Quantitative Assessment of Pediatric Joint Contributions to Foot Clearance and Dynamic Leg Length

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INTRODUCTION

It has been noted that tripping and falling are the greatest source of accidental injury in children with motor disabilities[1]. Tripping most commonly occurs due to a decrease in foot clearance or ineffective limb shortening during the swing phase of gait. Moosabhoy and Gard developed equations based on a planar model of the leg to look directly at joint contributions to foot clearance in the adult population (Fig. 1)[2]. We modified and applied the analytical techniques used by Moosabhoy and Gard to analyze a new population of patients.

OBJECTIVE

To determine the joint contributions to foot clearance and limb shortening in the pediatric population in order to compare to pediatric patients with gait pathology.

METHODS

Participants 5 boys and 7 girls aged 6-12 years old, including 10 typically developing and 2 with different gait pathologies. The controls were chosen based on their self-selected walking speed being within 10% of children with gait pathologies.

Data collection and processing Previously collected Visual 3D kinematic files were analyzed in Matlab to quantify the joint contribution to foot clearance and limb shortening. The joint contributions were calculated based on modified Matlab code developed by Little, McGuirk, and Patten[3].

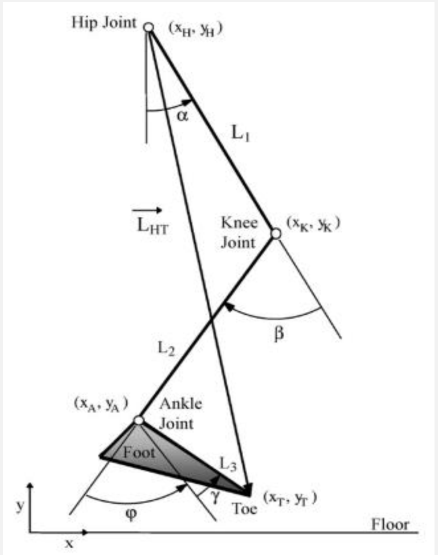

Fig 1: Planar model of the leg in the sagittal plane

Foot clearance (FC) is defined by the y coordinate of the foot marker. We used hip-toe distance as our proxy for limb shortening (ELL). This distance was normalized to the static, measured length of the limb.

Joint contribution was quantified by calculating joint sensitivity. Sensitivity is defined by how much a single degree change in angle (ie. hip flexion) changes the FC or ELL. For FC, positive sensitivity values indicate that the joint is helping clear the foot and for ELL, more negative values indicate that the joint is helping to shorten the leg.

RESULTS

Toe off (TO) of controls, occurred at 65% of the gait cycle, first dashed vertical line (Fig. 2 and 4). TO for the patients, indicated by the first solid vertical lines (64.7%, 57% and 60%, 67%) demonstrate earlier TO on the pathologic side (Fig. 2, 4). The second set of vertical dashed and solid lines denote the times of minimal ELL for the controls and the patients (Fig. 2 , 4).

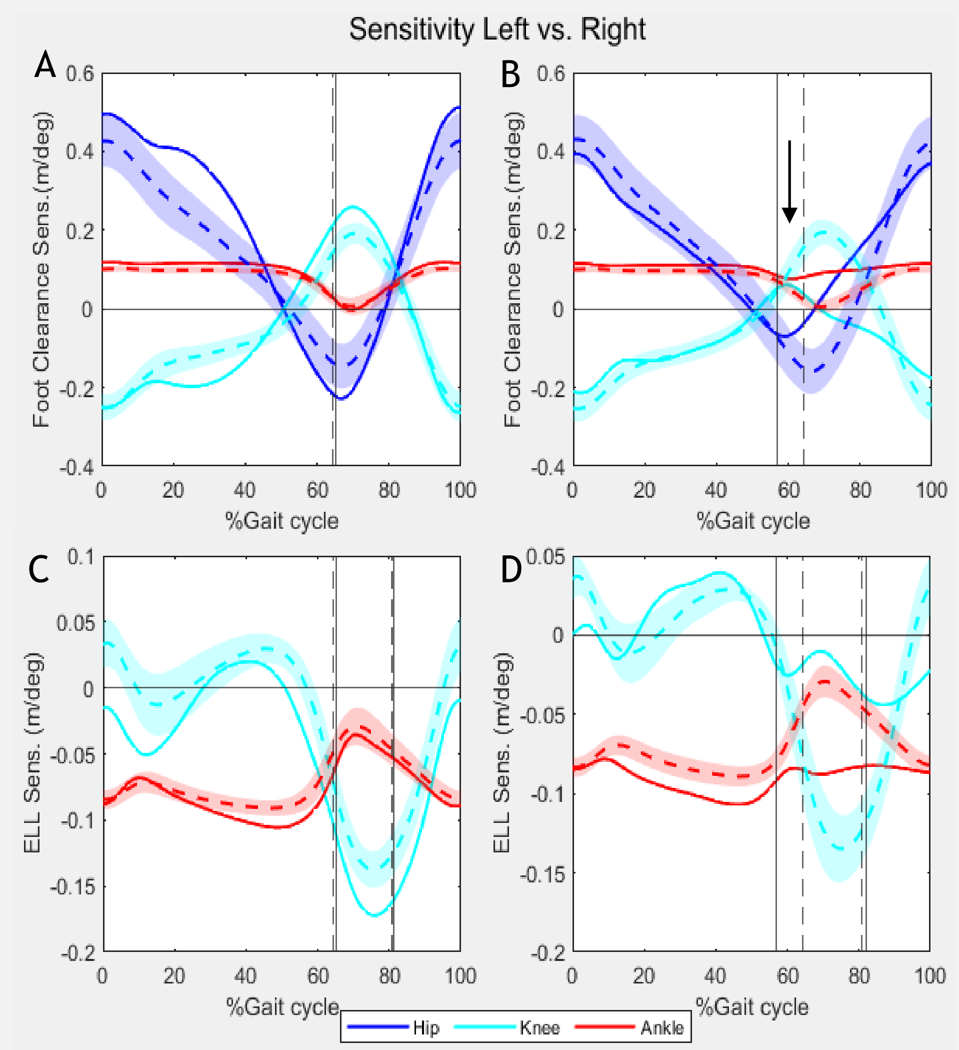

Fig 2: Sagittal plane joint contributions to FC (2a,2b) and ELL (2c, 2d) in a transverse myelitis patient.

Fig 3: Child with transverse myelitis. Severely decreased knee flexion on the right mid swing (a) compared to the left knee mid swing (b).

Minimal FC on the right (arrow), FC is most sensitive to rotational changes in the ankle (0.080m/deg), then hip (-0.061m/deg) then knee (0.060m/deg). Compared to the controls, the patient's knee sensitivity is severely reduced indicating that the knee is failing to clear the foot. The increased sensitivity magnitude of the hip and the ankle indicate increased hip flexion and increased ankle dorsiflexion to compensate for the decreased knee flexion.

Minimum ELL occurs at 81% through the gate cycle on the right (2nd solid line). The sensitivity for the ankle is -0.083m/deg. and for the knee is -0.037m/deg. The less negative value for knee sensitivity indicates that the knee is the greatest contributor to leg lengthening therefore impairing ELL. While, the ankle sensitivity is significantly more negative than the controls at this point indicating compensation.

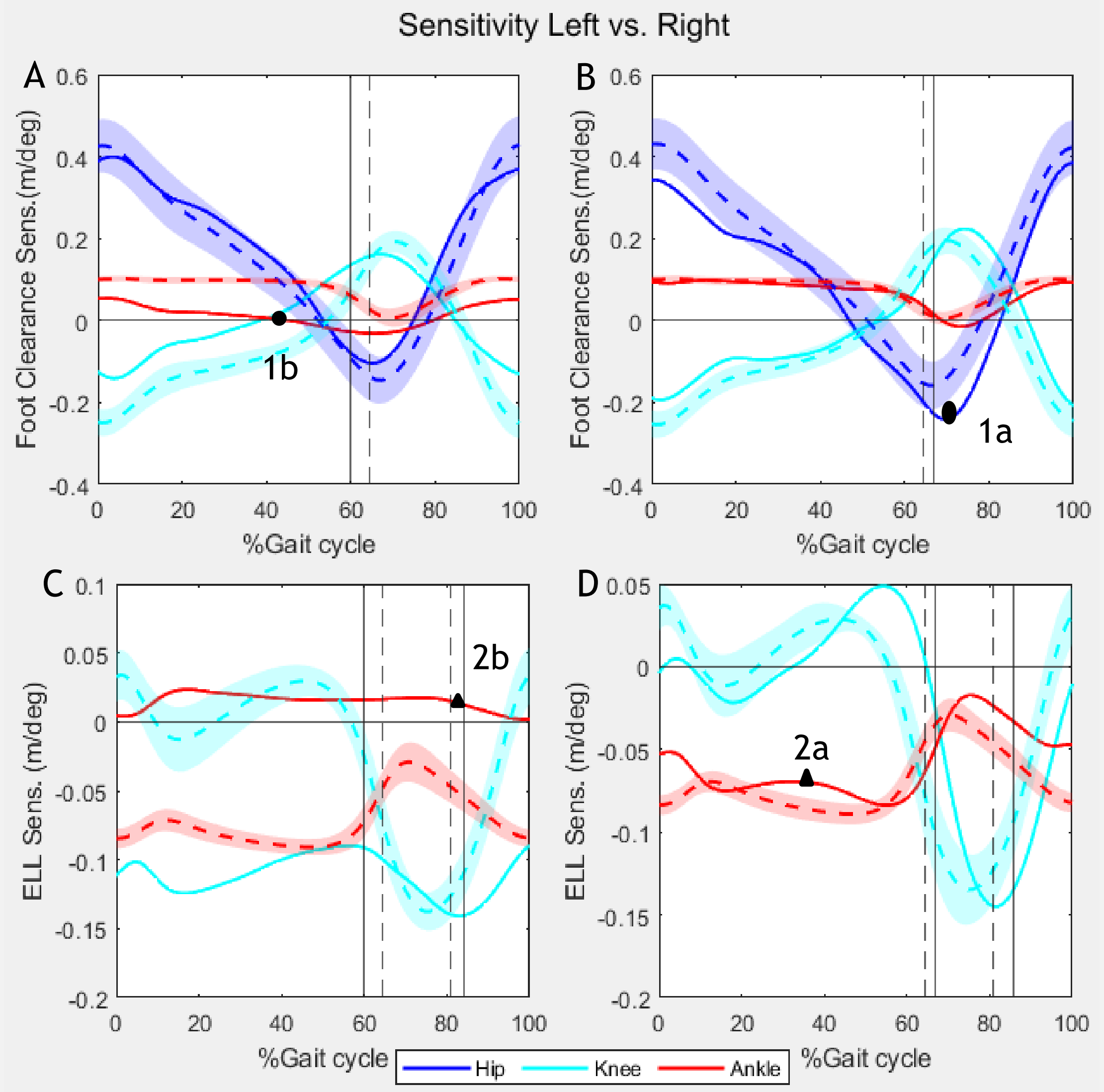

Fig 4: Sagittal plane joint contributions to FC (4a,4b) and ELL (4c, 4d) in a child with left hemiplegic cerebral palsy (CP).

Minimum FC on the right (1a), right hip sensitivity is -0.238m/deg, which equates to a long limb in swing. However, at the same time point on the contralateral leg (1b), ankle sensitivity is 0.007m/deg indicating that the ankle is lengthening the left leg during stance allowing the right leg to clear.

On the left mid swing (2b), the knee sensitivity is -0.139m/deg and the ankle sensitivity is 0.0157m/deg (Fig. 4c) The negative value for the knee indicates that knee flexion is helping shorten the limb and the positive value of sensitivity for the ankle is severely impairing limb shortening.

Fig 5: Child with left hemiplegic CP in mid swing on the right, with severe left ankle plantar flexion (a) and mid swing on the left with vaulting on the right (b).

CONCLUSIONS

- In typically developing pediatric patients, the point of minimal foot clearance was found to occur at 89% of the gait cycle on the left and the right. Through sensitivity analysis, the hip flexion has the largest contribution to foot clearance followed by the ankle dorsiflexion and knee flexion (Fig 2).
- For the transverse myelitis case, the quantitative analysis correctly identified the gait pathology (stiff right knee) and added additional information about compensation of the other joints (increased ipsilateral ankle dorsiflexion and increased hip flexion) (Fig. 2).
- For the CP patient, the quantitative analysis showed that significant left ankle plantarflexion allowed the right hip to overextend and not flex during swing on the right without tripping. The left ankle plantarflexion during swing impaired ELL the greatest (4c) and the right ankle compensated with vaulting during stance (4d)(Fig. 4).

Future work

- To better understand other compensatory mechanisms (ie. pelvic tilt or limb circumduction) for decreased FC and ineffective ELL the methodology could be expanded to the coronal and transverse planes.

REFERENCES

1. Gaebler-Spira, D., & Thornton, L. S. (2002). Injury prevention for children with disabilities. Physical Medicine and Rehabilitation Clinics of North America,13(4), 891-906. doi:10.1016/s1047-9651(02)00023-2
2. Moosabhoy, M. A., & Gard, S. A. (2006). Methodology for determining the sensitivity of swing leg toe clearance and leg length to swing leg joint angles during gait. Gait & Posture,24(4), 493-501. doi:10.1016/j.gaitpost.2005.12.004
3. Little, V. L., Mcguirk, T. E., & Patten, C. (2014). Impaired Limb Shortening following Stroke: What's in a Name? PLoS ONE,9(10). doi:10.1371/journal.pone.0110140

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