PERFORMANCE OF A SIMULATED INVERTED PENDULUM APPLIED TO HEMIPLEGIC CEREBRAL PALSY GAIT

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INTRODUCTION

Children with hemiplegic cerebral palsy exhibit diminished motor control, range-of-motion, and strength, not only of the affected lower extremity (Winters Type I, II, III), but also of the ipsilateral upper body (Type IV) [1]. Involvement may be slight (foot drop in swing), moderate (equinus throughout the gait cycle affecting the knee and hip), and severe (additional coronal and transverse plane anomalies). An inverted pendulum (IP) model of gait can be used to understand the role of gravity in propulsion [2], within a framework of biomechanical studies of human movement, particularly, joint power patterns [3]. Forward dynamic simulations of an IP [4], applied to normal gait during single support, demonstrated predictive value for gait velocities and horizontal ground reaction forces (GRF), but not for vertical GRF. We hypothesized that these findings would extend to patients with hemiplegic cerebral palsy, despite a range of mobility disabilities and prior treatment.

CLINICAL SIGNIFICANCE

A rigid IP model reveals the role of gravitational acceleration in human gait, while excluding contributions from joint powers [4]. If the rigid IP model proves adequate to predict GRF in these patients, it would suggest they rely, at least in part, on gravity for forward propulsion.

METHODS

After informed consent approved by the local human subjects committee, seven pediatric patients (mean age, height, mass: 11.6 yr, 1.4 m, 36.1 kg), diagnosed with hemiplegic cerebral palsy, were enrolled in the study. They presented as Winters Type I, II, and IV (n = 3, 1, 3, respectively). Five patients had prior heelcord lengthenings, one had concurrent hip adductor and iliopsoas lengthenings, one had gastrocnemius BOTOX injections, one had no prior treatment. Kinematic data were collected at 120 Hz using a ten camera Vicon 612 system. A thirteen-segment, full-body model was implemented in Visual3D (C-Motion Inc.), and the instantaneous center-of-mass (COM) was calculated. Horizontal and vertical GRF (*Fh*, *Fv*) were collected at 1560 Hz using three AMTI force plates. Subtracting average center-of-pressure (COP) coordinates from those of the instantaneous COM at mid-stance provided the length of a rigid IP for the affected side, used in forward dynamic simulations [4]. Bonferroni-adjusted dependent t-tests assessed differences across key points in forward velocity (*V*), timing (*t*), *Fh*, and *Fv* profiles [4]. Root mean square (RMS) errors quantified differences between actual and predicted *Fh* and *Fv*.

RESULTS

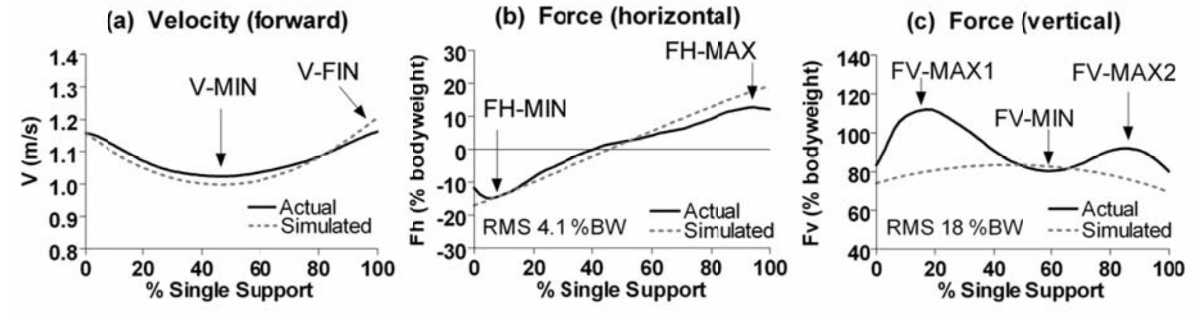

Figure. Forward velocity and ground reaction forces. For all panels, one walking trial for each of seven hemiplegic cerebral palsy patients were averaged across single support. Panels include actual (solid) and simulated (dashed) data for *V* (a), *Fh* (b) and *Fv* (c). RMS errors are % bodyweight (% BW).

Table. Results of Dependent T-Tests

	Variable	**Actual**		**Simulated**		***P* values**
Statistical results, means and (standard deviations), for actual data and forward dynamic simulations (n=7). Significant differences for dependent t-tests (*) are noted at a Bonferroni adjusted alpha of $P \leq 0.0056$ (0.05/9).	*V min*	1.013	(0.2243)	0.9950	(0.2127)	0.414620
	t Vmin	0.1833	(0.0646)	0.1789	(0.0436)	0.662920
	V final	1.162	(0.2447)	1.207	(0.2357)	0.007246
	t Vfinal	0.3917	(0.0394)	0.3834	(0.0401)	0.162693
	Fh min	-16.10	(6.057)	-16.21	(2.263)	0.959342
Notes	*Fh max*	14.07	(3.778)	18.06	(1.145)	0.038287
Velocities *V* (m/s)	*Fv max1*	114.5	(16.35)	80.61	(5.770)	**0.002476 ***
Time *t* (s)	*Fv min*	65.62	(17.75)	74.23	(11.76)	0.067971
Force *Fh Fv* (% bodyweight)	*Fv max2*	97.23	(10.42)	80.59	(4.593)	0.011245

DISCUSSION

Despite differences in Winters Type and prior treatments, the rigid IP reasonably simulated all but one variable of interest, *Fv-max1*, which coincided with a mean sagittal hip power burst (not shown). While this suggests these patients relied more on gravity for propulsion during single support, a telescoping IP may reveal the use of joint powers as well [4,5].

REFERENCES

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DISCLOSURE STATEMENT

NIOSH currently supports a simplified acquisition contract to C-Motion. The opinions expressed in this abstract are those of the authors and may not reflect the views of NIOSH.

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