Good Vibrations- Manual Wheelchair Design to Mitigate the Adverse Effects of Vibration

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"Everyone is entitled to his own opinion, but not to his own facts" (Moynihan)

INTRODUCTION

Significant exposure to vibration (whole body vibration - WBV) has been linked to a variety of adverse health conditions in able bodied workers exposed to WBV during occupation, especially in a seated posture. The International Standards Organization (ISO) has described WBV as "applicable to motions transmitted to the human body as a whole through the supporting surfaces: the feet of a standing person, the buttocks, back and feet of a seated person. . ." (ISO 2631, 1997) ISO has also established some guidelines for individuals regarding exposure to WBV. Among them, they have described a zone of exposure levels in which caution is indicated with respect to potential health risks, and above which health risks are likely.

What is vibration?

It is important at this point to distinguish between vibration, and another term that is often included in discussion of the topic yet refers to a different phenomenon: shock. Vibration can be described as a periodic motion resulting in acceleration in alternately opposite directions. It can be caused, for example, by the striking of a tuning fork in the tuning of a musical instrument or by wheeled movement over discontinuous surfaces. In contrast, shock is a nonperiodic motion resulting in a sudden acceleration. It can be caused, for example, by an impact or drop. Shock is a transient physical excitation.

To a certain extent, we can think of the difference between vibration and shock as characterized by regularity (periodic and repeated, or not), and magnitude. Think of it in terms of a roadway. If you're driving along a road that has rumble strips on the shoulder, and your wheels are rolling over those rumble strips, you will sense the vibration imparted to your vehicle through your hands on the steering wheel, and through your seating surface. That rumble strip is a discontinuous surface that produces accelerations up and down in very regular and repeated intervals (periodic motion). These 'bumps' are relatively small and do not cause you or your vehicle to accelerate very far vertically (magnitude). On that same roadway, however, one of your wheels may suddenly encounter a deep pothole. That pothole will create a very sudden vertical acceleration/deceleration as the wheel drops into it. Your car and your body will feel that shock. It will happen once (hopefully) and be over. It will be transient. It will be of significant magnitude compared to the rumble strip and will not be periodic (regular and repeated).

What are the effects of vibration on humans?

WBV and its effects are phenomena that may be experienced by all individuals. For individuals in wheelchairs, WBV can not only have an adverse effect on comfort, ride quality and energy expenditure, but the WBV these individuals experience in their chairs on a long-term basis can contribute to pain, degenerative conditions, interference with ADLs, increased spasticity and even motion sickness. Garcia Mendez, et al noted that "There is evidence that seated WBV exposure is a risk factor for spinal disorders, excessive muscle fatigue, and damage to the connecting nerves", and additionally that "vibration's cumulative effect plays an important role in WBV association with low back pain (LBP)", (Garcia-Mendez, 2013). Pope et al noted that "After exposure to whole body vibration, the muscles are fatigued, and the discs compressed (less capable of absorbing and distributing load). In this condition, the spine is in a poorer condition to sustain larger loads." (Pope, 1998)

In a study looking at 37 individuals in manual wheelchairs and the vibration loads to which they were exposed, Garcia-Mendez et al stated "Our results indicate that 100% of the subjects were exposed to vibration loads at the seat surface that were either within or above the health-caution zone established by the ISO 2631-1 standards." (Garcia-Mendez, 2013). Requejo et al investigated hand rim wheelchairs with rear suspension and the forces involved in curb descent landings. They noted "Exposure to shock (infrequent high loads) and vibration (low–magnitude repeated loads) has been linked to muscle fatigue, back injury and neck pain. Consequently, shock and vibration experienced during daily wheelchair riding can decrease an individual's comfort, increase their rate of fatigue and limit their functional activity and community participation." (Requejo, 2009).

How is vibration transmitted?

Vibration can be transmitted to a wheelchair through the elements of the chair in contact with the rolling surface, namely the caster wheels and the rear wheels. As those wheels roll across a surface, irregularities in that surface can impart perturbances to the wheels, which disrupt the smooth rolling of that wheel across the surface and impart movement and energy into the wheel. Those perturbations can then be transmitted through the tire material, through the spokes and hub, and in turn to the frame. The frame, of course, can then transmit many of those forces through to the user in the wheelchair, even with a cushion in place (Garcia-Mendez, 2013). It is worth noting that one of the areas of a wheelchair where vibration may be sensed the most, and where some of its effects are most noticeable is the footrest. The small caster wheels at the front end of manual wheelchairs are sustaining the vibrational energy from the discontinuous surface, transmitting that energy right up through the caster stem, caster wing, and through the connection to the footrest. In short, the vibrational energy doesn't have very far to travel to get from the casters to the footrests.

Many common surfaces which are traversed during normal wheeled mobility have physical characteristics that impart small oscillatory movements in multiple planes. The perturbance imparted to a wheelchair is commonly measured in terms of acceleration, with vertical acceleration being singled out as potentially the most significant. These surfaces may have rough texture, such as brushed concrete or exposed aggregate (e.g. asphalt), and they may contain seams and edges such as found on cobblestones, paver bricks and sidewalks. Many indoor surfaces, such as indoor tile and paver bricks, and carpeted surfaces are even responsible for imparting vibrational energy into wheeled mobility devices. All of this can add up to exposure to WBV for the wheelchair user.

What has been done to mitigate the effects of vibration?

Able bodied workers have developed strategies to limit the adverse effects of WBV from occupation by limiting exposure time, such as rotating through alternate tasks that don't involve vibration and ensuring an adequate recovery time between exposures. Additionally, vibration damping technology has been employed in many occupational situations to minimize WBV exposure for those workers. Those strategies, however, may not be feasible or practical for the person seated in a wheelchair. Wolf, et al noted "The harmful effects of WBV can be negated by an 8-hour rest period; however, this is extremely rare during an ordinary day of a manual or power wheelchair user, and through days, months, and years, cumulative exposure to WBV could result in secondary injuries." (Wolf, 2007), Wheelchair manufacturers have attempted to mitigate the detrimental effects of WBV through a variety of approaches in the past. Claims have been made regarding materials, frame design or specialized components.

For example, many have long thought that titanium, as a wheelchair frame material, is better than aluminum at damping vibration. Analysis of the properties of titanium and aluminum commonly used in the fabrication of ultralightweight manual wheelchairs does not support this belief. In a technical report on the characteristics of alloys commonly used in the manufacture of manual wheelchair frames Cochran found that titanium alloys do not dampen better than the 6000 or 7000 aluminum alloys used for that same purpose. In his investigation he noticed that "the best damping titanium alloy was slightly inferior to the two aluminum alloys of interest.", and that "All of the alloys (Ti, 6000 Al and 7000 Al) studied in this investigation have loss factors [damping capabilities] that are very low compared to the loss factors of other materials that go into the construction of a wheelchair." He concluded that "When considering Al vs Ti alloys, the material used to construct the frame of a wheelchair is of minimal importance to vibration damping when compared to the design of the wheelchair and/or the cushioning materials employed" (Cochran, 2011)

Wheelchair manufacturers have indeed used a variety of frame design concepts that have included various piston style shock absorbers, coil springs, torsion bars with elastomer dampers and suspension caster forks. Kwarciak, et al noted that placement and orientation of certain shock absorbing elements in some frame designs seems to be of importance: "During this process, the benefit of the suspension system may be compromised because of the orientation of the wheelchair" (Kwarciak, 2008). In this context, they were describing that piston style shock absorbers are unidirectional, and if forces imparting shock are not aligned in that direction, their effectiveness may be lessened.

Cooper, et al looked at seat and footrest shocks and vibrations in manual wheelchairs with and without suspension. They noted that while there was a frequency octave relative to the seated human where the power [result of vibration transmission] was not significantly reduced they went on to state: "Given its effects on vibration and shock transmission suspension, caster forks, such as Frog-Legs, should be considered for active clients or individuals who have chronic pain" (Cooper, 2003) Specialized components such as rear wheels purported to absorb shock and lessen vibration have also been employed to dampen WBV. It is important to note that incorporating an element to dampen vibration or make for a 'softer' and 'plusher' ride generally comes with a trade-off of requiring more energy to propel and maneuver a chair. Finding the optimal combination of vibration damping without sacrificing energy expenditure has been the holy grail in this endeavor.

Whether it is suspension incorporated into the frame design, or specialized add-on or replacement options such as caster forks or rear wheels, the technology to date has largely been shown to be insufficient to meaningfully dampen the WBV sustained by a manual wheelchair user. Wolf, et al noted "Wheelchair companies have attempted to address this problem by adding suspension to manual and power wheelchairs; however, studies have demonstrated that these additions do not necessarily reduce the amount of oscillatory and shock WBV." (Wolf, 2007)
Garcia Mendez, et al observed:

> *The results of these studies demonstrated that suspension casters can significantly reduce **peak** [emphasis added] accelerations transmitted to users (at the seat and footrest) and that rear-wheel suspension systems do reduce some of these vibrations, although they do not outperform traditional frame designs and still transmit vibration in the frequency range most harmful to humans (Garcia-Mendez, 2013, p2).*

The challenge continues to be how to completely isolate the user in a manual wheelchair from the harmful vibrations and shocks that the chair receives through contact with supporting surfaces. All of the examples above can either be described as unidirectional or having a connection to the wheelchair frame which may have the potential to allow vibratory energy to bypass that suspension element. There may be some promise in utilizing concepts employed in construction practices, wherein buildings and bridges, for example, are isolated from vibration and shock using polymers or viscoelastics that are placed in between the object being protected, and the source of possible vibration or shock. Kwarciak, et al noted that "Elastomer-based suspension systems provided good lo-level vibration control; however, they became relatively ineffective at reducing higher magnitude shock vibrations." and postulated that "perhaps elastomers could be used to couple sections of the wheelchairs where vibrations are greatest" (Kwarciak, 2008).

What is the solution?

Now, there is a solution to address the vibration that a wheelchair user sustains while riding in a manual chair. The Ethos K0005 rigid manual wheelchair, from Ki Mobility was designed to effectively manage vibration transmission to the wheelchair user. Taking some examples from other instances where base isolation can mitigate vibration transmission from a base to an object on that base, the Ki Mobility Ethos has a seat frame that is isolated from the base frame and utilizes scientifically proven vibration damping technology which dampens vibrations received by the body during normal use. The result is a ride so smooth that cracks and crevices seemingly disappear in the wake of every push.

Isolating the seat frame from the base frame and not connecting the caster wheels to the seat frame creates the ability to control WBV. The isolated seat frame and ISO Tech polymers in unison with the detached caster wheels shield the rider from the constant barrage of high frequency vibrations. Now every bump and jar that the caster wheel encounters are not immediately transferred to the rider's feet and legs via the footrest. Internal testing at Ki Mobility demonstrated a 50% reduction in vibration measured at the seat frame as compared to the base frame. Measurements at the base frame could be considered representative of traditional rigid wheelchair designs, both monotube and dual tube, where the caster housings and therefore wheels are connected to the seat frame. Patent pending technology available only on Ethos creates the incredibly smooth ride and shield from WBV. The superior ride quality can also be tailored to the preferences, personal or clinical, of the rider or clinician. The positive results Ethos has the potential to create through a better ride starts with the vibration damping benefits and ends with the availability of increased and unique adjustability with no negative impact to performance. The innovative and unique design of Ethos provides options and solutions which have previously not been available in custom manual ultra-lightweight rigid wheelchairs.

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