Wheelchair Stability Tests while using Fitness Equipment

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ABSTRACT:

The purpose of this study was to determine if instability could occur during normal exercises using standard fitness equipment while using a wheelchair. The exercises tested were the chest press, overhead press, and vertical press. The goal of this project was to use the test results to facilitate fitness equipment designs that would provide the rearward stability that a wheelchair user needs during exercises using strength equipment. In addition, these results will be used to guide the draft ASTM Accessible Fitness Equipment Standards that are currently being developed. The tests completed were to determine critical tricep extension forces that result in rearward tipping of a conventional wheelchair; the effect of body mass and size on rearward tip forces, and the effect of seat height on rearward tip forces.

KEYWORDS:

ASTM standard; fitness equipment; access; wheelchair load tolerance; universal design

BACKGROUND:

The need for exercise for people who use a mobility product is vital to the user's health. Wheelchair manufacturers often recommend against the use of a mobility device while exercising with strength equipment. Following is standard text found in a manual wheelchair user guide:

<MANUFACTURER> does not recommend the use of its wheelchairs as a weight training apparatus. <MANUFACTURER> wheelchairs have not been designed or tested as a seat for any kind of weight training. If occupant uses said wheelchair as a weight training apparatus, <MANUFACTURER> shall not be liable for bodily injury or damage to the wheelchair and the warranty is void.

While precautions should be taken, this view is unrealistic in some cases, since some individuals are not able to transfer in and out of their manual or powered wheelchairs into fitness equipment. To create the proper warnings, manufacturers would need more information about the types of exercises that can result in specific type of problems if they are to begin to properly warn wheelchair users about what could happen if a certain exercise is performed. Standard gym equipment, as found in a public facility, can be inaccessible for mobility device users and other users who have specialized exercise needs. In many cases, specialized exercise equipment is more expensive to both users and the exercise facility than standard exercise equipment that is commonly available (1). Standard exercise equipment designed with a broader target audience in mind would be beneficial to many, including people who use mobility devices, people in physical therapy, the elderly, and other users with special needs.

METHODOLOGY:

The exercise most commonly associated with rearward tipping is the forward press. These tests were done by setting up a calibrated RESNA wheelchair test dummy (as defined in the RESNA Standard for Wheelchairs Vol. 1 Sec. 11) that was representative of each weight and shoulder height percentile for 5th percentile female, 50th percentile female, 50th percentile male, and 95th percentile male in a fixed axle wheelchair and an adjustable axle wheelchair (2). The RESNA test dummy was pushed with a force reading sensor at the correct shoulder height for each percentile. Values measured include force to lift the front wheels from ground, angle of rearward tip, seat angles, back angles, and wheelchair frame angles. Scales were placed under the front wheels and the rear wheels. The force to lift the front wheels off of the ground was measured when the front scale went to zero and all angles were measured with a calibrated SmartTool™ Level.

Also tested was the vertical press, this action involves the user lifting weight straight up above their head. This test is useful for users who may use free weights as well. A standard size test dummy was loaded with weights in an Invacare Tracer SX, a standard depot-style wheelchair with a maximum user weight of 250 lb and a fixed axle, was examined for stress. The wheelchair tolerated up to 1,491 lb before reaching the scales limit. Some bending in the caster tube mounts occurred, however the wheelchair was still functional after this test. Despite the durability of this particular chair, it should be noted that when a mobility device user is lifting weights there should be some attention to the weight of the user and the weight being used to exercise so that the total does not exceed the maximum recommended payload for the wheelchair. Exceeding the wheelchair payload could void the warranty and potentially lead to injury if there was a catastrophic failure at the time of the exercise or if the component on the wheelchair were to break later on due to damage that could occur during an overloading event.

Determination of tricep extension forces that result in rearward tipping:

A test subject was seated in a fixed axle depot style wheelchair and was setup in a position to exercise in a manner that could cause a rearward instability. A force sensor was attached to the back of the chair to read forces on the user's back during the exercise. As the user performed a downward tricep curl, the force readings were taken at the tipping point of the wheelchair. It was discovered that after the front wheels of the chair lifted, the force to tip backwards decreased. This means, that once the chair's front wheels were up off the ground, it took very little force to tip the wheelchair over backwards.

Determining the effect of body mass and size on rearward tip forces:

A software program called PeopleSize by Open Ergonomics Ltd was used to determine the average height, weight, and shoulder height of a person in the following percentiles of the population: 5th percentile female, 50th percentile female, 50th percentile male, 95th percentile male. These percentiles were selected as a representation of the physical properties of a range of possible users. These tests were done with the fixed axle wheelchair with the axle aligned with the back support. Test dummies that were representative of each percentile were placed in the wheelchair and pushed with a force gauge at shoulder height until the front wheels lifted off the ground.

Determining the effect of rear axle position on rearward tip forces:

These tests were done with an Everest & Jennings Metro GT. This wheelchair has an adjustable axle with four axle positions. Each position is 17.5 mm apart. To ensure that only one variable was tested, the 50th percentile male was the only size/shoulder height used in these tests. A test dummy that was representative of a 50th percentile male was placed in the wheelchair and pushed with a force gauge at shoulder height until the front wheels lifted off the ground in each of the different axle positions.

Determining the effect of seat height on rearward tip forces:

These tests were done with the fixed axle wheelchair. Four different cushions were used to increase the seat height; from one to four inches (1" to 4"). To ensure that only one variable was tested, the 50th percentile male was the only size/shoulder height used in this test. A test dummy that was representative of a 50th percentile male was placed in the wheelchair and pushed with a force gauge at shoulder height until the front wheels lifted off the ground in each of the different seat height conditions.

RESULTS:

The results for determining the effect of body mass and size on rearward tip forces are displayed in Table 1. These data suggest that body mass and shoulder height are important factors in wheelchair stability. A 5th percent female only takes 13.2 kg to tip rearward in a wheelchair while the 95th percent male requires 16.7 kg. The taller a user is, the longer the distance from the wheelchair's pivot point (or the axle) the more leverage there is pushing force acting upon the user. It was also determined that the use of wheelchair wheel locks had little effect on avoiding backwards tipping.

Table 1. User weight and shoulder height effect on wheelchair rearward tipping forces

Forward pushing force needed to tip wheelchair rearward	5th Percentile Female	50th Percentile Female	50th Percentile Male	95th Percentile Male
Dummy weight (kg)	51	67	81	108
Total standing height (cm)	153.7	164.3	179.9	191.4
Shoulder sitting height (cm)	47.9	52.9	62.7	65.8
Push force – force sensor reading at front wheel lift (kg)	13.2	15.2	14.2	16.7

The results for determining the effect of rear axle position on rearward tip forces are displayed in Table 2. These data suggest that wheelchair rear axle position is the single most important factor affecting rearward wheelchair stability. As the rear axle moves forward, the force needed to tip the wheelchair over backwards decreases rapidly. The force decreases from 11.2 kg to 6.4 kg over the axle range.

Table 2. The effect of rear axle position on wheelchair rearward tip forces

Forward pushing force needed to tip wheelchair rearward – 50th percentile male	Axle Position 1	Axle Position 2	Axle Position 3	Axle Position 4
Dummy weight (kg)	81			
Total standing height (cm)	179.9			
Shoulder sitting height (cm)	62.7			
Axle position	Full Rear “0” (0 mm)	"+1" (17.5 mm)	"+2" (35 mm)	"+3" (52.5 mm)
Push Force – force sensor reading at front wheel lift (kg)	11.2	9.6	7.9	6.4

The results for determining the effect of seat cushion height on rearward tip forces are displayed in Table 3. These data suggest that although increased seat cushion height does decrease the amount of force needed to tip the wheelchair, 14.7 kg to 11.6 kg, it was not as significant a factor as rear axle position.

Table 3. The effect of seat cushion height on wheelchair rearward tip forces

Forward pushing force needed to tip wheelchair – 50th percentile male				
Seat Cushion Height (in (mm))	1.0 (25.4)	2.5 (63.5)	3.5 (88.9)	4.0 (101.6)
Dummy weight (kg)	81			
Total standing height (cm)	179.9			
Shoulder sitting height (cm)	62.7			
Push Force – force sensor reading at front wheel lift (kg)	14.7	13.3	12.1	11.6

DISCUSSION:

Many wheelchair users could be at risk of rearward instability while doing exercises using strength equipment, such as the chest press, tricep extension, and overhead press. The rearward stability of the chair is affected by many variables; however axle position is the greatest of these. Active wheelchair users typically have more forward mounted axles due to the increased dynamics of their wheelchair. This group is especially at risk of rearward instability while performing strength equipment exercises. There exist a number of ways to limit the movements of a wheelchair in the rearward direction. Some existing solutions include fitness equipment with seats that pivot out of the way with a vertical fixed back support pad that extends low enough to reach the back supports of most wheelchairs. Another solution is to use a personal trainer, assistant, or a wheelchair securement system to keep the wheelchair stable. This paper only studied three specific types of strength equipment exercises. Other types of exercises could also lead to lateral or forward stability issues which could result in severe injury if the wheelchair user fell out of the wheelchair or tipped over in another direction. These results will be used to further guide the ASTM standard that is currently under development, working title: "Standard Specification for Universal Design of Fitness Equipment for Inclusive Use by Persons with Functional Limitations and Impairments."

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