



University of
Pittsburgh

Department of Rehabilitation
Science and Technology
School of Health and Rehabilitation Sciences

CHARACTERIZATION OF WOVEN AIR CUSHIONS

Rolapal Testing – R2024-01

August 2024

OVERVIEW

Background

Seat cushions provide a critical interface between the wheelchair and user and have an impact on positioning and tissue integrity. Published technical standards for wheelchair seat cushions provide standardized terminology and methods for characterizing product performance.

Multiple ISO 16840 seating standards have been published. These voluntary standards provide cushion performance information that can be used by manufacturers to assess and benchmark their products, by consumers and clinicians to compare and select products, and by regulators, purchasers and third-party payers in regulatory and purchasing policies.

Methodology

ISO Standards

The following ISO standards should be referenced for more information on the procedures described in this test report:

- **ISO 16840-2:** *Determination of physical and mechanical characteristics of seat cushions intended to manage tissue integrity*
- **ISO 16840-6:** *Simulated use and determination of the changes in properties of seat cushions*
- **ISO 16840-12:** *Apparatus and method for cushion envelopment testing*
- **ISO 16840-13:** *Determination of the lateral stability property of a seat cushion*

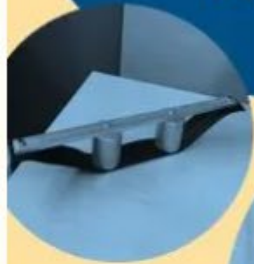
Procedural overview

The cushions underwent the following characterization tests:

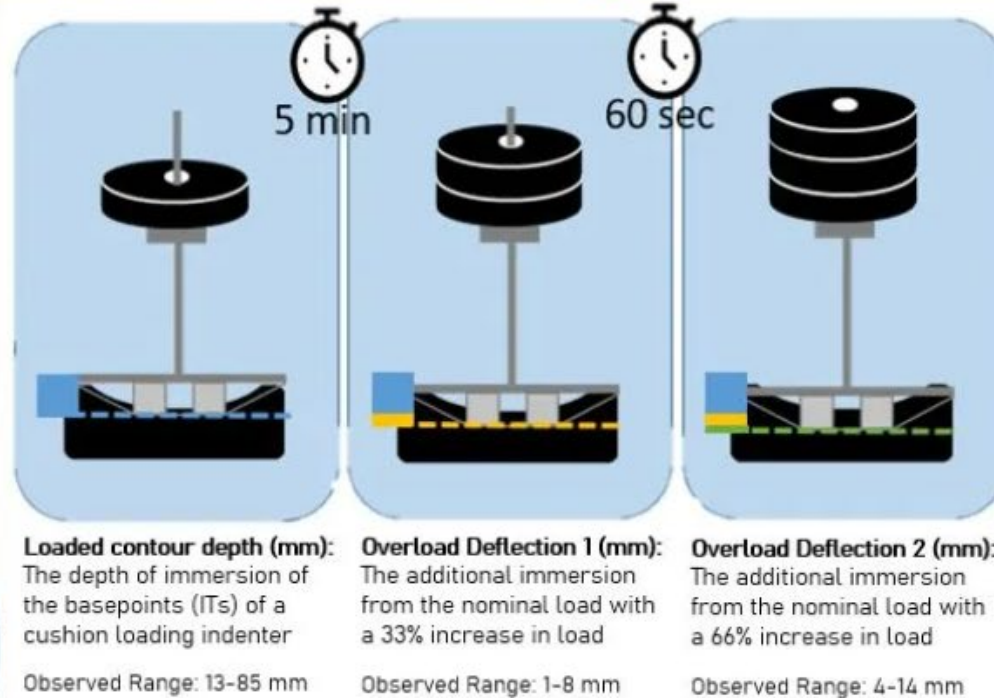
- **Loaded Contour Depth and Overload Deflection (ISO 16840-2:2018 Clause 11)**, a test to evaluate a cushion's ability to immerse the buttocks;
- **Lateral Stability (ISO 16840-13:2021)**, a test to evaluate a cushion's ability to resist moments at the pelvis;
- **Pressure Mapping (ISO 16840-6:2015 Clause 14)**, a test that utilizes interface pressure measurements to assess the magnitude and distribution of pressure on a loaded cushion before and after aging (relative changes).
- **Envelopment (ISO 16840-12:2021)**, a test that characterizes a cushion's ability to envelop and immerse the buttocks;

Loaded Contour Depth

This test measures the ability of a cushion to maintain tissue integrity by its ability to immerse and envelop the buttocks.



Metrics & Result Ranges*



*Result Ranges declared herein were measured in testing to date and are not a defined range that results must fall within

Guidance

Immersion: The depth a person sinks into the cushion.

A higher **Loaded contour depth** indicates more immersion into the cushion and distribution of pressure on the soft tissue.

Cushions with higher additional immersion under the **overload** conditions have higher margins of safety against bottoming out.



Loaded Contour Depth and Overload Deflection

Test Overview and Methodology

Loaded contour depth and overload deflection is a test that measures the ability of a cushion to immerse the buttocks. Immersion is defined as the depth to which a person sinks into the cushion. A higher Loaded Contour Depth may indicate more immersion into the cushion and greater distribution of pressure on the soft tissue. Cushions with higher additional immersion under the overload conditions have higher margins of safety against bottoming out. Figure 1 shows a visualization of the Loaded Contour Depth procedures from ISO 16840-2:2018, Clause 11 that were followed.

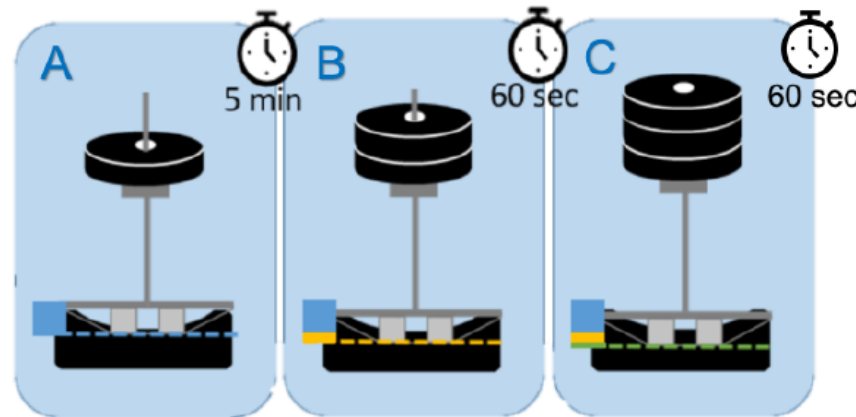


Figure 1. A: A nominal load of 140N is applied to the cushion for 300 seconds then immersion is measured as Loaded Contour Depth (mm); B: An overload 33% greater than the nominal load is applied to the cushion for 60 seconds and additional immersion is measured as Overload Deflection 1 (mm); C: An additional overload 66% greater than the nominal load is applied to the cushion for 60 seconds and additional immersion is measured as Overload Deflection 2 (mm).

There are three key outcomes of this test: Loaded Contour Depth, Overload Deflection 1 and Overload Deflection 2. Loaded Contour Depth is the depth of immersion of the basepoints (ITs) of a cushion loading indenter (includes pre-contouring and loaded contouring). Overload Deflection 1 is the additional immersion beyond the Loaded contour depth with a 33% increase in load from the nominal load. Overload Deflection 2 is the additional immersion beyond the Loaded contour depth with a 66% increase in load from the nominal load.



Loaded Contour Depth and Overload Deflection

Results

Loaded Contour Depth test results are provided in Table 2 and Figures 2-5.

Table 2. Loaded contour depth and overload deflection results

	Loaded Contour Depth (mm)	Overload Deflection 1 (mm)	Overload Deflection 2 (mm)
Woven Air	70	4.0	7.0
Sprint	64	3.7	7.5
G7	64	5.2	10.5
STX2	90	4.4	9.4

A higher Loaded Contour Depth may indicate more immersion into the cushion and greater distribution of pressure on the soft tissue. Cushions with higher additional immersion under the overload conditions have higher margins of safety against bottoming out.



Loaded Contour Depth and Overload Deflection

Test Descriptive Statistics:

Test	Q1	Median	Mean	Standard Deviation	Q3	Range
Loaded Contour Depth (mm)	39	51	48.3	15.2	57	13-85
33% Overload Deflection (mm)	3	4	4.3	1.5	5	2-8
66% Overload Deflection (mm)	6	8	8.3	2.5	10	4-14

Loaded Contour Depth & Overload Deflections 1 & 2

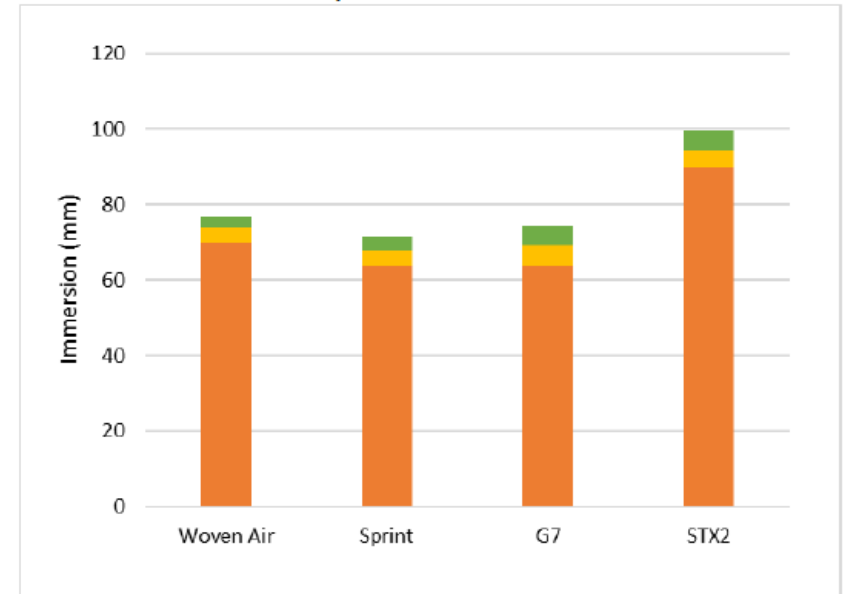
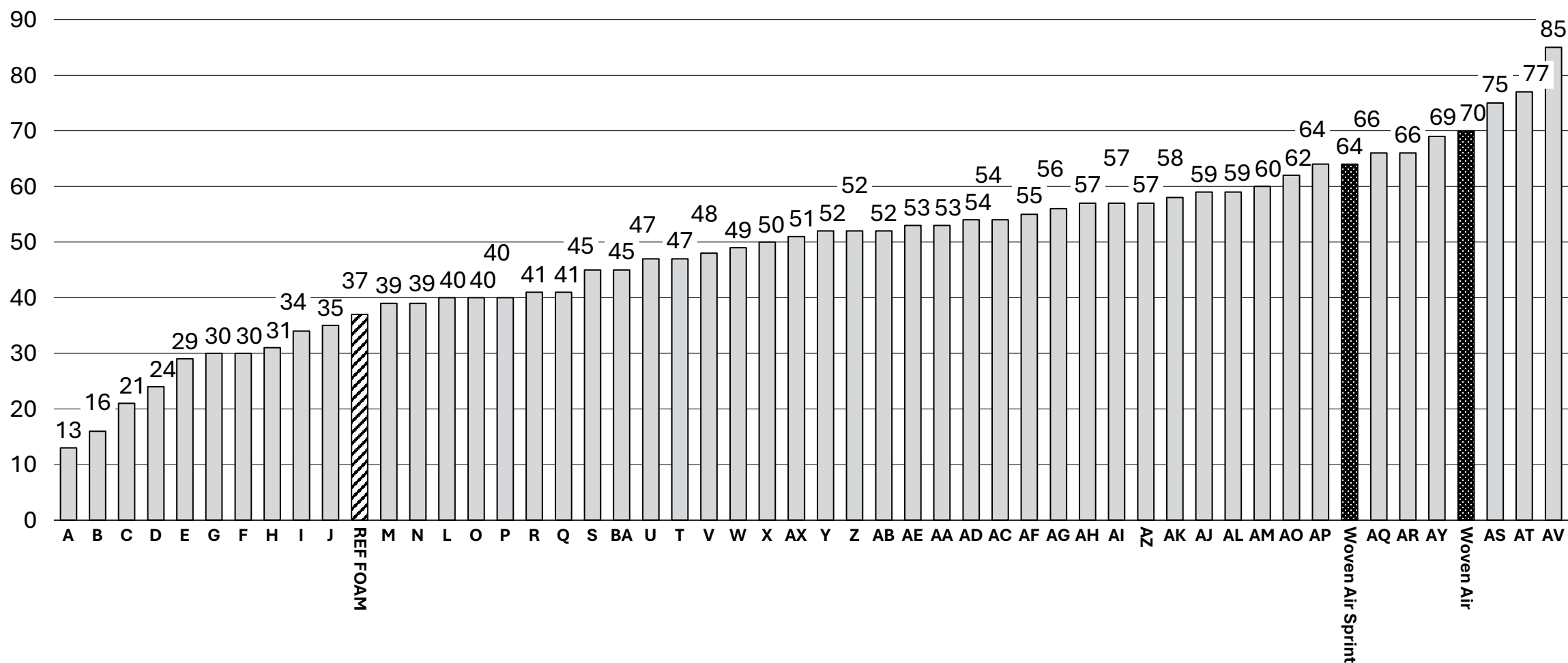


Figure 2. Loaded Contour Depth (orange), Overload Deflection 1 (yellow) and Overload Deflection 2 (yellow + green).



Loaded Contour Depth and Overload Deflection

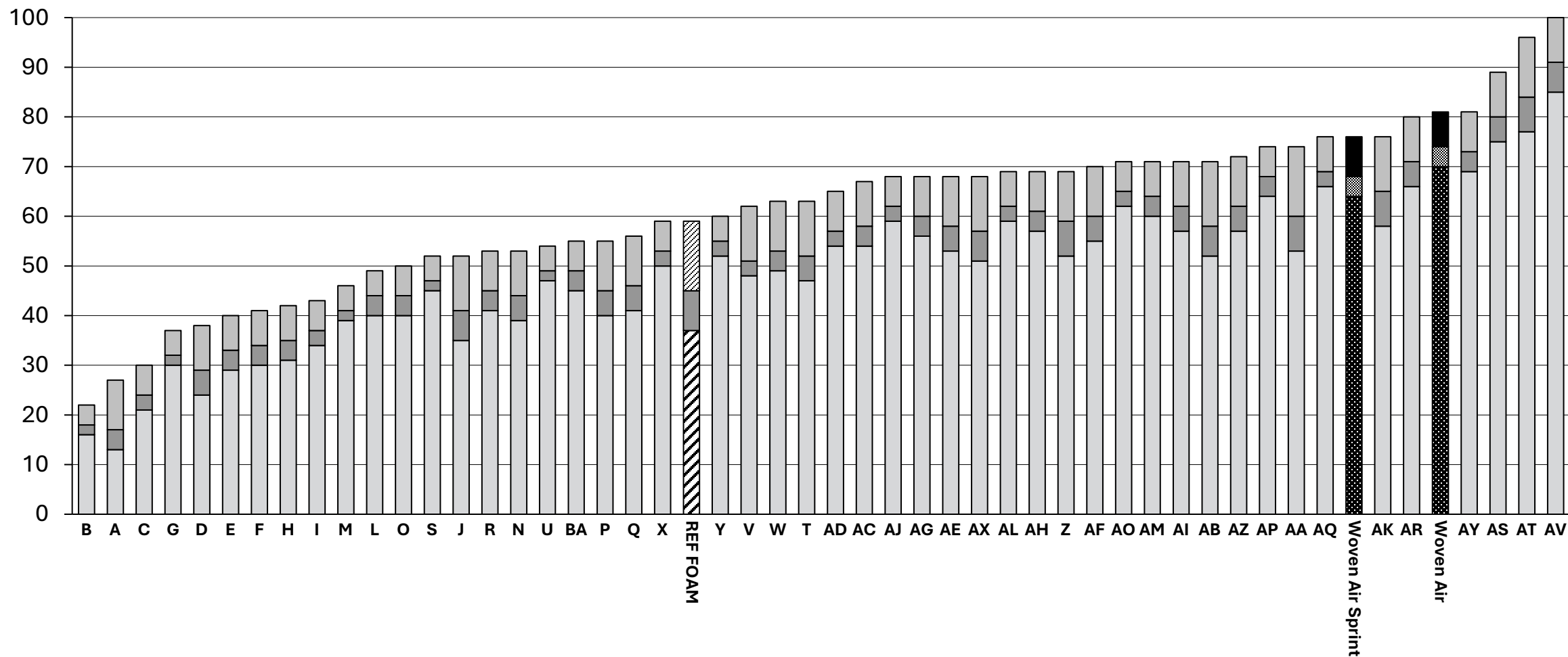
Loaded Contour Depth





Loaded Contour Depth and Overload Deflection

Loaded Contour Depth plus Overload Deflection

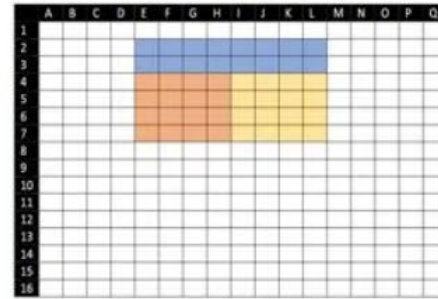
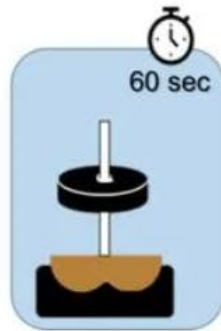


Pressure Mapping

This test's measurements assess the distribution of pressure on a loaded cushion.



Definition of Metrics



NOTE: The left and right sides are defined from the view of the indenter, so the right zone is the right side of the indenter (as defined by when a person is sitting on a cushion) and the left zone is the left side of the indenter.

All metrics are recorded 60 seconds after the cushion is loaded

Contact Area (mm²): The total load bearing area.

Peak Pressure Index (mmHg): The maximum pressure in the right (orange) and left (yellow) base zones.

Dispersion Index (mmHg): The proportion of the total indenter weight supported in the sacral (blue), right (orange) and left (yellow) base zones.

Guidance

High **Contact Area** indicate a large base support.

Low **Peak Pressure Indices** generally indicate higher envelopment of the buttocks.

A low **Dispersion Index** indicates lower concentrations of pressure in areas representative of the sacrum and ischial tuberosities.



Test Overview and Methodology

Pressure Mapping is a test that utilizes interface pressure measurements to assess the magnitude and distribution of pressure on a loaded cushion. This method is not a stand-alone validated or standardized test method and is intended to be used only to compare pressure mapping metrics before and after simulated aging. Figure 6a shows a visualization of the Pressure Mapping test procedures from ISO 16840-6:2015 Clause 14 that were followed. A BT2-3232-200 BodiTrak2 pressure mat that has a 32x32 array and 47cm x 47cm sensing area was used for pressure mapping pressure measurements. Each sensor is 11mm x 11mm with 2mm spacing and saturates at 200 mmHg.

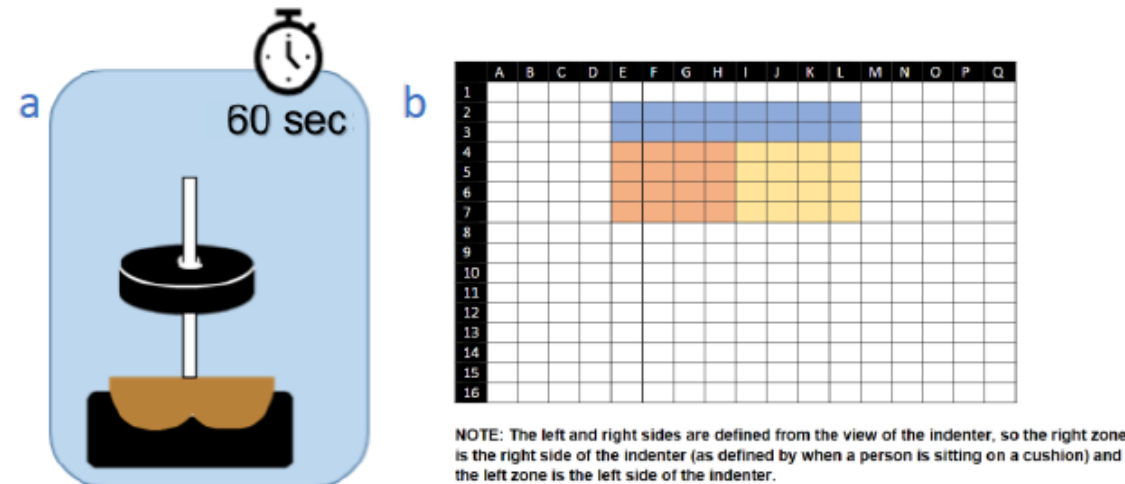


Figure 6. a: The cushion is loaded with a rigid cushion loading indenter and load totaling 500N and pressure map placed at the interface between the cushion and indenter records for 60 seconds. b: Guidance on interpretation of the pressure map and base zones. Representation of a pressure map that shows Right (orange) and Left (yellow) Base Zones as well as Center (blue) zone (a 16x16 map is shown, but a 32x32 array was used for testing).

The standard defines several key outcomes for the interface pressure measurement test including Peak Pressure Index for the right and left base zones, Dispersion index, and Contact area. For more information on these metrics please reference ISO 16840-6:2015 Clause 14. Low Peak Pressure Indices and Dispersion Index are desirable, and high Contact Area is desirable.



Loaded Contour Depth and Overload Deflection



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Wheelchair & Cushion Performance Testing Standards

Using test standards to assess device performance

Test Descriptive Statistics:

Test	Q1	Median	Mean	Standard Deviation	Q3	Range
Contact Area (mm ²)	52346	65924	63532.2	12955.9	71276	34925-92614
Dispersion Index (%)	49	59	56.6	13	63	24-86

	Dispersion Index (%)	Contact Area (mm ²)
Woven Air	43%	86,363
Sprint	41%	78,339
G7	53%	76,819
STX 2	39%	83,323

Dispersion Index

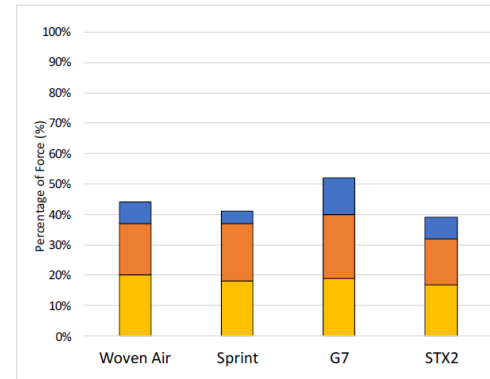


Figure 7. Percentage of force seen on the Left Base Zone (LBZ) (yellow), Right Base Zone (RBZ) (orange) and Rear center zone (CZ) (blue).

Contact Area (mm²)

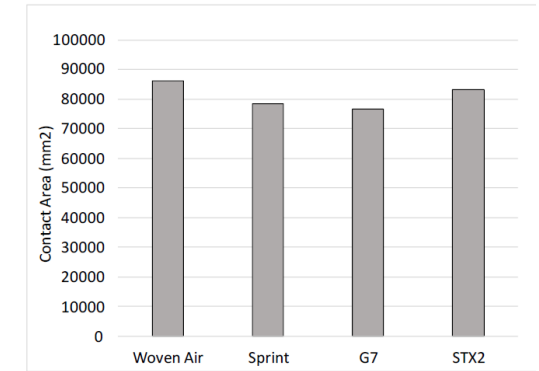
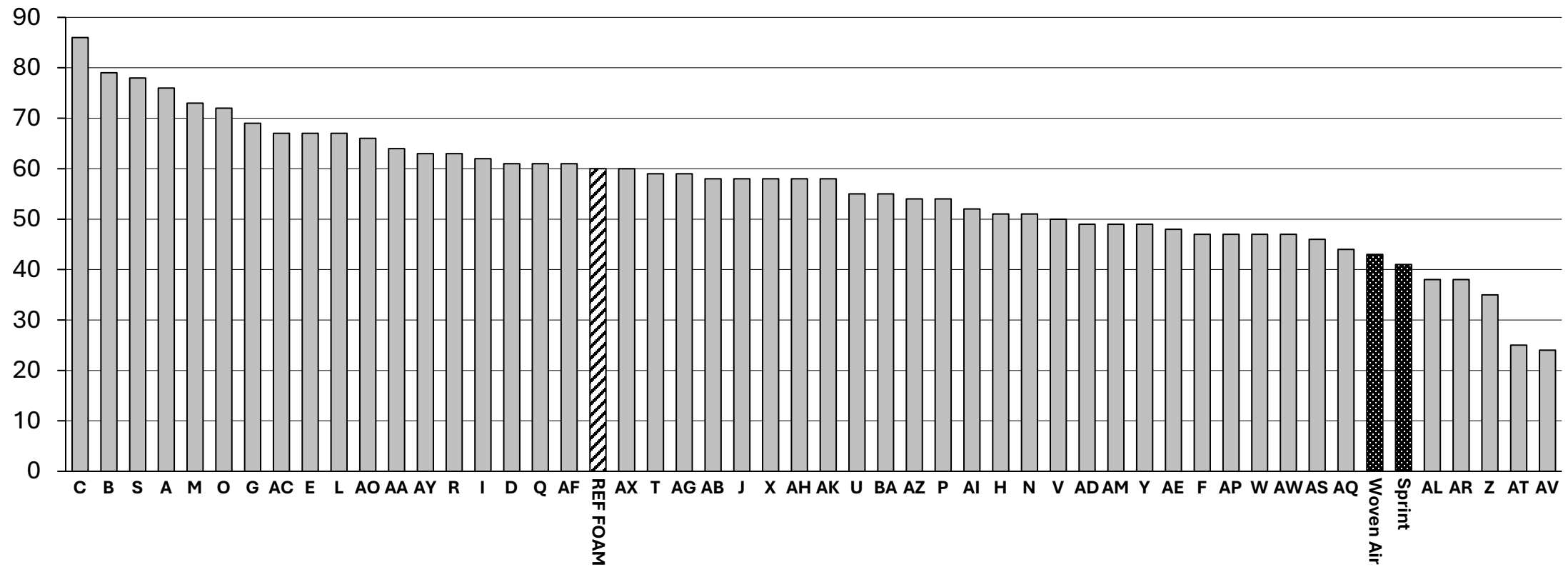


Figure 9. Contact Area



Pressure Mapping

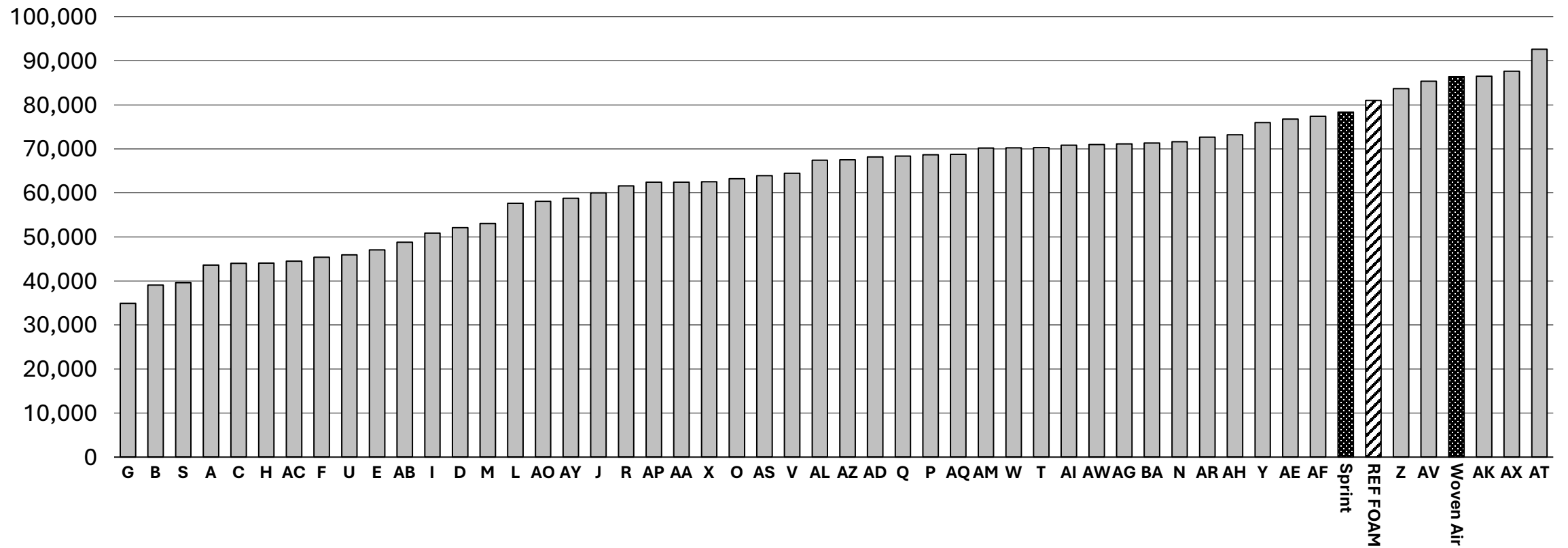
Dispersion Index – lower the better





Pressure Mapping

Contact Area

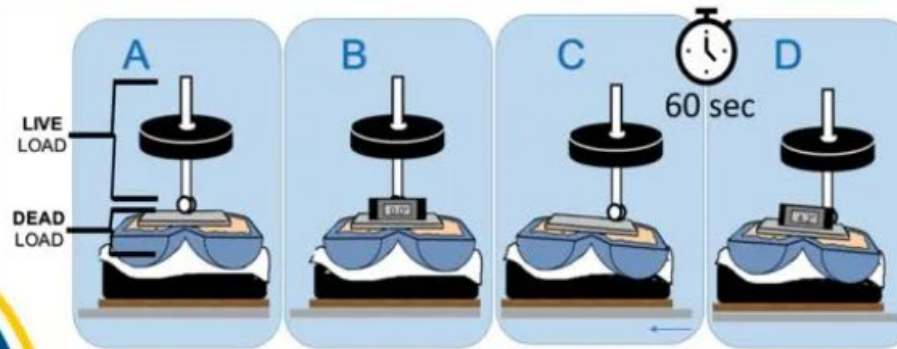


Lateral Stability

This test characterizes the cushion's ability to stabilize a user when leaning to the side.



Definition of Metrics



Average Tilt Angle (°):

The change in orientation of the indenter after a lateral shift in the center of mass, measured at 10s increments for 60s following the shift.

Observed Ranges:

Avg tilt angle at 10s: 2.4°-6.9°

Avg tilt angle at 60s: 2.7°-7.5°

Guidance

A cushion with a lower **Average Tilt Angle** would provide more support for a person when they lean to the side.

A higher **Average Tilt angle** may indicate that more effort would be needed to return to a neutral position.



Lateral Stability

Test Overview and Methodology

The Lateral Stability test evaluates the cushion's ability to resist moments at the pelvis. Moments in the test method are created with an off-center load applied to a standard indenter simulating the buttocks and upper thighs. Resulting indenter tilt angles are measured to characterize the cushion response. The intended use of the method is to differentiate stability performance between cushion models and evaluate the effect of setup configurations and the addition of postural inserts on individual cushions. Figure 14 shows a visualization of the Lateral Stability test procedures in the ISO 16840-13 standard that were followed.

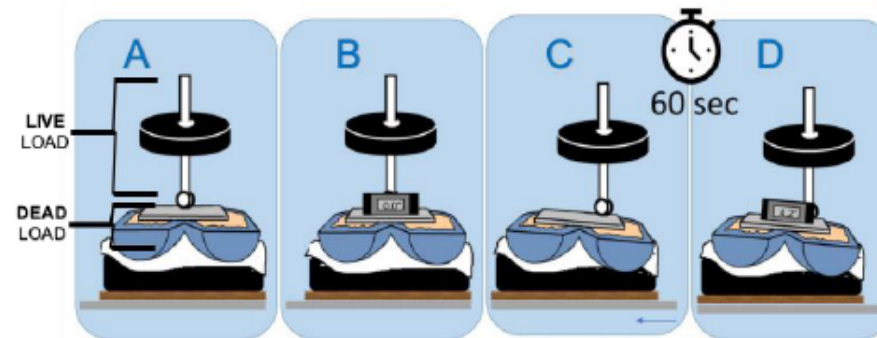


Figure 14. A: The cushion is loaded with a live load (the (60%) portion of the load that translates in the horizontal plane to shift the center of mass relative to the test cushion) and dead load (the (40%) portion of the total load, including the rigid cushion loading indenter, that does not translate in the horizontal plane relative to the test cushion) totaling 500N; B: The indenter is leveled and the initial angle is recorded; C: The dead load is shifted 75 mm laterally to create a tilt condition; D: The tilt angle is recorded every 10 seconds for 60 seconds after the shift is applied.

The main outcome of this test is the change in tilt angle, which indicates the amount of rotation of the indenter allowed by the cushion. Changes in lateral tilt are averaged over five trials and measured every 10 seconds for 60 seconds after a 75 mm lateral weight shift is applied. Anterior-posterior tilt was measured at 0 and 60 seconds.

Investigating interface pressure can supplement the tilt angle data. Procedures for the pressure mapping portion of the lateral stability test can be found in Annex A of ISO 16840-13. A BT2-3232-200 BodiTrak2 pressure mat that has a 32x32 array and 47cm x 47cm sensing area was used for pressure mapping pressure measurements. Each sensor is 11mm x 11mm with 2mm spacing and saturates at 200 mmHg.



Lateral Stability

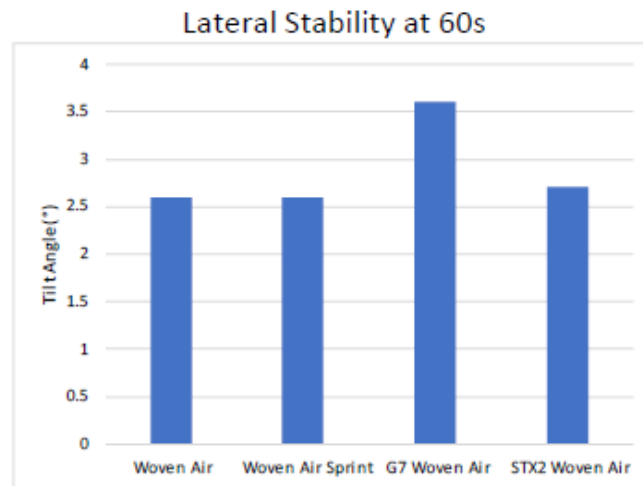


Figure 15. Average tilt angle at 60s.

Table 4. Average lateral tilt (degrees) of five trials at each time point

	Lateral tilt (°) at					
	10s	20s	30s	40s	50s	60s
Woven Air	2.5	2.54	2.58	2.6	2.62	2.62
Sprint	2.46	2.52	2.56	2.56	2.62	2.62
G7	3.24	3.38	3.46	3.48	3.54	3.58
STX2	2.46	2.54	2.58	2.6	2.64	2.66

Test Descriptive Statistics:

Test	Q1	Median	Mean	Standard Deviation	Q3	Range
Stability Tilt Angle @ 10s (°)	3.7	4.3	4.5	1.18	5.5	2.4-6.9
Stability Tilt Angle @ 60s (°)	4.2	4.6	4.9	1.2	5.9	2.7-7.5



Lateral Stability

Tilt Angle– lower the better

