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DETECTION OF IMPAIRED STABILITY OF WALKING BY SIMULATED RESPONSE TO TRIPPING PERTURBATION

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INTRODUCTION

The purpose of this study was to introduce a simulation-based method for detection of impaired walking stability as it relates to fall risk. Falls result commonly from tripping while walking [1]. An ability to limit torso motion after a trip has previously been shown to separate fallers from non-fallers [2]. Here, the immediate passive response of torso to tripping perturbation in a simulation was analyzed during walking so as to test subjectsô stability. The studied subjects were children with and without spastic diplegic cerebral palsy (CP). It was hypothesized that, due to impaired walking stability, perturbation induces greater kinematic changes in the subjects with CP than in the unimpaired subjects.

METHODS

The basis of the present study is in the previously created muscle-driven simulations of two steps of two unimpaired children [3] and nine children with CP [4], which were created by combining a generic musculoskeletal model and experimental gait data. In the present study, these simulations were analyzed further through a forward dynamics analysis employing the OpenSim software [5]: The model was perturbed by applying a backward force with a magnitude of 10 % of the subjectôs body weight to the swing-foot of the model. This force is similar, but was not meant to be identical, to forces observed in an actual tripping of humans [6]. Such perturbation was performed for a period of 20 ms, and was repeated at 1 ms intervals throughout the swing-phase. Changes in the torso angular velocity, $\Delta\omega$, in the sagital plane were computed. $\Delta\omega$ was plotted versus percentage of the swing-phase, so that each plotted data point represented a result of a single perturbation, and the entire curve the results of such perturbations for varying the time of perturbation during the swing-phase.

RESULTS AND DISCUSSION

Figure 1. depicts $\Delta\omega$ for one unimpaired subject and for one CP subject. The unimpaired subjects exhibited both positive and negative values of $\Delta\omega$ during each step, whereas the CP subjects exhibited only positive ones, with one exception; one CP subject exhibited positive values during one step and both positive and negative values during the other step. If $\Delta\omega$ displayed both positive and negative values, then there was a time during the swing-phase such that, if perturbation was performed then, there was only a negligible $\Delta\omega$. This negligible $\Delta\omega$ indicates existence of a dynamic equilibrium at that instant of time since perturbation did not cause a clear motion. The CP subjects were concluded to have impaired stability as they had difficulties in reaching a dynamic equilibrium. That is, they were more sensitive to tripping perturbation and, consequently, likely to be more susceptible to falling than the unimpaired subjects.

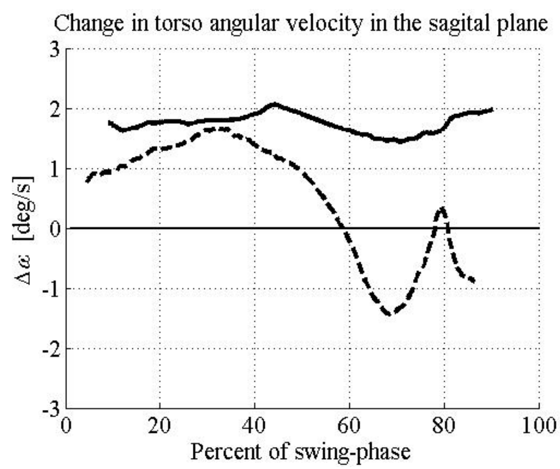

Figure 1: Changes in the torso angular velocity in the sagital plane for one CP subject (solid line) and for one unimpaired subject (dashed line) when varying the time of perturbation during the swing-phase.

One of the challenges in creating subject-specific simulations is to validate simulated muscle forces since multiple sets of muscle forces produce a desired motion, and a subject's actual muscle forces cannot usually be measured. The present EMG data have shown some disagreement with the simulated muscle activations. Such disagreement may be in part due to experimental errors in the gait data, and the generic model that does not account for subject-specific muscle-tendon properties. However, the main cause for the differences between the subject groups was their different gait kinematics and kinetics, so the errors in muscle activations and forces were not dominant in the present study.

CONCLUSIONS

A novel method for detecting impaired stability was introduced in this study. The findings revealed that during the swing-phase the CP subjects had difficulties in reaching a dynamic equilibrium, a state where the torso is stable with respect to a tripping perturbation. In light of this, the method was demonstrated to indicate that children with spastic diplegic cerebral palsy have balance problems when subjected to a generic tripping perturbation. Nevertheless, more research, involving other patient groups, is needed to see if these results can be generalized. The method can be utilized when searching individuals with high fall risk, and when monitoring and evaluating outcomes of therapy or surgery in rehabilitation.

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REFERENCES

1. Bentley, T.A. et al., Ergonomics 41: 1859-1872, 1998.
2. Pavol, M.J. et al., Journal of Gerontology A: Biological Sciences and Medical Sciences 56: M428-M437, 2001.
3. Liu, M.Q. et al., Journal of Biomechanics 41: 3243-3252, 2008.
4. Steele, K.M. et al., Journal of Biomechanics 43: 2099-2105, 2010.
5. Delp, S.L. et al., IEEE Transactions on Biomedical Engineering 54: 1940-1950, 2007.
6. Pijnappels, M. et al., Journal of Biomechanics 37: 1811-1818, 2004.