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Evaluation of methods for determining rearward static stability of manual wheelchairs

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Abstract—Wheelchair standards have been under development for several years. A set of tests has been approved by the American National Standards Institute (ANSI) and by the International Standards Organization (ISO) but continue to be refined. Static stability is one of the indicators used to evaluate manual wheelchairs and is measured by placing a loaded wheelchair on a platform that is tilted until the wheelchair's front wheels lift off of the platform. Currently, if the wheelchair parking brakes slip, a block is placed behind the rear wheels and the tip angle is measured. The results for eight different wheelchairs with three load cases showed that the rearward tip angle for the block is significantly different ($p<0.05$) from that with the brakes alone.

Key words: *static stability, testing, tilt angle, wheelchair standards.*

INTRODUCTION

There are numerous persons in the United States who rely on wheelchairs for their mobility and for their well-being. Wheelchairs are required for their recreation, vocation, and nearly every other regular activity. Close to 1.2 million Americans use wheelchairs as their primary source of mobility (1). This translates into a substantial number of people dependant on research in wheeled mobility for their quality of life.

The American National Standards Institute (ANSI) and RESNA have approved a comprehensive set of wheelchair standards, whereas the International Standards Organization (ISO) has only approved a partial set and continues to develop a complete set of standards. Standards are required to establish minimum performance and durability criteria for wheelchairs (2). Standards benefit consumers, manufacturers, and third-party providers. The ANSI Technical Advisory Group (TAG), organized by RESNA, is made up of representatives from many different disciplines (2) to help ensure that engineering, ergonomic, aesthetic, and performance needs are considered. Standards help manufacturers when comparing their products on a quantitative basis with other manufacturers' products and establishing minimum design criteria. Consumers benefit by being able to evaluate wheelchairs before making a purchase. Purchasing agencies are assisted in establishing reasonable acceptance criteria. The ANSI/RESNA TAG group developed the ANSI/RESNA Wheelchair Standards.

Standards consist of two primary components: 1) tests, and 2) normative values. Although tests have been developed, some refinement will be needed to develop the normative values which can only be identified by applying the tests. The development of normative values is most likely to show

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several needs, not the least of which are: (*a*) modification of some of the standards; (*b*) independent evaluation; and, (*c*) disclosure. Presently, this process is under way.

This study focused on some improvements in the determination of rearward static stability (3,4) which was determined by placing a loaded wheelchair on a platform which was then tilted. The angle at which the up-slope wheels lifted off of the platform was measured and recorded. When a wheelchair is facing up slope, the wheelchair may slide before the front wheels lift off. Currently, if the wheelchair slides, a block is placed against the downhill wheels (the rear wheels for the purpose of this note) to prevent sliding, and the platform is tilted until the front wheels lift off. However, because the two test situations—with the brakes alone (when no sliding occurs) and with the block—may yield different results, a new method was proposed (5). That method required that the rear wheels be restrained by a flexible membrane (belt) attached to the upper edge of the platform and, at the other end, attached to the back of the wheelchair backrest, as shown in **Figure 1** (4,5). The belt method and the block method are intended to prevent the wheelchair from sliding on the test surface, (i.e., the tilt table). It was hypothesized that the belt and brake alone without sliding would yield similar results; whereas, the block would yield significantly different results.

METHODS

The rearward static tip angle for each of eight manual wheelchairs **(Table 1)** using three load cases (55-kg person with paraplegia, 100-kg ambulatory person, and a 100-kg ISO test dummy) was measured (6). Measurements were made with three different restraints: 1) the wheelchair brakes (or wheel locks); 2) a flexible belt fixed to the rising edge of the platform, the other end of which, after being wrapped around the rear wheels, was attached to the backrest of the wheelchair; and, 3) a block behind the rear wheels **(Figure 1)**. In all cases, the brakes were activated. The brakes were adjusted or the braking force was supplemented to prevent wheel rotation (3). Only backward tip angle was measured, and with the axle in the farthest rearward position in all cases, the static tip angle was measured, using a machinist protractor and level, when a standard piece of paper could pass under the front wheels without turning them.

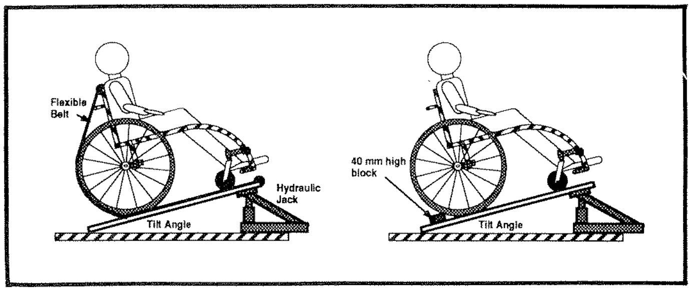

Figure 1.
Experimental configuration with belt around rear wheels and with 40-mm block behind rear wheels.

Table 1.
Wheelchairs tested.

Active	**Depot**
Quickie 2 w/swing away footrests	Quickie Breezy
Quickie 1 w/swing away footrests	Hoyer H 1000
Quickie GP	E & J Hollywood
Kuschall 2000	Turbollino
N = 8	

All of the wheelchairs used in this study had seat widths in excess of 42 cm, hence use of a 100-kg dummy was appropriate. During the tests, each test load (e.g., test dummy, ambulatory person, and person with paraplegia) was positioned as far as possible to the back of the seat, equidistant from either side. The legs of each test load were positioned to touch the rear edges of the footrests. The dummy was secured to prevent movement from the above-described position during the test (3).

The order of the test loads and the tests were randomly selected. The test loads were not removed from the wheelchair between trials, that is, all tests were performed for the selected test load on a specific wheelchair before continuing testing.

A three-factor analysis of variance (ANOVA) was performed on the data (load device, chair type, and test condition). Scheffe *post-hoc* tests were performed to determine factors related to significant results. A significance level of $p<0.05$ was set, *a priori*.

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RESULTS

The means and standard deviations for rearward tip angle based upon load type and test condition, are presented in **Table 2**. There were no significant differences ($p>0.05$) in rearward tip angle found between the two types of wheelchairs: the depot (hospital issue, stock manual chair) versus the active (prescription manual chair). There were significant differences ($p=0.0095$) found among the three types of load device. The data for the 55-kg person and the 100-kg person were significantly different ($p<0.05$) from that of the ISO dummy, with that for the dummy being the more conservative measurement. There were no significant differences ($p>0.05$) found between the data for the two people.

There were significant differences ($p=0.0001$) found between test conditions. Both the tests using the wheelchair brakes and the belts differed significantly ($p<0.05$) from the test using the blocks. However, no significant difference ($p>0.05$) was found between the results when using the wheelchair brakes or the belt method. Results of using the three test conditions (belt, brake alone, block) were significantly different for each of the load devices: ISO dummy ($p=0.0026$); 55-kg person ($p=0.0001$); and the 100-kg person ($p=0.0001$); that is, results for the block method were different from the other two methods regardless of load device.

Table 2.
Static tip angle, in degrees, with loaded chair facing up the inclined plane.

Test Load	Belt		Brake		Block	
	M	SD	M	SD	M	SD
55 kg person w/paraplegia	10.47	2.181	11.38	1.784	20.08	3.104
100 kg ambulatory person	11.47	1.993	11.39	1.957	18.66	3.685
100 kg ISO dummy	7.31	2.590	8.30	2.796	14.38	4.991

M = mean
SD = standard deviation

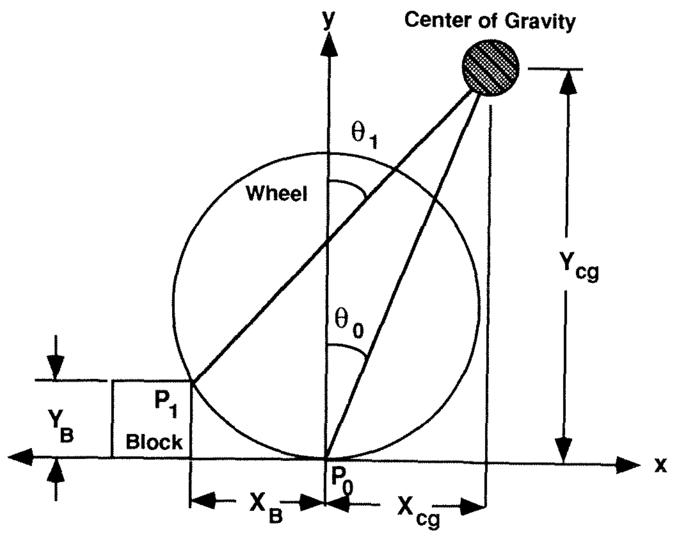

Figure 2.
Schematic diagram showing pivot points and tilt angles for belt/brakes-alone and for block testing methods.

DISCUSSION AND CONCLUSION

The results indicate that there is no difference between the rearward static tip angle when measured using the wheelchair brakes (or wheel locks) or when using a flexible belt around the rear wheels. The current test procedure using the block behind the rear wheels, when the brakes slip, biases the results in favor of wheelchairs that require the block. Therefore, the standard for rear static tip angle should be changed to use the belt or flexible membrane method, instead of the block method which nearly doubles the rear static tip angle.

The difference in the rearward static tip angle can be explained by the change in the pivot point between that for the belt/brake-alone and the block methods. The wheelchair/rider will pivot about the point of contact of the rear wheel with the tilt table when using the belt or brake-alone methods. The wheelchair/rider will pivot about the point of contact between the rear wheel and the block when using the block method. When the wheel is restrained from rotating about its hub, the block has the effect of moving the pivot point rearward and of slightly lowering the height of the wheelchair/rider center of gravity (cg) with respect to the pivot point **Figure 2**. The tilt angles for the two pivot points are derived below, where X_{cg}, Y_{cg}, X_B, and Y_B are all positive numbers:

$$\tan \Theta_0 = \frac{X_{cg}}{y_{cg}} \qquad \tan \Theta_1 = \frac{X_{cg}+X_B}{Y_{cg}-Y_B}$$

$$\frac{\tan \Theta_1}{\tan \Theta_0} = \frac{X_{cg}Y_{cg}+X_BY_{cg}}{X_{cg}Y_{cg}-Y_BX_{cg}} \geq 1$$

For the rearward tip angles presented in **Table 2**, the trigonometric terms above can be linearized using the method of Lagrange (sin $\theta_0 = \theta_0$, sin $\theta_1 = \theta_1$, cos $\theta_0 = 1$, and cos $\theta_1 = 1$) which yields:

$$\frac{\Theta_1}{\Theta_0} \geq 1 \Rightarrow \Theta_1 \geq \Theta_0$$

Hence, using the block yields a larger tip angle than does either the belt or brake-alone method.

The rearward static tip angles measured with the ISO dummy were consistently lower than they were for the human subjects. With the use of the dummy, the wheelchair rearward static tip angles were about 75 percent of those for the human subjects. Because the dummy yields more conservative estimates of the wheelchair static tip angle, it—rather than a person—should be used when making these measurements.

Both the depot and active wheelchairs with the rear axle in the farthest rearward position yielded similar results for rearward static tip angle. This suggests that manufacturers of active duty wheelchairs design their wheelchairs to incorporate the more conservative rear axle position of depot wheelchairs and then allow greater forward adjustment as the user becomes more skilled.

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