ANALYSIS OF VIBRATION AND COMPARISON OF FOUR WHEELCHAIR CUSHIONS DURING MANUAL WHEELCHAIR PROPULSION

Carmen P. DiGiovine B.S., Rory A. Cooper Ph.D., Erik J. Wolf, James Hosfield, and Thomas Corfman, M.S.

Human Eng. Res. Lab., Center of Excellence in Wheelchairs and Related Technologies, Dept. of Phys. Med. and Rehab. Dept. of Rehab. Sci. and Tech., Univ. of Pittsburgh., PA 15261

Reprinted With Permission

RESNA July 17, 2000

ANALYSIS OF VIBRATION AND COMPARISON OF FOUR WHEELCHAIR CUSHIONS DURING MANUAL WHEELCHAIR PROPULSION

Carmen P. DiGiovine B.S., Rory A. Cooper Ph.D., Erik J. Wolf, James Hosfield, and Thomas Corfman, M.S.
Human Eng. Res. Lab., Center of Excellence in Wheelchairs and Related Technologies,
Dept. of Phys. Med. And Rehab. Dept. of Rehab. Sci. and Tech., Univ. of Pgh., Pgh., PA 15261

ABSTRACT

The purpose of this study was to compare four cushions, a Jay Active (JA), and PinDot Comfort-Mate (PDCM), a Roho Low Profile (RLP), and a Varilite Solo (VS), based on their ability to minimize the vibrations transmitted from the wheelchair to the individual during manual wheelchair propulsion (MWP). Accelerometers measured the vibrations at the wheelchair/cushion interface and at the individual's head as the individual traversed an obstacle course. The VS performed the best, followed by the PDCM, the RLP and finally the JA, suggesting that a combination of foam and air minimizes the transmission of vibration. Cushions designed for static pressure relief may not perform well in other areas potentially related to secondary injuries such as vibration.

INTRODUCTION

Typically, cushions are prescribed by clinicians based on the cushion's pressure distribution Properties, especially under the ischial tuberosities and the sacrum. Active individuals may need a firm cushion (e.g. foam based rather than air based) in order to perform independent transfers, or a light cushion in order to minimize the weight of the wheelchair/seating system.

The ability of the cushion to minimize impact (shock) and cyclic (repetitive) vibrations an individual experiences is typically not considered. Whole-body vibration experienced during manual wheelchair propulsion (MWP) can decrease an individual's comfort and increase the rate of fatigue [1]. Exposure to whole-body vibration has been shown to exceed the comfort and fatigue thresholds during MWP [2, 3]. This may adversely affect the physical performance of the individual. It may lead to social inactivity since the individual becomes fatigued faster. Finally, it may lead to poor body mechanics during MWP, transfers, or other activities of daily living, consequently increasing the individual's susceptibility to developing a secondary injury.

The purpose of this study was to compare four cushions, a Jay Active (JA), a PinDot Comfort-Mate (PDCM), a Roho Low Profile (RLP), and a Varilite Solo (VS), based on their ability to minimize vibration transmission from the wheelchair to the individual during MWP. Determining the cushion that minimizes vibrations provides clinicians additional information when recommending the most appropriate cushion. This is especially relevant in today's healthcare environment where letters of medical necessity are required by the majority of funding agencies.

METHODS

A triaxial accelerometer (Analog Devices ADXL05, ±4g) was mounted on a seat-plate which rested on the wheelchair's seat tubes (rails). The cushion was then affixed on top of the seat-plate. The accelerometer was positioned midway between the ischial tuberosities, directly below the sacrum. A second triaxial accelerometer was mounted on a bite-bar. The bite-bar was held between the individual's teeth, with a mouth guard to protect his/her teeth. This accelerometer measured the vibration experienced by the individual at his/her head. The acceleration signals were sampled at 200 Hz via a battery powered custom-designed data acquisition system [4].

A total of 10 unimpaired individuals propelled an instrumented wheelchair (Invacare XTR) while negotiating nine obstacles 48 times (four cushions by four back supports by three trials). Only the cushions were examined in this study, rather than the back supports or complete seating systems. The nine obstacles consisted of a unidirectional (a.k.a. rumble) strip, a ramp (1:25 slope), a curb drop (5 cm), a simulated door threshold, three sinusoidal bumps of varying height, a strip of truncated domes (a.k.a. dimple strip), and carpet.

The seat-plate and bite-bar accelerations were compared using the following equations:

$$RR = \frac{max\ (BB) - min\ (BB)}{max\ (SP) - min\ (SP)} \qquad (1)$$

$$RMSR = \frac{RMS\ (BB)}{RMS\ (SP)} \qquad (2)$$

where max (BB) and max(SP) are the maximum vertical accelerations recorded at the bite-bar and seat-plate, respectively, min(BB) and min(SP) are the minimum vertical accelerations recorded at the bite-bar and seat-plate, respectively, RR is the range ratio comparing the range of bite-bar vertical accelerations to the range of seat-plate vertical accelerations, and RMSR is the root-mean-squared (RMS) ration comparing the RMS of the bite-bar vertical accelerations to the RMS of the seat-plate accelerations. The RR describes the cushion/human system's (CHS) ability to minimize peak vibrations, which are primarily due to impact vibrations (e.g. traversing the curb drop). The RMSR describes the CHS's ability to minimize the cyclic vibrations (e.g. traversing the unidirectional strip or repetitive motions of MWP). For both ratios, a value below one indicates the CHS reduces the vibrations, whereas, a value above one indicates the CHS amplifies the vibrations.

The cushions were compared for significant differences using a mixed-model ANOVA with a Bonferroni post-hoc test ($p<0.05$). The mean RR and RMSR values for each cushion were determined by averaging these values across the backs and trials. The RR and RMSR means were used as data points in the statistical analysis. The mixed-model ANOVA was implemented in order to account for the fact that the data for each cushion was obtained from the same group of individuals. A single-factor ANOVA could not be implemented because the data violates the assumption that the groups of individuals were independent.

RESULTS

The mean plus/minus the standard deviation of RR and RMSR across ten participants are listed in Table I. The cushion with the lowest (i.e. best) ratios was the VS, followed by the PDCM, the RLP, and finally, the JA. The RR and RMSR of the VS were significantly different than the other three cushions ($p<0.05$). The RR of the PDCM was significantly different from the JA ($p<0.05$). The CHS reduced the range of peak accelerations (RR<1) and amplified the RMS accelerations (RMSR>1).

Table I. Mean ± Standard Deviation (n=10) of the Range Ratio (RR) and the RMS Ratio (RMSR) for the four cushions. The letters A, B, C, or D indicate a significant difference at the p<0.05 level.

Cushions	Range Ration (RR)	RMS Ratio (RMSR)
A. Varilite Solo (VS)	0.4l±0.088: B, C, D	1.32±0.16: B, C, D
B. PinDot Comfort-Mate (PDCM)	0.48±0.095: A, D	1.39±0.16: A
C. Roho Low Profile (RLP)	0.48±0.094: A	1.41±0.19: A
D. Jay Active (JA)	0.52±0.10: A, B	1.43±0.18: A

DISCUSSION

The RR and RMSR for the VS is significantly less than the other three cushions used in this study (Table I). The VS is composed of a foam base below an adjustable air pocket. This combination minimized the transmission of impact vibrations (i.e. due to shock), as described by the RR, and cyclic vibrations (i.e. due to repetitive motions), as described by the RMSR. The PDCM (foam only) and RLP (air only), had similar results, but were in contrast to the results of the VS (foam and air), suggesting that vibrations are minimized by the interaction of the air and foam, rather than one or the other.

The results obtained by the JA cushion, which generated the largest (i.e. worst) RMSR and RR values, can be explained by the material properties of the cushion. This cushion consists of a contoured foam base below a gel layer. Gel has inadequate reactive properties, that is, it feels like a solid object when the individual encounters impact vibrations. This is because it is designed to provide pressure relief in static or pseudo-static situations, rather than to absorb vibrations. Since the gel is extremely stiff during impact and cyclic vibrations, the foam base is the only component which has the ability to minimize the vibrations transferred to the individual, likely producing poor results relative to the other cushions.

Currently, the main focus of cushion design is on appropriate pressure distribution, especially under the ischial tuberosities and the sacrum. The JA and RLP are typically used by clinicians for individuals who are at a greater risk of developing pressure sores. However, the RLP and JA may not be the ideal cushions for active users, especially in minimizing vibration. As described in the introduction the amount of vibration an individual experiences will directly affect the individual's comfort and rate of fatigue. This could compromise the individual's ability to actively participate in the community and independently perform activities of daily living.

The RMSR and RR are accurate metrics to determine a cushions ability to minimize the vibration transmitted to the individual. Both parameters were consistent in rating the cushions, and in discriminating that the VS was significantly better than the other three cushions (Table I). The RR indicated that all the CHSs were able to reduce the range of vibrations experienced by the individual (RR<l). Upon initial examination of the RMSR it appeared that the CHS increased vibration transmission (RMSR>l). This is due to the fact that the vibrations experienced during MWP were in the same frequency range as the natural frequencies of the human body [6]. Therefore it is appropriate to suggest that the RMSR parameter was greater than one due to the properties of the human body rather than the cushion. Since the individuals remained constant across groups, and differences in the RMSR were a direct result of the different cushions used in this study.

Future investigations will examine the RMSR and RR parameters on an obstacle by obstacle basis, will compare back supports and seating systems rather than just cushions, will examine parameters in the frequency domain rather than the time domain, and will include individuals who use a manual wheelchair as their primary form of mobility.

REFERENCES

l. ______, (1985). Evaluation of Human Exposure to Whole-Body Vibration – Part l: General Requirements, ISO 2631/1,Washington DC: ANSI Press.
2. DiGiovine CP & Cooper RA, (1999). Analysis of Whole-body Vibration during Manual Wheelchair Propulsion using ISO Standard 2631. Proceedings of the 22nd Annual RESNA Conference, Long Beach, CA, 242-244.
3. Tai C, Liu D, Cooper RA, DiGiovine MM, & Boninger ML, (1998). Analysis of Vibrations during Manual Wheelchair Use. Saudi J Disabil Rehabil, 4, 186-191.
4. VanSickle DP, Cooper RA, & Gonzalez J, (1997). Smart Accelerometer: A Device to Measure Three-Axis Acceleration for the Purpose of Evaluating wheelchair Ride Comfort, Proceedings of the 20th Annual RESNA Conference, Pittsburgh, PA, 245-247.
5. ________, SAS, ver. 7, SAS Institute, Inc., 1990.
6. DiGiovine CP, Cooper RA, & Boninger ML, (1999). Comparison of Absorbed Power to Vertical Acceleration when Measuring Whole-body Vibration during Wheelchair Propulsion. Proceedings of the 21st Annual International Conference of the IEEE-EMGS, Atlanta, GA, 610.

ACKNOWLEDGEMENTS
This project was supported through a grant from the U.S. Dept. of Veterans Affairs (B805-RA).

ADDRESS
Carmen P. DiGiovine
7180 Highland Drive, 151R-1, Building 4, Room 058E
Pittsburgh, PA 15206
cpdst11@pitt.edu