STEPPING ON AN OBSTACLE WITH THE MEDIAL FOREFOOT: USE OF A 3D DYNAMIC CONTROL MODEL TO SIMULATE AGE AND NEUROPATHY

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INTRODUCTION

Approximately 24% of falls in the elderly occur while walking on irregular surfaces [1]. Irregular surfaces are known to increase the step width variability in the elderly, particularly those with peripheral neuropathy [2]. Bilateral ankle braces generally decrease this variability [3].

A previous study in healthy young women showed that unexpectedly stepping on a 15 mm-high object with the medial forefoot shifts the center of pressure (COP) medially, thereby decreasing the ankle eversion moment and increasing inversional stance foot acceleration [4]. Increased inversional foot acceleration has been associated with a narrowed recovery step, and sometimes even a crossover step [4].

Our goal was to develop a model to 1) simulate stance leg single support phase dynamics during a sudden medial shift in COP progression during gait, and 2) provide insights in how age, neuropathy, and attachment of an ankle brace might affect maximum inversional stance foot acceleration.

METHODS

A 3D dynamic control model of the stance leg was developed to simulate an unexpected sudden medial shift in COP during the stance phase and to correctly reproduce angular dynamics comparable to those obtained from experimental studies (Figure 1). The equations of motion were implemented in a Matlab Simulink control model with anatomic joint torques under feedback control. The model was then ‘aged’ through a) reduction of the maximum torque inputs [5], b) adjustment of joint stiffness [6], and c) increased feedback delays [7]. Furthermore, the effect of neuropathic nerve conduction delays on inversional foot acceleration was investigated. Finally, attachment of an ankle brace was simulated by increasing the model’s ankle stiffness [8].

RESULTS AND DISCUSSION

Aging the model resulted in increased maximum inversional foot acceleration in presence of a medial shift of the COP (Figure 2). Adjusting feedback delays to those of a neuropathic patient further increased inversional foot acceleration (Figure 2). However, simulating attachment of an ankle brace by increasing ankle stiffness resulted in decreased inversional foot acceleration (Figure 2).

CONCLUSIONS

We conclude that the increased neural latencies and decreased muscle strength associated with old age and neuropathy act to increase maximum inversional stance foot acceleration following an unexpected medial COP shift. Bilateral use of ankle braces help reduce this effect.

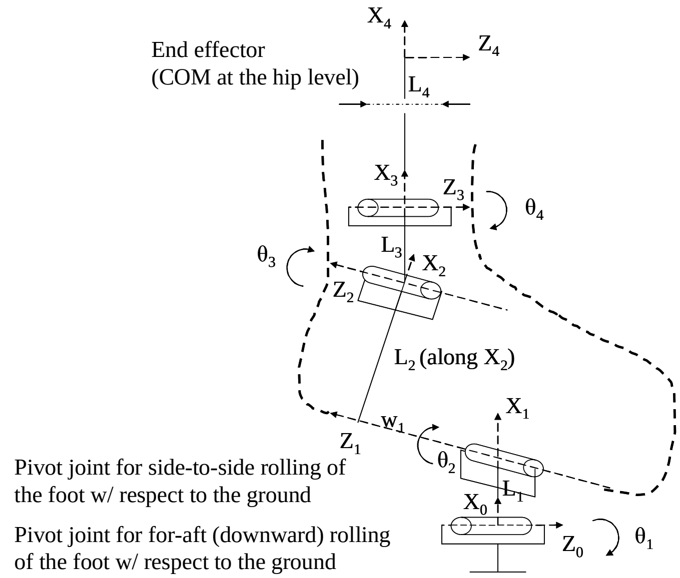

Figure 1: *Model schematic according to Denavit-Hartenberg convention: 2 segments (foot & leg) and 4 rotational joints. The COP (operating point, L1=0) is represented by the 2 lower joints at a given time instant. The two upper (anatomic) joints represent inversion/eversion and plantar/dorsi flexion. Changes in w1 correspond to COP forward progression, while changes in L2 correspond to a medial shift of the COP.*

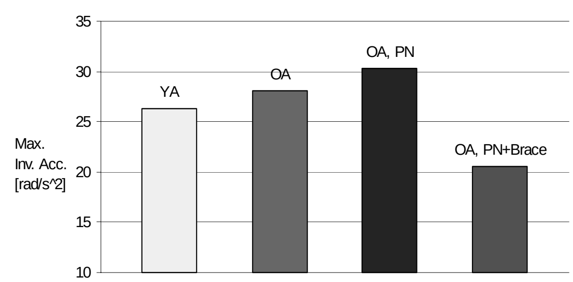

Figure 2: *Effect of age, neuropathy, and ankle brace on maximum inversional foot acceleration (YA: young adult, OA: old adult, PN: peripheral neuropathy).*

REFERENCES

1. Berg WP, et al. *Age Ageing* **26**, 261-8, 1997.
2. Thies SB, et al. *Gait Posture*, in press.
3. Richardson JK, et al. *J Am Geriatr Soc* **52**, 510-5, 2004.
4. Thies SB, et al. *ASB XXVIII*, Portland, Oregon, 2004.
5. Thelen et al. *J Gerontol* **51A**, M226-32, 1996.
6. Lark et al. *Clin Biomech* **18**, 848-55, 2003.
7. Lin et al. *J Mot Behav* **34**, 37-44, 2002.
8. Siegler et al. *JOSPT* **26**, 299-309, 1997.