DYNAMIC GEAR RATIO IN CHILDREN AND ADULTS DURING WALKING AND IMPLICATIONS FOR MUSCLE MECHANICAL EFFICIENCY

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The aim of this study was to gain a better understanding of how skeletal geometry and muscle leverage determine muscle function and movement. Ten children (Age: 9.2±1.3 years, 1.36±0.04 m, 30.61±5.91 kg) and 12 adults (Age: 27.4±2.6 years, 1.75±0.10 m, 71.03±10.49 kg) walked unshod on an instrumented treadmill (Bertec, OH, USA) at 80% of their preferred over-ground walking speed (0.66±0.81 and 1.07±0.13 ms^{-1}, respectively) for a 10 min period. Reflective markers placed on the lower leg and foot provided lower body and Achilles tendon movement kinematics. Gait cycle events were determined from treadmill ground reaction force data and dependent variables were averaged over six consecutive walking steps for each participant. Average moment arm showed a slight decreasing trend over the stance phase in both groups. The average external moment arm was larger in adults but the gear ratio was similar.

KEYWORDS: gear ratio, muscle mechanics, growth, children.

INTRODUCTION: Movement defines human life in all its forms and even the simplest human movement depends on very complex interactions of several systems under the control and coordination of the central nervous system. In the human body, movement is the result of joint rotations in the musculoskeletal (MSK) system. Muscles provide the “engine” for movement acting with leverage or a moment arm around joints. The muscle moment, which generates joint rotation, is the product of muscle force and moment arm, so this leverage represents the mechanical advantage of the muscle. Muscle moment arms therefore play an important role within the context of muscle function.
Accurate knowledge of muscle-tendon moment arms is vital for accurately determining basic biomechanical and physiological parameters such as tendon loading, muscle force capacity or specific tension (muscle force per cross sectional area). In addition to being an important determinant of muscle moment and strength, the muscle-tendon moment arm has important functional implications within the context of more complex movement performance by dictating the extent of joint rotation and subsequently influencing the MSK system’s functional properties (Lee and Piazza, 2009; Nagano and Komura, 2003). The extent of muscle-tendon length change that occurs with joint rotation is strongly dependent on the muscle's moment arm and has implications for the stretch-shortening cycle, a series of movement patterns which are used to enhance the performance of locomotion, throwing, hitting and kicking activities by utilizing the elastic energy storage potential of the tendon. Skeletal gearing is a measure of the mechanical leverage provided by the lever arm ratio of an input (muscle) to output (point of application) force. The internal moment arm influences the musculoskeletal system’s functional properties by amplifying muscular forces and dictating the extent of joint rotation, but it is not known how this ratio changes dynamically during gait in children or adults.

METHODS: Participants were 10 children (Age: 9.2±1.3 years, 1.36±0.04 m, 30.61±5.91 kg) and 12 adults (Age: 27.4±2.6 years, 1.75±0.10 m, 71.03±10.49 kg) who walked on an instrumented dual belt treadmill (Bertec) at their preferred over-ground walking speed (0.66±0.81 and 1.07±0.13 ms^{-1}, respectively) for a 10 min period. Three-dimensional kinematic analysis using a Vicon system was combined with the ground reaction force (GRF) measurements from the two treadmill force plates. Nine markers were attached on anatomical landmarks in each leg for calculating segmental kinematics. Two markers were also positioned approximately 5 and 10 cm proximal to the calcaneus to represent the Achilles tendon (AT) line of action. Two ultrasound probes were fixed on the right calf one imaging the gastrocnemius medialis (GM) muscle belly and the second the GM myotendinous junction (MTJ) during the gait cycle. This protocol allowed the calculation of dynamic changes in the Achilles tendon (internal) and GRF (external) moment arms around the ankle joint during the stance phase of walking gait. The dynamic gear ratio during gait was then calculated as external/internal moment arm at each instant of the stance phase. Differences in gear ratio between adults and children throughout the stance phase were analysed using statistical parametric mapping.

RESULTS: The average AT moment arm ranged from 0.045 to 0.048m over the stance in adults and from 0.038 to 0.041m in children showing a slight decreasing trend over the stance phase in both groups (Figure 1).

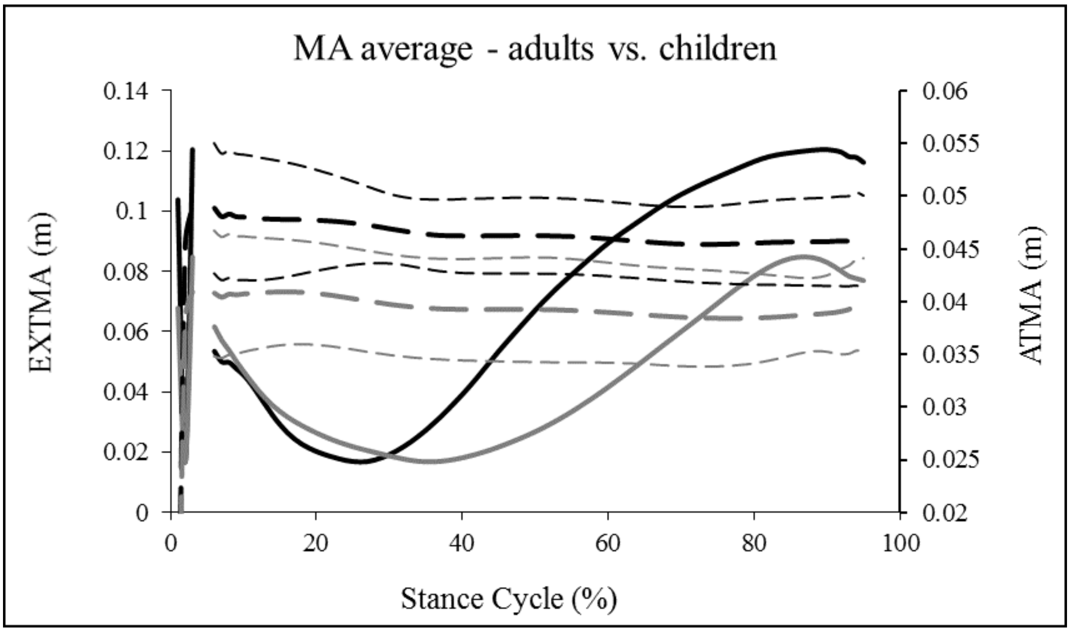

Figure 1: Achilles Tendon moment arm (dashed) variation during the stance phase and corresponding external (solid) moment arms (m) in adults (dark) and children (light).

The average external moment arm ranged from 0.016 to 0.120 m in adults and from 0.016 to 0.084 m in children. The gear ratio in adults ranged from 0.3 to 2.6 whereas in children the range was from 0.4 to 2.2 (Figure 2).

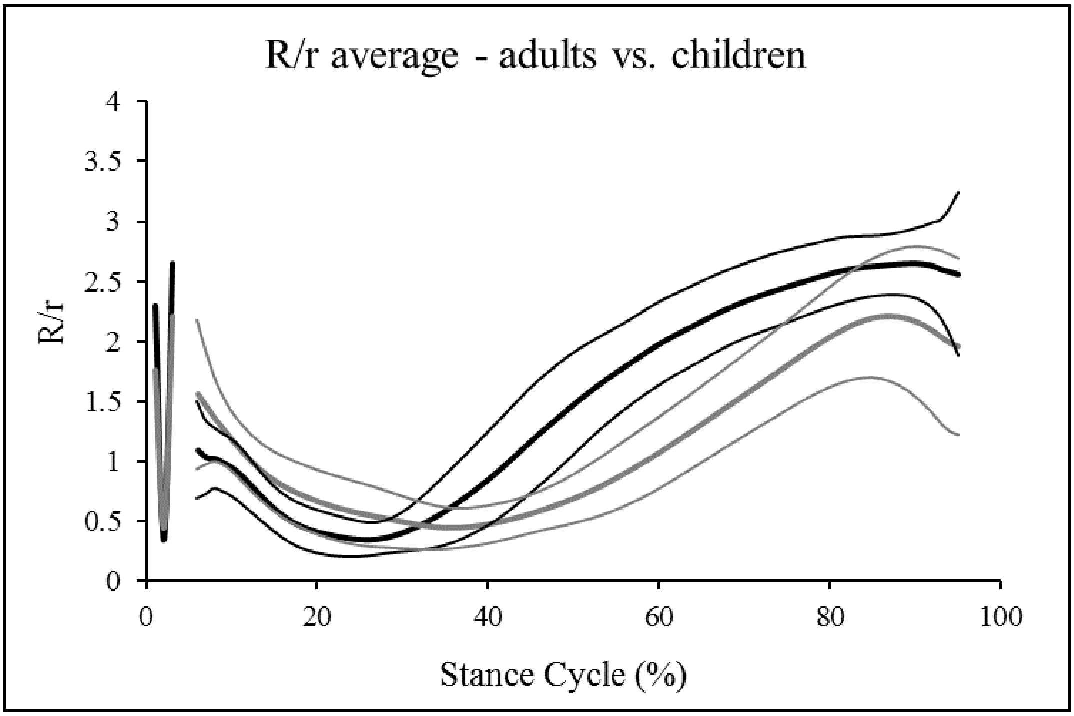

Figure 2: Gear Ratio variation during the stance phase in adults (dark) and children (light).

Statistical parametric mapping analysis (Figure 3) indicated that there was a significant difference in the gear ratios between adults and children only between the period 40-60%of the stance phase (see shaded area in bottom graph of Figure 3).

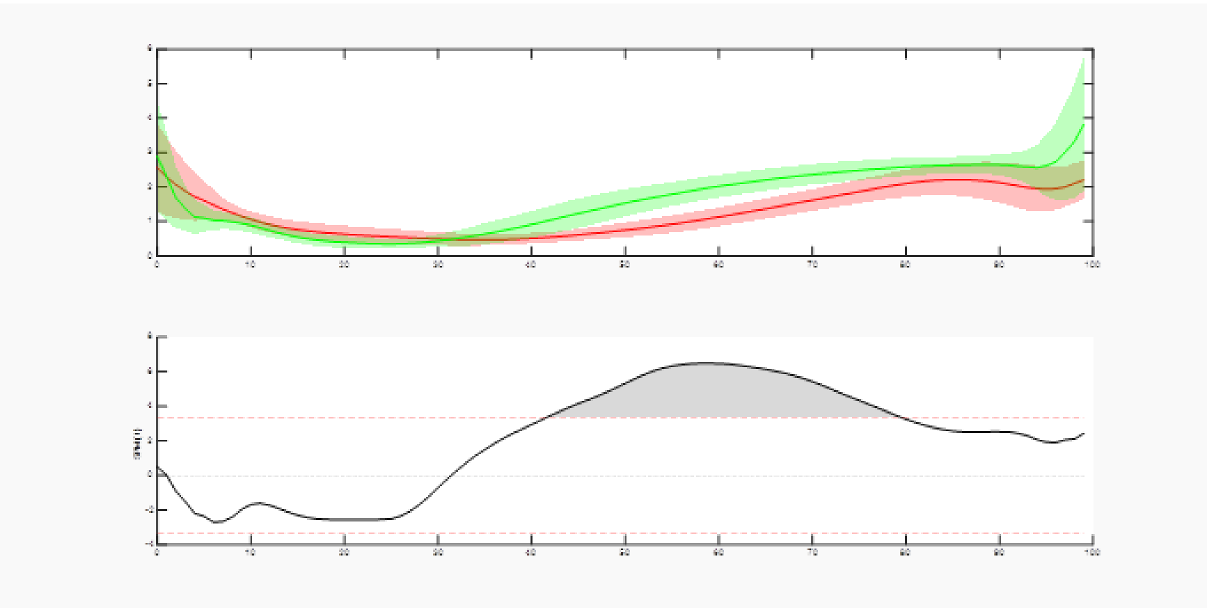

Figure 3: Statistical parametric mapping analysis of gear ratios between adults and children over the stance phase. Significant differences are indicated by the shaded area in bottom graph.

DISCUSSION: These findings suggest that the gear ratio is affected mainly by the change in external moment arm given its large variation and the relatively constant AT moment arm. The external moment arms and gear ratios were maximum near the end of the stance phase and minimum at ~25% stance phase in adults and ~35% in children. Since the muscle efficiency is optimised when the muscle is working close to isometric conditions without a great change in fascicle length and the gear ratio influences muscle-tendon and fascicle length changes, the differences in gear ratio between adults and children may affect fascicle length and velocity changes and hence muscle efficiency. Furthermore, since the main change in gear ratio was due to the external GRF vector moment arm, this might have implications for practice because a modification of running technique in children and the resulting changes in GRFs can influence gear ratios and potentially muscle efficiency when running.

CONCLUSION: Achilles Tendon moment arm was ~ 22% larger in adults. The gear ratio is affected mainly by the change in external moment arm given its large variation and the relatively constant AT moment arm. The external moment arms and gear ratios were maximum near the end of the stance phase and minimum at ~25% stance phase in adults and ~35% in children. Fascicle length and velocity loops during walking are currently being analysed to be linked to gear ratios and muscle efficiency.

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