

Dynamic Response of Wheelchair Cushions to the ISO Impact Damping Test

B.M. Chung

Rehabilitation Engineering Research Center on Wheeled Mobility, Georgia Institute of Technology, Atlanta, GA, U.S.A.

Abstract— The International Organization for Standardization defines tests that characterize the properties of wheelchair cushions (ISO 16840-2). The impact damping test (IDT) characterizes cushions' abilities to reduce impact loading on tissues and to help maintain postural stability. The ISO test reports the number of rebounds greater than 10% of the peak impact acceleration and the ratio of the second to first rebound acceleration in order to determine the damping properties. We performed IDTs on three different wheelchair cushions: 3" elastic foam (EF), 3" viscoelastic foam (VEF), and a 3" laminar cushion (LC); a viscous fluid bladder on the top of an elastic foam. The LC had two rebounds greater than 10 % of the peak acceleration while the EF and VEF had one. The LC had highest ratio (0.48) followed by the EF (0.29) and the VEF (0.25). According to ISO, these results indicate that EF and VEF dampen impacts quicker than LC and have superior abilities to help maintain postural stability. Based upon this analysis, three critical issues about the ISO IDT have been identified. The first is the ISO should incorporate impact magnitude in the analysis, since impact loading on tissues is a stated purpose. The second is the ISO should use impact instead of rebound accelerations. Results show that nonlinear responses are evident in rebounds in all three cushions. The third issue is that oscillation from impact is not a simple second order damped harmonic. Analysis showed that three to five natural frequencies are embedded in the damped harmonic oscillation, so simple ratios of accelerations do not represent the damping properties of cushions. In conclusion, the ISO IDT should utilize impact accelerations and employ more complex analysis to better characterize the damping properties of wheelchair cushions.

Keywords— Cushions, Dynamic Response, Impact Damping Test.

I. INTRODUCTION

Pressure ulcer is skin break down due prolonged unrelieved pressure, shear, tissue deformation, and friction. The annual cost of treating pressure ulcer is approximately 5 to 8.5 billion dollars in U.S. [1] Extensive research has been conducted to understand the role of mechanical loading in the development of pressure ulcer over several decades [2-3]. Different types of wheelchair cushions have been developed to reduce the aforementioned four factors causing pressure ulcer. The International Organization for Standardization (ISO) defines sets of tests that characterize the physical and mechanical properties of wheelchair cushions

(ISO 16840-2) [4]. The impact damping test (IDT) characterizes the ability of a wheelchair cushion to reduce impact loading on tissues and to help maintain postural stability. Although the ISO IDT has been defined, thus far, there is no body of work that investigates the impact damping characteristics of wheelchair cushions using the ISO IDT. In this study, three different types of cushions are evaluated using the ISO IDT and the results are reported. In addition, some concerns about the ISO IDT are also discussed.

II. METHODOLOGY

A. Instrumentations

Test Rig

The IDT rig was built according to the ISO. The schematic diagram of the IDT rig is shown in Figure 1.

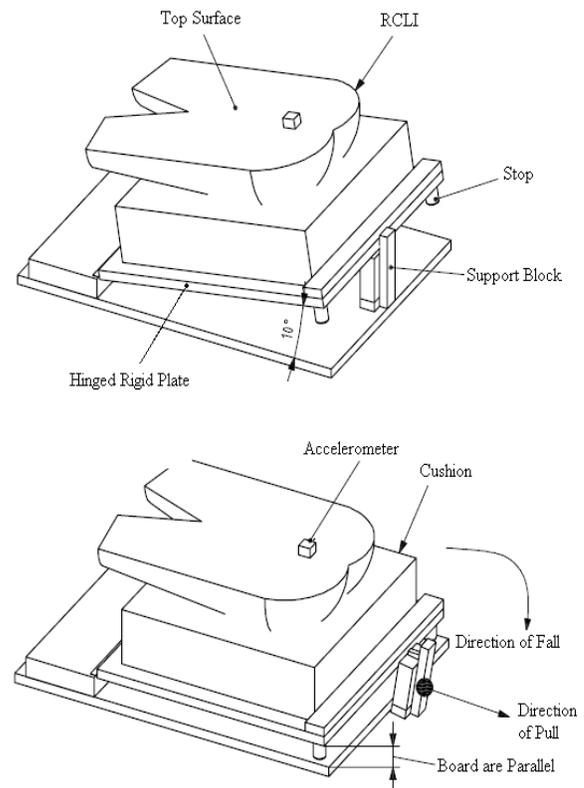


Fig. 1 Schematic diagram of the test rig

It consists of a rigid cushion loading indenter (RCLI); a modified version of the buttock shape indenter designed by Staarink (1995), a hinged rigid plate, a support block, and an accelerometer (MMA7260Q, Freescale Semiconductor, Inc.). The RCLI was also fabricated based on the dimensions provided by the ISO. The hinged rigid plate (500 mm by 500 mm by 15 mm) is fabricated with plywood. The supporting block is constructed with plywood to establish the angle of 10° between the horizontal testing surface and the rigid plate. Two 25 mm diameter hard rubber cylindrical stops are placed with their centers at the corners of the hinged rigid plate, 25 mm from the adjacent edges. The accelerometer was fixed to the center of an aluminum bar that is attached to the RCLI. The aluminum bar is attached such that accelerometer is located at approximately 130 mm forward of the rear edge of the RCLI.

In addition, three stops were incorporated in the set up, as shown in Figure 2, to enforce the consistent placement of the RCLI in every test.

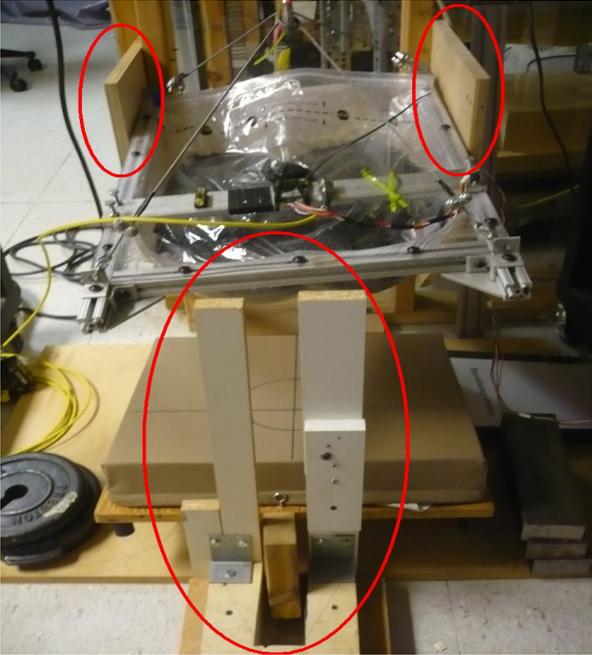


Fig. 2 Impact damping test rig with three stops

Wheelchair Cushions

Three different commercially available wheelchair cushions were evaluated in this study. These cushions were made with different materials: 3" elastic foam (EF), 3" viscoelastic foam (VEF), and a 3" laminar cushion (LC); a viscous fluid bladder on top of an elastic foam.

B. Experimental Protocols

Precondition

According to ISO IDT protocol, cushions were kept in the test environment for more than 12 hours. The ambient temperature and relative humidity of the testing environment was 24.1 °C and 50 %, respectively. Each cushion was loaded with 830N for 3 minutes and unloaded for 2 minutes. Then, it was reloaded for another 3 minutes and unloaded for 5 minutes.

Impact Damping Test

First, the hinged rigid plate was set at a 10° angle by placing the support block. Then, the cushion was placed on top of the hinged rigid plate, and the RCLI (500 N) was placed on the cushion such that its ischial tuberosities are positioned at the location approximately 140 mm forward from the rear edge of the cushion. Finally, the support block was released, and the acceleration was recorded at 200 Hz. After the IDT, the cushion was unloaded for 5 minutes. Total of 19 the IDTs for each cushion have been performed by 2 operators over 2 days.

C. Data Analysis

A Matlab script was created to filter the raw data and to determine the four values used in the ISO IDT analysis. The Matlab script employed a butterworth filter. A butterworth filter was set as a low pass filter. The order and the cutoff frequency were set to 3rd and 50 rad/sec (7.96 Hz), respectively. Using the filtered data, the Matlab script determined the mean number of rebounds greater than 10% of the peak impact acceleration, the mean of peak rebound acceleration, a_a , the mean of the second highest rebound acceleration, a_2 , and the mean of ratio of a_2 to a_a . In addition, the initial impact, the 2nd impact, the 3rd impact, and the impact ratio of 3rd to 2nd were also obtained.

Additional Matlab script was created for the curve fit analysis. The filtered data was fit to the solution of an under damped case of a simple harmonic oscillation using a least square curve fit. The under damped case of a simple harmonic oscillation is shown in Equation 1.

$$x(t) = x(0) \cdot e^{-\zeta \omega_n t} \left(\frac{\zeta}{\sqrt{1-\zeta^2}} \sin(\omega_n \sqrt{1-\zeta^2} \cdot t) + \cos(\omega_n \sqrt{1-\zeta^2} \cdot t) \right) \quad (1)$$

where ζ is a damping ratio, ω_n is a natural frequency, and $x(0)$ is a peak impact acceleration.

III. RESULTS

Table 1 shows the four criteria that ISO uses to characterize the impact damping. Based on the ISO, these results indicate that EF and VEF dampen impacts quicker than LC and have superior abilities to help maintain postural stability. In addition, results indicate that EF reduces impact loading efficiently than VEF and LC since it has the least mean number of rebounds greater than 10% of the peak impact acceleration.

	# Reb	1st Reb (m/s ²)	2nd Reb (m/s ²)	Reb Ratio
EF	1.00 ± 0.00	4.88 ± 0.29	1.41 ± 0.49	0.29 ± 0.10
VEF	1.16 ± 0.37	13.82 ± 2.92	3.19 ± 0.50	0.25 ± 0.13
LC	2.00 ± 0.33	7.30 ± 0.59	3.49 ± 0.44	0.48 ± 0.06

Table 1 Results of the ISO IDT of three cushions

Table 2 shows the initial impact, the 2nd impact, the 3rd impact, and the impact ratio of 3rd to 2nd of three cushions. EF and LC has the lower initial impact compared to VEF. VEF has the lowest impact ratio of 3rd to 2nd. These results indicate that EF and LC have the superior ability to reduce the impact load compared to VEF, while VEF has the best ability to help maintain postural stability.

	Initial Impact (m/s ²)	2nd Imp (m/s ²)	3rd Imp (m/s ²)	Imp Ratio
EF	-24.03 ± 0.90	-3.53 ± 0.48	-0.92 ± 0.46	0.26 ± 0.13
VEF	-37.96 ± 2.00	-7.69 ± 1.32	-1.16 ± 0.28	0.15 ± 0.04
LC	-25.11 ± 2.94	-5.77 ± 0.71	-2.10 ± 0.42	0.37 ± 0.07

Table 2 Impact side results of the ISO IDT

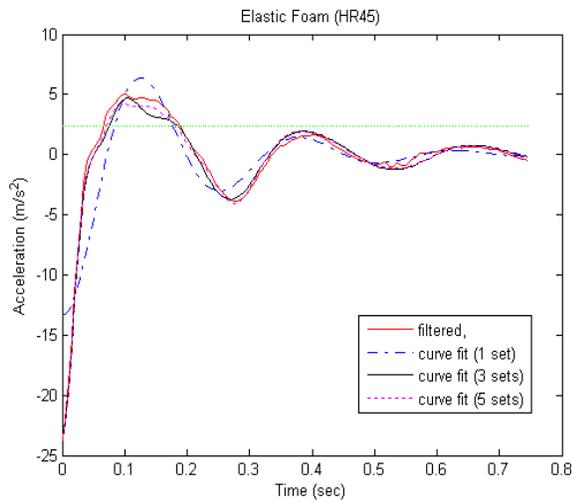


Figure 3: Result of the frequency analysis

Figure 3 shows the curve fit result of elastic foam. When 1 set of frequency, amplitude, and damping ratio was used to fit the data, it did not fit well. However, when 3 or more sets of frequency, amplitude, and damping ratio were used in a fit, the data and curve fit matched well. This shows that the oscillation resulted from the IDT is not a simple damped harmonic oscillation.

IV. DISCUSSION

Among the four criteria that ISO IDT considers in the analysis, we looked at the mean number of rebounds greater than 10% of the peak impact acceleration and the ratio of a_2 to a_a to evaluate the cushion's ability to reduce the impact loading and to help maintain postural stability. Although the mean number of rebounds greater than 10% of the peak impact acceleration represents the cushion's ability to reduce the impact loading, simply employing the actual initial impact value in the analysis will facilitate characterizing the cushion's response to an impact loading.

As shown in Figure 3, the oscillation obtained from the ISO IDT is not a simple damped harmonic oscillation. The nonlinear material that a cushion is made of is a factor that could cause the nonlinear behavior of the oscillation. In addition, the change in the contact area is also a factor that causes the nonlinear behavior. Figure 4 shows the expected change in the contact area during the rebound. As the RCLI rebounds, the contact area is expected to continuously decrease. This nonlinear decrease in the contact area is expected to be the major reason for the nonlinear characteristics shown at the rebounds. Therefore, the ISO should consider the impact side information in the analysis instead of the rebound side information.

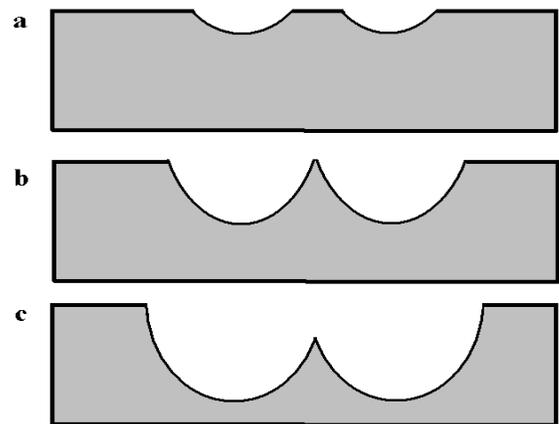


Figure 4: Expected contact area during the rebound; a) at the rebound, b) a midpoint between the rebound and the impact, c) at the impact

Lastly, the ISO should incorporate more rigorous analysis than a ratio of two rebounds to estimate the damping characteristics of the cushion since the result is not a simple damped harmonic oscillation as shown in Figure 3.

V. CONCLUSIONS

The ISO IDTs of three cushions were performed. Based on the ISO IDT analysis, 3" elastic foam and 3" viscoelastic foam had the superior ability to help maintain postural stability. Results also show that 3" elastic foam had the best ability to reduce the impact loading. In addition, it was suggested that the ISO IDT should incorporate the initial impact value in the analysis, use the impact side information instead of the rebound side information, and employ more complex analysis to better characterize the damping properties of wheelchair cushions.

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