BIOMECHANICAL ANALYSIS OF A WHEELCHAIR WHEELIE IN PERSONS WITH SCI

Nethravathi Tharakeshwarappa[1,2], Alicia Koontz[1,2], Rory Cooper[1,2], and Michael Boninger[1,2]
[1]Dept. of Rehab. Science and Technology, University of Pittsburgh, Pittsburgh, PA 15261
[2]Human Engineering Research Laboratories, Highland Drive VA Medical Center, Pittsburgh, PA
net5@pitt.edu web:www.herlpitt.org

INTRODUCTION

A wheelie is an acquired skill that involves elevating the front castors and balancing on the rear wheels. A wheelie makes it easier to overcome daily life physical barriers, such as rough surfaces, curbs, bumps and door thresholds. Bonaparte et al. (2001) studied wheelie proactive/reactive strategies and Lin et al. (2002) studied the relationship between wheelchair pitch angle and pushrim force. Both studies were conducted with unimpaired individuals as the test subjects. The purpose of this study was to investigate trunk motion, applied pushrim forces, and pitch angles during the initiation and balance phases of a wheelie to better understand the strategies used by wheelchair users with spinal cord injuries.

METHODS

Four men and one woman (mean age 37.6 ± 6 years, height 1.8 ± 0.1meters and weight 65.4 ± 11 kg) with a spinal cord injury ranging from T4 to C7 provided informed consent to participate in the study. Subjects had to be able to perform a wheelie and balance on the rear wheels for one minute to be included in the study. An OPTOTRAK (Northern Digital, Inc.) motion analysis system was used to record motion of the body and the wheelchair at a sampling rate of 60Hz. A SMART^{Wheel} (Three Rivers Holdings, Mesa, AZ) was used to record the 3D dynamic forces and moments imparted to the pushrim at a rate of 240 Hz, and two AMTI force plates were used to record ground reaction force data at 360Hz. SMART^{Wheels} were installed on the subject's own wheelchair and infrared markers were placed on thirteen salient points on the right upper extremity and trunk as well as the wheelchair frame. The subject started with the wheelchair centered on the force plates. Marker coordinates, force plate, and pushrim forces and moments, were recorded for 10 seconds during which time the subject popped a wheelie and maintained the wheelie position until given a verbal cue after 9 seconds to land the front casters. The pitch angle was defined as the angle between the line connecting two markers on the wheelchair frame with respect to their locations at the beginning of the trial when all four wheels were on the ground (Figure1). Trunk angle was defined as angle between the thigh and trunk.

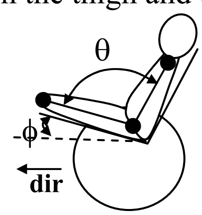

Figure 1. Pitch (ϕ) and trunk (θ) angle

Pushrim resultant force magnitude and direction with respect to the wheelchair, instantaneous direction (**dir**) was calculated as given in Equations 2 and 3. Unlike the previously mentioned studies, wheelchair motion was not assumed to be along a Cartesian axis.

$$\mathbf{dir} = \frac{(\mathbf{H}-\mathbf{L})\times(\mathbf{R}-\mathbf{L})}{\|(\mathbf{H}-\mathbf{L})\times(\mathbf{R}-\mathbf{L})\|} \ (1); \quad F_{mag} = \|\mathbf{F}\| \ (2); \quad F_{dir} = \mathbf{F} \bullet \mathbf{dir} \ (3)$$

The **dir** is a unit vector along the wheelchair's instantaneous forward direction and is calculated using Equation 1 where **H** is the 3D coordinates of the marker on the hub, and **L** and **R**, are the left and right contact points on the force plate respectively. F_{dir} in Equation 3 indicates the component of the resultant push rim force

(**F**) along the instantaneous direction (**dir**). If F_{dir} is positive, it implies that **F** acts along **dir,** and if F_{dir} is negative, it implies that **F** acts opposite to **dir**.

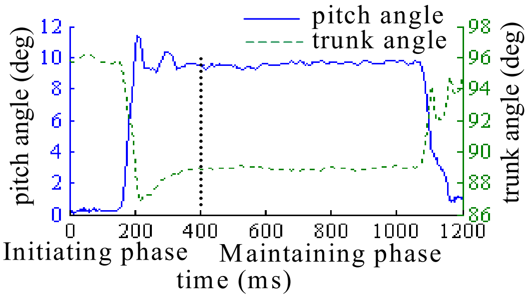

Figure2: Pitch and trunk angle (ensemble average of all five subjects)

The plot of pitch and trunk angle was visually inspected to discern the initial lift off of the casters and wheelie balance. (Figure 2). Maximum pitch angle, minimum trunk angle, trunk range of motion (ROM), and Maximum force (normalized to body weight), were determined for the initiation phase. Pitch angle, trunk angle, and normalized force were averaged over the middle five seconds of the maintaining phase.

RESULTS AND DISCUSSION

In all the subjects, the pitch angle was higher in the initiation phase than in the maintaining phase indicating that they tended to overshoot their balance point upon initial elevation of the castors. Conversely, the trunk angle is higher in maintaining phase than in initiating phase indicating that subjects used greater trunk flexion to elevate the castors than to balance in the wheelie. In the initiation phase, the maximum pitch angle occurred at the point when the trunk was maximally flexed (Figure 2). A forward flexed trunk causes the body's center of mass to move forward and thus the wheelchair must then be tipped further backward to keep the combined body/wheelchair center of mass over the rear wheels. The two subjects with cervical level injuries were noted to have the smallest trunk ranges of motion during the initiation phase and one of them applied forces almost 30% his body weight to lift the castors off the ground. As expected, subjects needed to exert more force to initiate the wheelie versus maintaining the wheelie.

SUMMARY

This study provides insight into the relationships between pitch angle, trunk angle, and pushrim force for a wheelie maneuver. The body's center of mass with respect to the rear axles also influences wheelie performance. Future studies that involve a larger sample of wheelchair users and an investigation of axle position location on wheelie performance are warranted.

REFERENCES

Bonaparte JP et al. (2001). *Arch Phys Med Rehabil*, **82**, 475-9.

Lin PC et al. (2002*). Proceedings of American Society of Biomechanics*

ACKNOWLEDGEMENTS

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Table 1. Kinetic and kinematic data in wheelie initiating and maintaining phases

Subjects	Initiating phase				Maintaining phase (5 sec)		
	Max. pitch angle (deg)	Min. trunk angle (deg)	Max. pushrim force / body weight(%)	Trunk ROM (deg)	Mean Pitch angle (deg)	Mean Trunk angle (deg)	Pushrim force / body weight(%)
1(C7)	9.3	82.8	5.05	11.7	6.1	87.4	1.57
2(C7/C8)	12.3	88.8	29.34	9.7	11.0	90.0	2.55
3(T7/8)	12.3	78.6	6.57	28.1	10.7	90.4	0.95
4(T12-L1)	16.8	86.7	6.65	15.8	11.6	89.4	2.12
5(T4)	12.1	75.6	18.87	22.1	8.0	84.4	7.25
Mean(SD)	12.6(2.7)	82.5(5.4)	13.3(10.55)	17.5(7.6)	9.5 (2.3)	88.3 (2.5)	2.9(2.5)