Vibration Exposure in Wheelchairs: The Effect of Inflation Pressure and Tire Type

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INTRODUCTION

Wheelchairs have been shown to produce vibrations that are transmitted into the occupant during day-to-day activities. Research has demonstrated that vibrations exceed the safety limits set by the International Organization for Standardization as defined in the ISO 2631-1 [1-3]. Back and neck pain, spasticity, and pressure wounds are among the many conditions that are caused or exacerbated by vibrations. Accelerometers are typically used to assess whole body vibrations in wheelchair users. Research has examined wheelchair design and componentry as factors affecting transmitted vibration. Specialty wheels [4], cushions and back supports [5], have been investigated as features that may affect vibration exposure in wheelchair users. Vibration exposure has been investigated over particular surfaces in manual and power wheelchairs [6], but tire types were not specifically compared. Ordinary wheelchair propulsion can expose a wheelchair occupant to potentially harmful vibration levels. Of 37 subjects studied in a 2-week trial, 100% of the subjects exceeded the ISO 2631-1 health caution zone [7].

Many aspects of wheelchair setup are aimed at optimizing parameters such as wheel access, weight distribution, overall weight, drive wheel and caster configurations, and many others. Given the importance of mitigating vibration exposure, the properties of the drive wheel tire may offer benefits that rank its importance high on the list of features to be optimized. Within the bicycling world, there has been a paradigm shift toward wider tires. The idea that narrower tires have lower rolling resistance has been shown to be a fallacy under test conditions [8]. Because wider tires have a larger volume, they are presumed to offer a smoother ride. Suspension losses are a biomechanical energy-robbing phenomenon caused by the effect of high frequency vibration (e.g. riding over cobbles) in cycling [9]. Most of the benefits enjoyed by cyclists can be conferred to wheelchair users. This investigation seeks to evaluate tire volume and tire pressure as factors influencing vibration transmission to the user.

METHODS

Two pneumatic tire types were tested, one a 28-559 Schwalbe Durano, hearafter referred to as the Low Volume or narrow tire, and the 44-559 Rene Herse Naches Pass, referred to as the High Volume or wide tire. Each tire was tested at three different pressure equivalencies. The Apple iPhone™ built-in accelerometer measures acceleration in the fore-aft, medial-lateral, and superior-inferior directions (x, y, and z axes). Values used for analysis are the *Z* axis since it is the force vector for vertical acceleration relative to the mounting of the iPhone on the wheelchair axel. A Smartphone app, Sparkvue (Pasco Scientific, Roseview, CA) enabled recording sessions to be performed and the acceleration values uploaded to a laptop computer. The iPhone was secured to the camber tube of a rigid wheelchair. This was deemed to be the most logical position in which to place the instrument to measure vibration transmitted from the substrate into the wheelchair through the drive wheels. A 13.5 meter course was constructed of plywood and lath to provide a uniform and pronounced vibration input to the wheelchair. The lath (wood strips approximately 9mm high and 40mm wide) was attached across the course at approximately 40 cm intervals. The wheelchair was occupied by an unimpaired person and pushed by an attendant. An attendant was used to 1) help maintain a constant speed (using a metronome), 2) eliminate the pulses of acceleration-deceleration from the push-stroke of a wheelchair occupant and 3) eliminate the potential damping effect of the occupant gripping and releasing the wheels or hand rims during a push-stroke. The recording sessions were performed at a sampling rate of 200 Hz. The wheelchair, a Quickie Q7 (Sunrise Medical, Fresno, CA) with 26” (559) spoke wheels was used for all of the trials. Although multiple trials were run, consistency between trials enabled us to select three trials per tire for statistical analysis. The duration of each trial ranged between 12-13 seconds, so the speed of each trial was approximately 1 meter/sec. Trials were selected for similarity in duration/speed, and absence of outliers. This resulted in 6600 data points per tire per session. The data was analyzed using Microsoft Excel. Using the Excel Data Pack requires equal sample size for a 2-Way ANOVA.

The High Volume (wide) tire has almost 2.5X the volume of the Low Volume (narrow) tire. Since the load, volume (and tire cross section diameter), and pressure are interrelated, we could calculate "pressure equivalency" to compare the High and Low Volume tires (Fig. 1). This approach applies *Hoop Stress* and *Casing Tension* mechanics to determine pressure equivalency [10]. We assume that tire casing thickness is the same between tires, and that the tire approximates a circle in cross section. The tire diameter and inflation pressure vary interdependently, and casing tension (force) is held constant. This results in a proportion that can be used to determine comparable inflation pressure in the wide (w) tire from the narrow (n) tire. Trials were run for the narrow tire at 85, 100, and 115 psi, and the respective pressure for the wide tire 54, 64, and 73 psi.

$$P_n D_n = P_w D_w$$

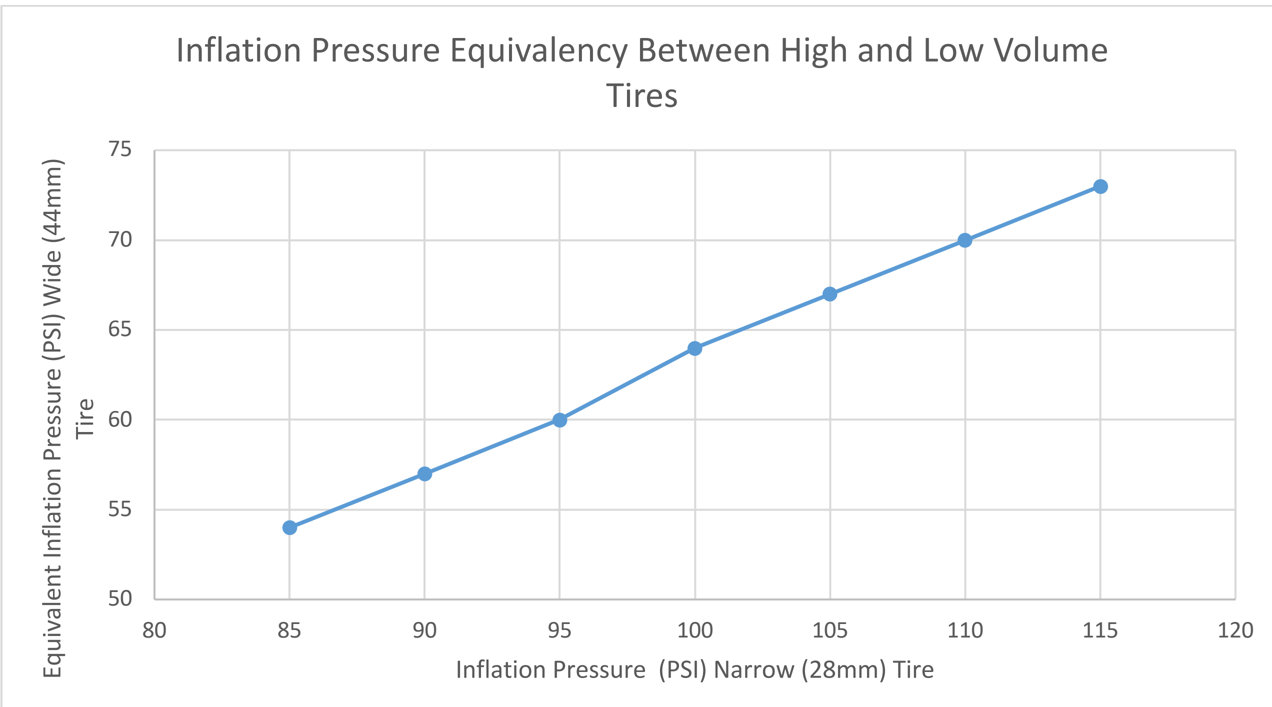

Fig. 1. Pressure equivalency between High Volume (wide) and Low volume (narrow) tires

RESULTS

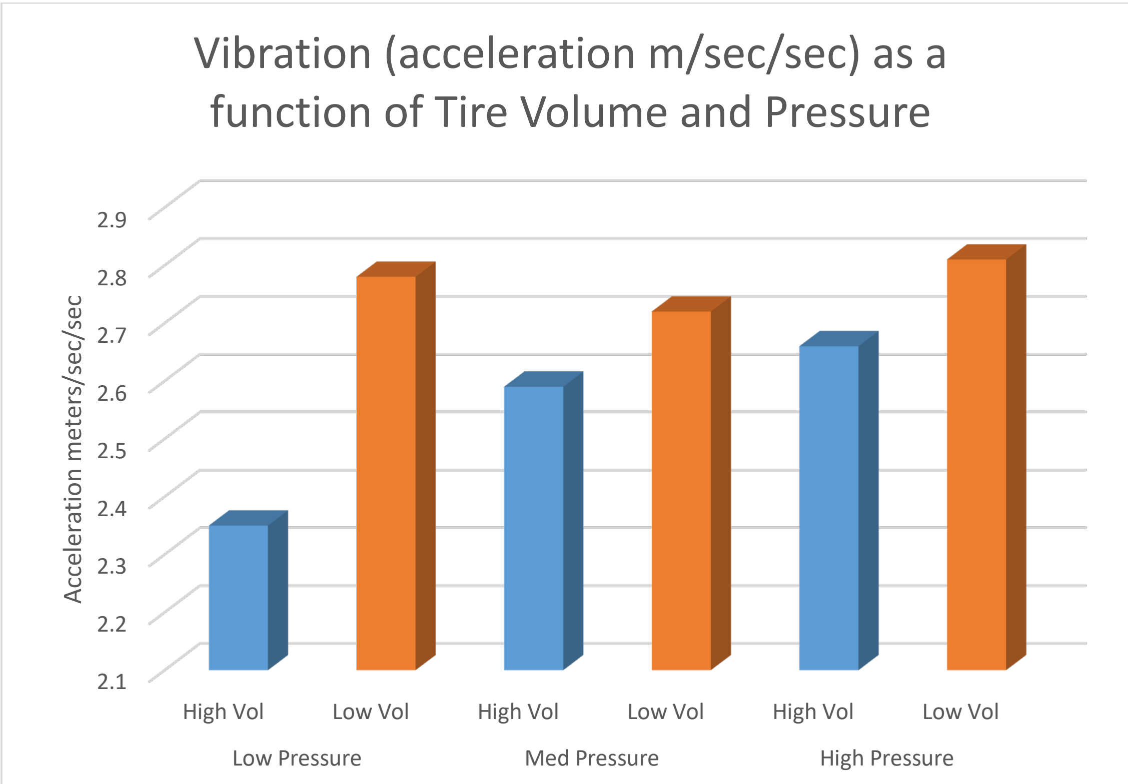

Fig. 2. Vibration amplitude at three different pressure equivalencies. High volume (44mm) tires damp vibration transmitted into the wheelchair as compared to low volume (28mm) tires. A direct relationship between tire pressure and vibration amplitude is also observed

A Two-Factor ANOVA was performed. The data was treated by dividing it into two groups, High (wide) and Low (narrow) Volume tires respectively. Each group was compared within the three tire pressures, Low, Med, High. Statistically significant differences in vibration were observed between the High Volume and Low Volume tires, $p<.0001$, as well as between the Low Pressure, Medium Pressure, and High Pressure treatments, $p<.001$. There was also a significant interaction effect $p<.001$, so that the impact of tire volume on vibration was interrelated at the different levels of tire pressure.

DISCUSSION

Tire choice and inflation pressures are basic interventions that can have positive outcomes for many manual wheelchair users. Choosing wider tires and running them at moderate pressures can help damp potentially harmful vibrations. Conventions within the wheelchair industry have resulted in “flat-free” tires, which tend to be hard and produce a less compliant ride. [11] Routhier, et.al. 2015 showed that hard urethane tires roll more poorly than pneumatic tires and that this effect increases with increased weight on the wheelchair. Most of the pneumatic tires available for wheelchairs tend to be between 25-37mm. Most customizable manual wheelchairs are available with 26” (559) wheels. There are hundreds of tires available from the bicycle industry that will fit this tire size. Larger volume tires will perform better over rough surfaces because of their ability to easily deform as they go over an obstruction, such as a crack or abrupt curb-cut transition. A reasonable upper limit exists for tire width. Hand rim access can be affected by tires exceeding a certain width. Tire style should also be considered.

A lighter "road style" tire will produce less rolling resistance than a typical knobby tire such as a mountain bike tire due to the hysteresis of the thick rubber tire lugs. Optimizing tire volume and pressure can confer advantages for persons experiencing axillary pain and fatigue from a long day in a wheelchair. Both comfort and performance can be enhanced. Flat protection is a valid concern for most wheelchair users. The thinner liquid tire sealants used in tubeless bicycle tires provides good protection for most circumstances, if it is maintained a few times a year. Every practitioner must weigh the pros and cons of choices that impact lifestyle dynamics.

This investigation did not seek to measure vibration transmitted into the occupant, only into the wheelchair. The measurements were made with the on-board accelerometers of a Smart Phone device. They offer repeatable measurements based on our results, however in our opinion their value is in a comparative capacity and not for documenting absolute vibration measurements. Further, we do not follow the ISO 2631-1 protocol and do not claim our measurements translate to specifications published in that document. We do emphasize however, that tire type and tire pressure are manageable factors that can improve the ride quality, and reduce vibration, and that these factors merit serious consideration in efforts to optimally configure wheelchairs in general, and active-style manual wheelchairs in particular.

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Acknowledgements: Andrew Batchelar, Schwalbe Tires America; James des Lauriers Emeritus Professor of Biology; Jim Jewell, InHome Medical, Andrea Alderson, and Steve May.