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1 **Measuring the effective mechanical advantage of the plantarflexors during heel-toe walking and**
2 **voluntary toe-walking: A comparison of two methods**

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8

9 **Introduction**

10 The ratio between lever arms (LA) of the internal muscle-tendon force and external ground reaction
11 force (GRF), known as effective mechanical advantage (EMA), influences the required muscle force
12 and movement economy [1], both of which impair mobility of children with gait pathologies. EMA is
13 commonly altered by clinical interventions, yet rarely quantified. Current methods to quantify EMA of
14 the plantarflexors define the Achilles tendon (AT) as a straight line, however in plantarflexed positions
15 the AT becomes curved [2]. It is not known whether quantifying the internal LA and EMA of the
16 plantarflexors in this way is appropriate when studying the muscle mechanics that contribute to
17 habitual toe walking (TW).

18 **Research Question**

19 Does accounting for AT curvature affect comparisons of plantarflexor EMA between heel-toe walking
20 (HW) and voluntary TW?

21 **Methods**

22 Plantarflexor EMA of 11 typically developed young adults was calculated, while HW and voluntarily
23 TW on an instrumented treadmill. External LA was the shortest distance between the ankle axis of
24 rotation (between malleoli markers) and GRF vector. Internal LA was the shortest distance between
25 the ankle axis of rotation and AT line of action; defined between a corrected calcaneus marker and (1)
26 the myotendinous junction tracked with ultrasound, assuming a straight tendon, and (2) a corrected
27 marker positioned over the AT bend point, accounting for curvature. To assess the repeatability of
28 both methods, seven participants repeated the protocol. Statistical parametric mapping was used to
29 compare methods and repeatability sessions throughout stance, and to compare walking conditions
30 in the propulsive phase, when HW demonstrates a meaningful plantarflexion moment.

31 **Results**

32 When accounting for AT curvature, internal LA was constant throughout stance and did not
33 significantly differ between HW and TW (4.6 vs 4.7cm; Figure 1a). However, when assuming a straight
34 tendon, internal LA decreased throughout stance in HW, leading to a smaller internal LA than TW
35 during propulsion (4.5 vs 5.3 cm, $p < 0.01$; Figure 1a). Therefore, when assuming a straight tendon, EMA
36 during propulsion was greater in TW than HW (mean difference=0.2, $p = 0.007$; Figure 1c vs 1d), but
37 there were no differences in EMA when accounting for AT curvature ($p > 0.05$; Figure 1c vs 1d). Both
38 methods showed good repeatability (mean typical error of EMA=0.05; Figure 1c & 1d).

39

40 **Discussion**

41 When comparing HW to TW, it is necessary to account for AT curvature to avoid Type I error, as
 42 assuming a straight AT overestimated differences in EMA between walking conditions. Many clinical
 43 interventions for TW alter the plantarflexors' EMA, so the ability to measure EMA correctly may aid
 44 clinical decision-making in the future. The simplicity of the proposed method to account for AT
 45 curvature may also facilitate its routine use in gait laboratories. However, further work is required to
 46 investigate the applicability of this method in habitual TW.

47 **References**

- 48 [1] A.A. Biewener, et al., J Appl Physiol 97 (2004).
 49 [2] S.J. Obst, et al., Ultrasound Med Biol 40 (2014).

50

51 **Figure**

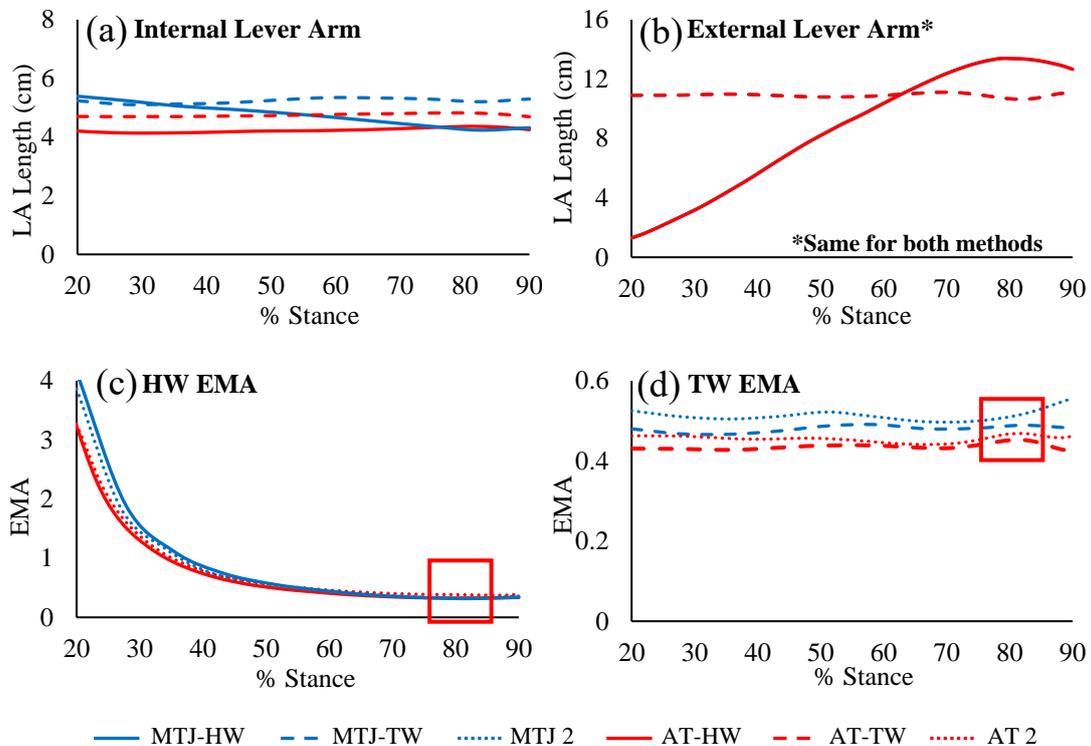


Figure 1. Group averages for (a) internal lever arm length, (b) external lever arm length, (c) heel-toe walking effective mechanical advantage, and (d) voluntary toe-walking mechanical advantage. Red squares highlight the significant differences in effective mechanical advantage between heel-toe walking and voluntary toe-walking (c vs d) in the propulsive phase, when assuming a straight tendon. MTJ 2 and AT 2 represent repeatability sessions in both walking conditions (c & d).

MTJ – myotendinous junction method (straight tendon); AT – Achilles tendon method (curved tendon); HW – heel-toe walking; TW – toe-walking; LA – lever arm; EMA – effective mechanical advantage.

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