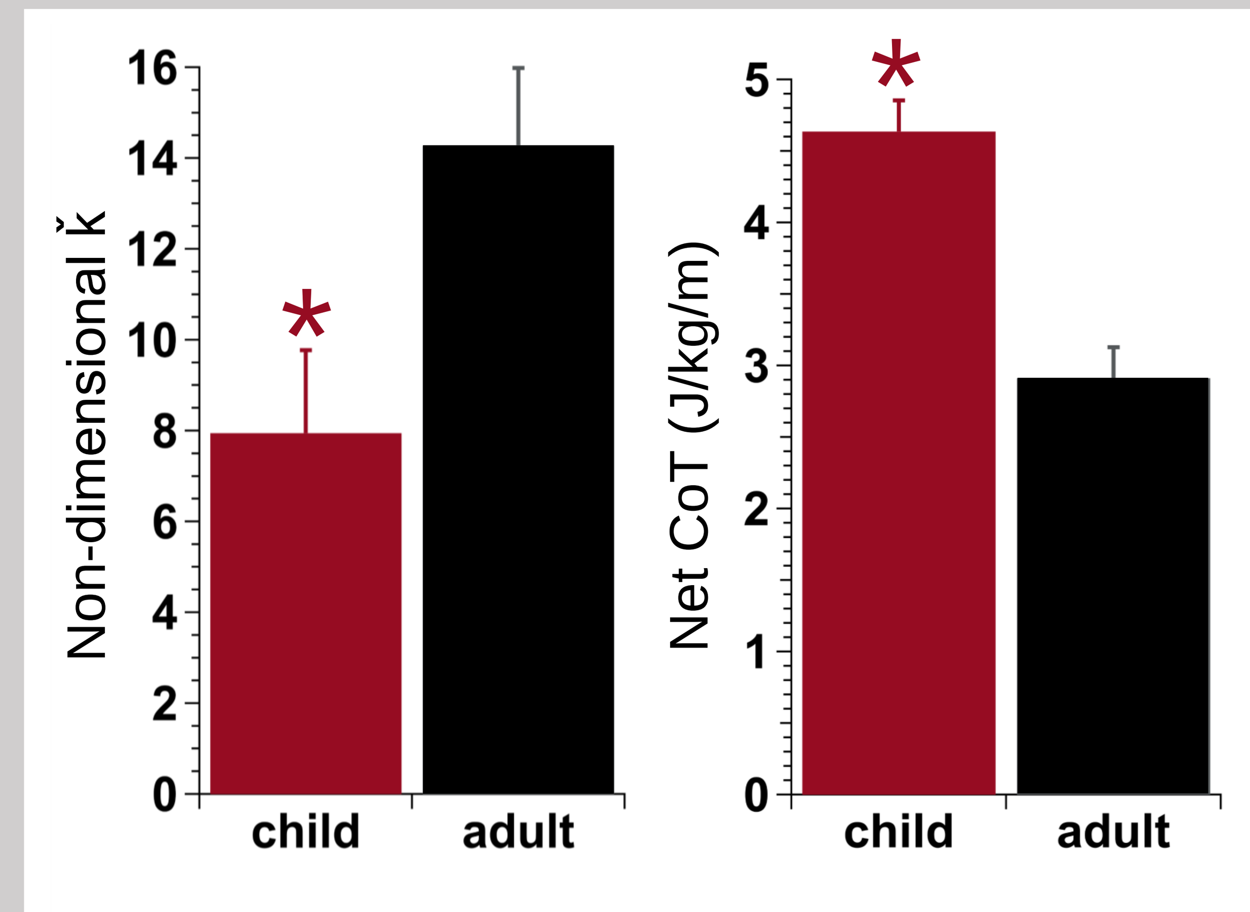


Figure 2. Across all frequency conditions, main effect for age group, **left** $\check{k}$ (p=0.025) & **right** net CoT (p<0.001)

RESULTS & CONCLUSIONS

1. $\check{k}$ is smaller in children (-6.334, F=79.28, p=.025)
2. $\check{k}$ is modulated similarly across step frequency
3. $\check{k}$ is a significant predictor of net CoT (Figure 3)

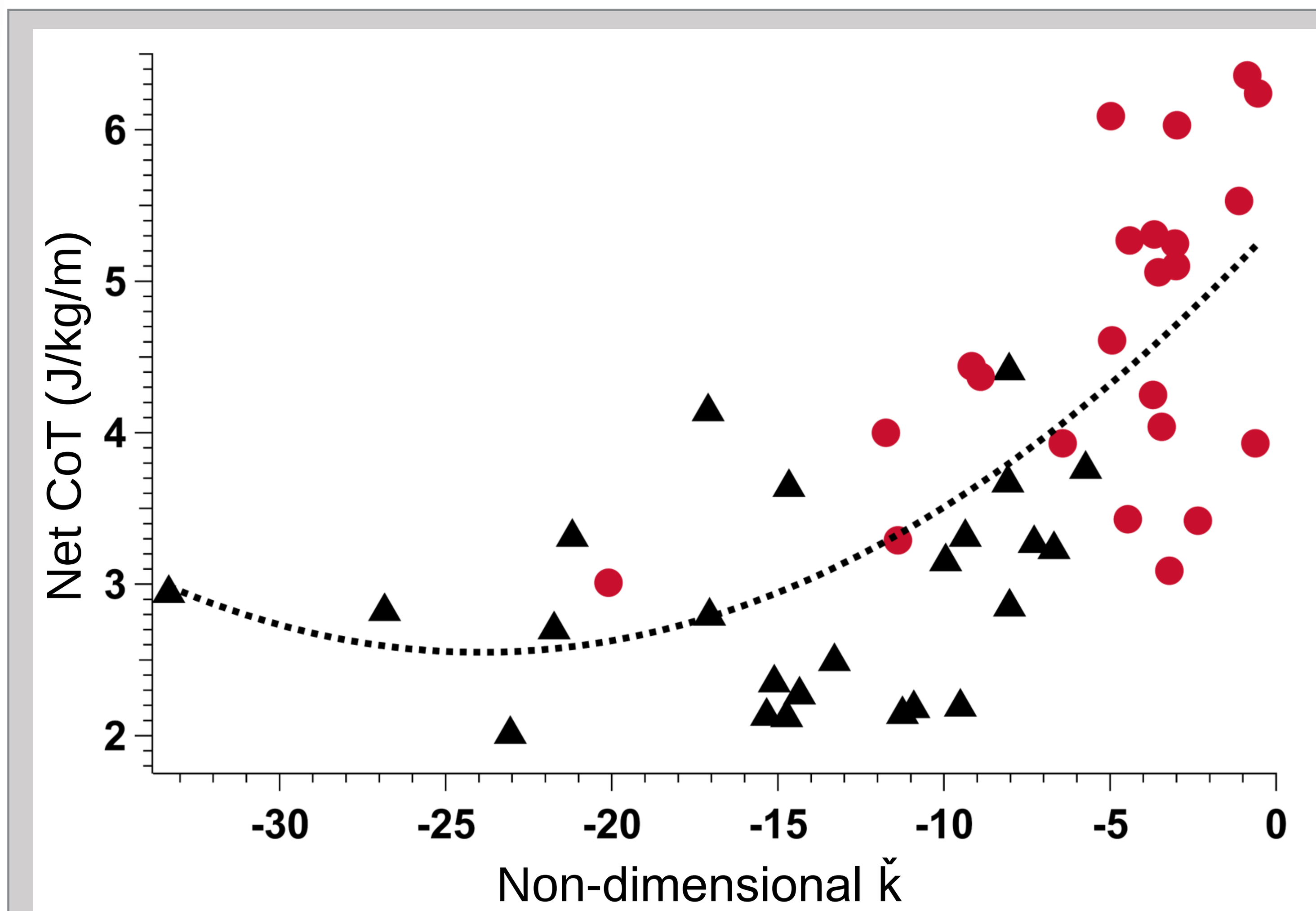


Figure 3. Regression model with quadratic fit R=.675, R^2=.431, F=18.44, p<.001, Red circles are children, Black triangles are adults

Incorporating a spring element into a simple walking model acknowledges the role of elastic mechanisms in storing and returning energy and supports a theoretical connection between the mechanics and the energetics of walking. Overall, children operate their springs in a similar manner, but at very different scaled $\check{k}$ and CoT values. It is possible that differences in child $\check{k}$ and net COT may be the result of physiological differences in leg muscles and tendons and their capability to operate as a spring.

References. 1. Fukunaka et al. *Proc R Soc B Biol Sci*. 2001, 2. Sawicki et al. *Exerc Sport Sci Rev.* 2009, 3. DeJaeger et al. *Pflugers Arch Eur J Phys* 2001, 4. Geyer et al. *Proc R Soc B Biol Sci.* 2006. We acknowledge Anna Larrson, Danny Guevara, and Daisey Vega for assistance with data collection. No conflicts of interest to disclose.