Improving wheelchair quality by translating community findings to lab-based standards testing

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INTRODUCTION

Wheelchairs are pivotal for the mobility of people with spinal cord injuries, multiple sclerosis, and similar diagnoses. According to the World Health Organization, 75 million people need a wheelchair for mobility and access to education, employment, and social engagement as well. [1][2] In spite of how vital wheelchairs are to their users, several studies indicate poor wheelchair quality and repair practices in both high-income and less-resourced settings. About 44-88% of wheelchair users experience one or more breakdowns over a 6-month period. [3][4] In the context of less-resourced environments, where the wheelchairs are exposed to higher levels of humidity, dirt, debris, mud, and uneven surfaces, breakdowns occur every 3 months. [5][6] One-third of users experiencing breakdowns face adverse consequences like being stranded and missing school, work, and medical appointments. [3] Without a functional wheelchair, users are constrained to a bed and experience pressure sores, and rehospitalization which ultimately leads to a downward spiral in health and quality of life. [3][7]

One-third of wheelchair breakdowns are due to caster failures. [8][9] A caster failure can be harmful to users as it leads to tipping and falling out of the chair, the cause of most serious wheelchair rider injuries. [8] Casters fail in a multitude of ways including locked and missing bearings, damaged bolts, fractured stems, wheels, and forks, worn-out tires, and missing fasteners. [9] The majority of these failures cannot be reproduced during wheelchair quality standards testing. Our literature review found that lack of inclusion of environmental factors observed in less-resourced settings and rural areas of high-resourced settings has led to such discrepancy. To address this, the International Society of Wheelchair Professionals Standards Working Group has developed and published ISO 7176-32, a caster testing protocol using community data on wheelchair usage and failures. [12] Previous validation studies have matched failure modes between laboratory test results and community (See Figure 1). [9] The next step in this standards research is validation of caster's time-to-failure. This ongoing validation study aims to analyze community data on caster failure from a wheelchair repair registry and compares the findings to lab-based ISO 7176-32 testing of caster models.

Figure 1. Comparison of the same caster model experiencing similar failure modes in the community (left) and the laboratory (right).

METHODS

Secondary data analysis of caster failures

The Wheelchair Repair Registry (WRR) is a wheeled mobility device failure repair registry developed by the Rehabilitation Engineering Research Center at the University of Pittsburgh. [10] The WRR currently has over 60,000 repairs conducted on more than 5,000 wheelchairs from 25 manufacturers in United States. [10] Manual wheelchair models in the WRR were assigned Healthcare Common Procedure Coding System (HCPCS) codes found on wheelchair order forms. Caster repairs and failures reported for all manual wheelchair manufacturers and their models beginning in January 2017 until October 2019 were analyzed. The analyzed caster failure types were classified based on the associated risks of wheelchair user injury and damage to other wheelchair parts [11]. Caster wheel fracture and bent parts were designated as high-risk failures while bearing failure and worn-out tires were designated as low-risk failures. Caster models with at least 100 failures were analyzed. Chi-square testing was conducted to evaluate differences in risk-proportions among the models. Models with more than 25 samples and having greater than or equal to 25% high-risk failures were chosen for testing and time-to-failure comparison.

ISO 7176-32 caster durability testing

Five samples of each model were ISO 7176-32 tested until a high-risk or low-risk failure. The ISO 7176-32 caster durability testing protocol includes corrosion testing in a salt fog chamber (as per ASTM B117) followed by shock and abrasion testing on a test bed (See Figure 2 left). [12] Each sample experiences 200 hours each of wet and

dry salt fog exposure and then repeated the caster durability testing exposure as specified in ISO 7176-32. The time-to-failure of each test sample was determined by the total cycles completed on the caster durability test. Testing was discontinued following a sample failure. The standard test cycles represent two-years of outdoor use. The time-to-failure for common failure mode were compared using the two-tailed unequal variance T-test ($\alpha = .01$). The time-to-failure in the community was difference between purchase date and failure date for samples of the model.

Figure 2. ISWP Chakra (left) and the salt-fog chamber (right)

RESULTS

The study analyzing this data identified 6470 caster failures of wheelchairs from 4 leading manufacturers. [13] A key finding from this analysis, shown in Figure 3, was that tilt-in-space manual wheelchairs experience significantly more high-risk failures than their ultralightweight wheelchairs, $X^2(3, N = 704) = 42.15$, $p < 0.05$. [13] Due to the identification of this trend, two tilt-in-space wheelchair caster models (See Table 1) having more than 25 samples in the registry and greater than 50% high-risk failures (cracked wheel plus bent caster) were chosen for ISO 7176-32 testing. Table 2 shows the time-to-failure comparison for the models. Their failure modes can be seen in Table 1.

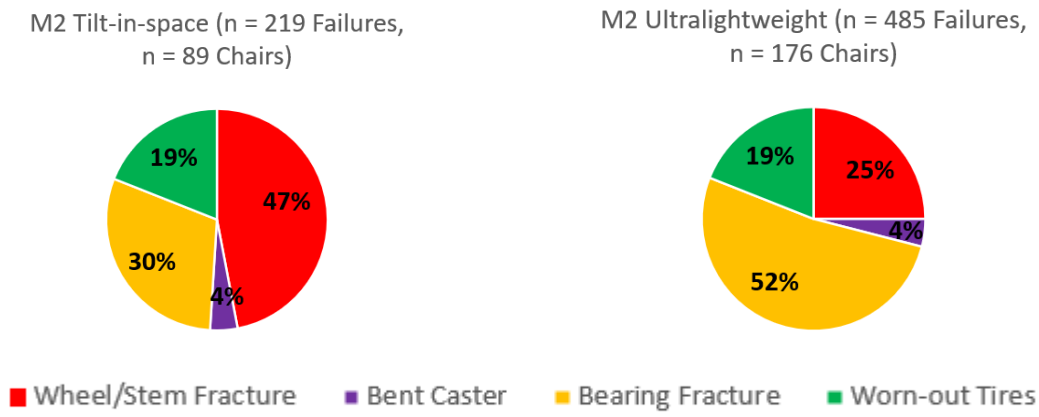

Figure 3. Failure distributions for tilt-in-space and ultralightweight wheelchairs from Manufacturer #2

Table 1. Pre- and post-testing photos of the tilt-in-space casters selected for the study

Caster Model	Pre-test Photos	Failure Mode Photos

6” x 2” Semi-Pneumatic		
8” x 1.5” Pneumatic Urethane		

Table 2. Statistical comparison of failure modes and time-to-failure of tilt-in-space wheelchair

Caster model	Community Data Findings		ISO 7176-32 Test Results		P-Value
	Community Failure Modes	Time-to-Failure	Lab Failure Mode	Lab Time-to-Failure	
8” x 1.5” Pneumatic Urethane	Cracked Wheel (38%)	2.88±0.46 (n=42)	Cracked Wheel (100%)	1.57±0.51 (n=5)	0.014
6” x 2” Semi-Pneumatic	Cracked Wheel (25%)	2.02±0.57 (n=58)	Worn Tire (100%)	4.99±1.29 (n=5)	NA, cannot compare different failure modes

DISCUSSION

Wheelchair caster failures pose a significant risk to the health and life quality of the wheelchair user. The proportion of high- and low-risk caster failures are unique across the tilt-in-space and ultralightweight caster model reported in the WRR. Tilt-in-space models encounter nearly twice the high-risk failures than their ultralightweight counterparts. This suggests that users who require a higher level of seating support and have complex rehabilitation needs are at a greater risk of experiencing caster failures that can cause user injury and other adverse consequences. The ISO 7176-32 standard provides an avenue for benchmarking wheelchair quality in the laboratory to use settings.

The time-to-failure validation study for two caster models resulted in contrasting but promising results. The 8” pneumatic urethane model failed due to cracked wheel hubs in all five samples tested with the protocol. This is consistent with the community data as cracked wheels are also the most common failure reported for this configuration. The matching time-to-failure for this model strongly supports the evidence-based development of the ISO 7176-32 testing protocol. Alternately, the 6” semi-pneumatic model consistently failed due to worn-out tires that inhibited caster function and began to damage the wheel hub. The worn-out tire failure was the second most common failure mode in the community for the model. However, the lab-tested samples lasted significantly longer than seen in the community. The test protocol could not simulate this model's high-risk cracked wheel failure. This may be due to testing the casters under standard load rather than manufacturer-rated load. The tilt-in-space wheelchair model should be measured to determine weight distribution on the casters, integration of the caster with the rest of the wheelchair, and use patterns compared to standard wheelchairs. This may lead to specific testing changes for tilt-in-space wheelchair casters that differentiate the process from standard wheelchair caster testing. It would be beneficial to know the rated load from the manufacturer prior to conducting further validation testing with the model. Due to the variety in designs, it is possible that each wheelchair/caster type could need its own procedure for testing.

Testing of the 8" model reveals a high-risk failure and a short time-to-failure which calls for design improvements. Wheelchair manufacturers can avail the caster testing facility to improve wheelchair reliability and safety in use settings. Other stakeholders can request the details on standards testing prior to making a device selection. The authors are testing four ultralightweight caster models from 2 different manufacturers in this ongoing standard validation study.

CONCLUSION

Frequent wheelchair caster breakdowns often lead to injury, inconvenience, and a lower self-perception of quality of life. This study demonstrates the poor reliability of tilt-in-space wheelchair caster models and high risk of injury for users of these devices, stressing the need for improving caster quality. The ISO 7176-32 caster testing protocol is developed using community data and exposes casters to corrosion, shock, and abrasion exposure. Calibrating the failure modes and time-to-failure of this testing method to community evidence is a vital step in adding further validity to this protocol. The authors have established the validity of mimicking outdoor caster failures on the lab-based test and in this study, taken the next steps towards validation of time-to-failure. Findings indicate the need for individualized protocol for caster models of tilt-in-space wheelchairs that vary in design compared to other wheelchair devices.

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