University of Pittsburgh

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

OFFICE CHAIR PERFORMANCE CHARACTERIZATION

June 2022

OVERVIEW

Background

Published technical standards for wheelchair seat cushions provide standardized terminology and methods for characterizing product performance. Ten ISO 16840 seating standards have been published (https://www.iso.org/committee/53792/x/catalogue/). These voluntary standards provide 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. These standards were modified and applied to a cohort of office chairs.[1]

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 16840-13****: Determination of the lateral stability property of a seat cushion*

Procedural overview

The chairs 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;*
    - *Performed with a 40 mm LCI and standard loads*
    - *Performed with a 25mm LCI and CMS/PDAC loads*
- ***Horizontal Stiffness (ISO 16840-2:2018 Annex C),*** *a test to evaluate the cushion's response to slight horizontal movements in the forward direction;*
    - *Performed with a jean RCLI, a shear sensor & 10 mm pull*
- ***Lateral Stability (ISO 16840-13:2021),*** *a test to evaluate a cushion's ability to resist moments at the pelvis;*
    - *Performed with and without a shear sensor*
    - *Performed with a jean covered RCLI*
- ***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).*
    - *Performed with a jean covered RCLI*

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[1] This work was funded by Anthros

- ***10% Force Deflection (ISO 16840-6:2015),*** *a test that evaluates the force deflection of the seat surface*

Office Chair Selection
Office Chairs listed in Table 1 were selected for testing.

Table 1. Samples tested by the University of Pittsburgh

	Manufacturer	**Model & Additional Detail**
1	Secret Lab	Titan 2020, Medium size, Softweave fabric upholstery
2	Maxnomic	Dominator Black, standard
3	Herman Miller	Embody Chair, White/Titanium Frame/Base, Canyon Upholstery, SKU CN122AWAAXT91BB3SY03
4	Herman Miller	Aeron Chair, Graphite/Graphite color, Medium Size, SKU AER1B23DFALPG1G1BB231032109
5	Anthros	Anthros Chair
6	X Chair X3	X3 ATR Mgmt Chair, Blue A.T.R fabric, no headrest
7	Humanscale	Freedom Task Chair, Item code F111GFT10
8	Steelcase	Gesture, 442 Series, Style Number 442A50
9	Steelcase	Leap, 462 Series, Style Number 46267189
10	All33	All33 Backstrong C1, Vegan Leather Upholstery *

***A strap was implemented with the All33 Backstrong chair to prevent swivel during testing. This strap could affect results disclosed herein.**

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. 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 guided immersion testing of the office chairs.

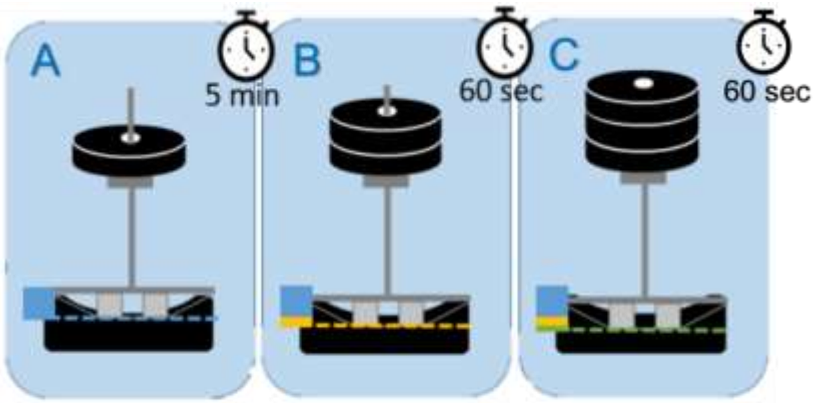

Figure 1. A: A nominal load of 135N is applied to the cushion for 300 seconds; B: An overload 33% greater than the nominal load is applied to the cushion for 60 seconds and additional immersion is measured as Overload Deflection 1 (mm); C: An additional overload 66% greater than the nominal load is applied to the cushion for 60 seconds and additional immersion is measured as Overload Deflection 2 (mm).

Loaded Contour Depth and Overload Deflection methods are used for verification for CMS coding. CMS differs from the ISO Loaded Contour Depth for the General Use cushions, which are tested with a 25-mm cushion loading indenter at a nominal load of 140N and overload of 187N. Skin Protection cushions are tested with the ISO 40-mm cushion loading indenter. According to the requirements set forth by the CMS Wheelchair Seating – Policy Article (A52505), a cushion passes testing if there is contact between the trochanter buttons of the cushion loading indenter and the cushion for all three trials of Loaded Contour Depth testing and exhibits a median Overload Deflection 1 of greater than or equal to 5mm when rounded to the nearest 5mm. A cushion must pass this testing before (pre-) AND after (post-) simulated aging procedures to meet official coding verification requirements.

For office chair testing, each chair was tested according to the ISO test method using a 40-mm indenter and tested using the CMS PDAC test method using a 25-mm indenter. Three key outcomes were assessed: Trochanter contact at the nominal load, Overload Deflection 1 and Overload Deflection 2. Contact was assessed 300 seconds after the application of the nominal load. Overload Deflection 1 is the additional immersion with a 33% increase in load from the nominal load. Overload Deflection 2 is the additional immersion with a 66% increase in load from the nominal load.

Results

Results for the office chair cohort using the ISO test method with the 40-mm cushion loading indenter can be seen in Table 2 and Figures 4-5, 8, 10, 12, 14, 16, 18, 20, 22, 24 & 26. Results for the Anthros cohort using the CMS PDAC test method for General Use cushions with the 25-mm cushion loading indenter are shown in Table 3 and Figures 6-7, 9, 11, 13, 15, 17, 19, 21, 23, 25 & 27.

Table 2. LCD and ODs using ISO test method and 40-mm cushion loading indenter

	CMS PASS/FAIL Contact	Overload Deflection 1 (mm)	CMS PASS/FAIL Overload	Overload Deflection 2 (mm)
Secret Lab Titan	Pass*	2.9	Pass	7.3
Maxnomic Dominator	Fail	3	Pass	5.9
Herman Miller Embody	Pass	4.8	Pass	8.2
Herman Miller Aeron	Pass*	3.2	Pass	6.1
Anthros Chair	Pass	5.8	Pass	13.3
X Chair X3	Pass	4.5	Pass	9.5
Humanscale Freedom	Pass	4.9	Pass	10.8
Steelcase Gesture	Pass	5.5	Pass	10.6
Steelcase Leap	Pass	5.5	Pass	13.2
All33 Backstrong	Fail	5.6	Pass	10.4

*Contact occurred for only a portion of the trochanter button. See figures 14 & 20 for more detail.

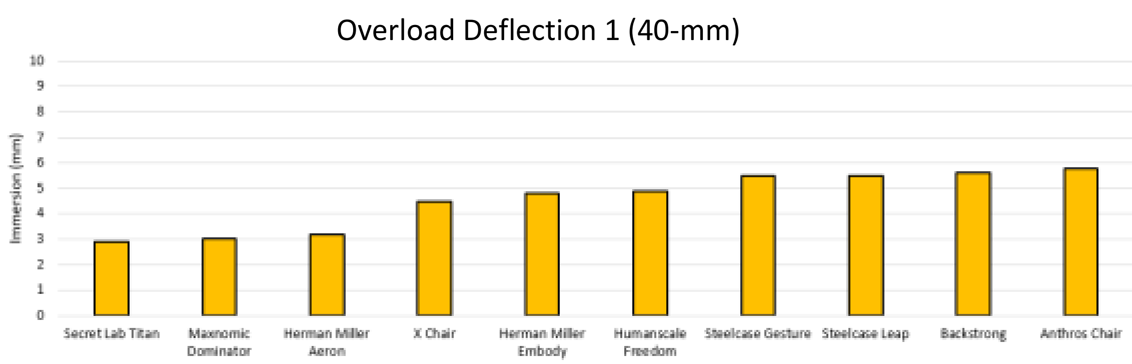

Figure 4. Overload Deflection 1 sorted least to greatest using the 40-mm LCI

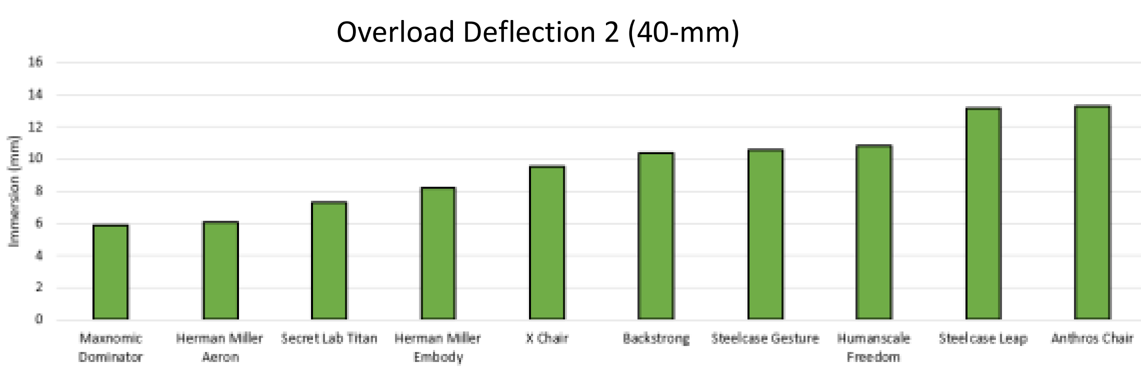

Figure 5. Overload Deflection 2 sorted least to greatest using the 40-mm LCI

Table 3. LCD and OD using CMS PDAC method and 25-mm cushion loading indenter

	CMS PASS/FAIL Contact	Overload Deflection 1 (mm)	CMS PASS/FAIL Overload	Overload Deflection 2 (mm)
Secret Lab Titan	Pass	3.8	Pass	7.1
Maxnomic Dominator	Fail	2.5	Pass	5
Herman Miller Embody	Pass	4.1	Pass	8.2
Herman Miller Aeron	Pass	3.6	Pass	6.1
Anthros Chair	Pass	6.7	Pass	13.5
X Chair X3	Pass	3.8	Pass	8
Humanscale Freedom	Pass	4.9	Pass	10.9
Steelcase Gesture	Pass	5.6	Pass	11.7
Steelcase Leap	Pass	5	Pass	11.1
All33 Backstrong	Fail	4.7	Pass	9.6

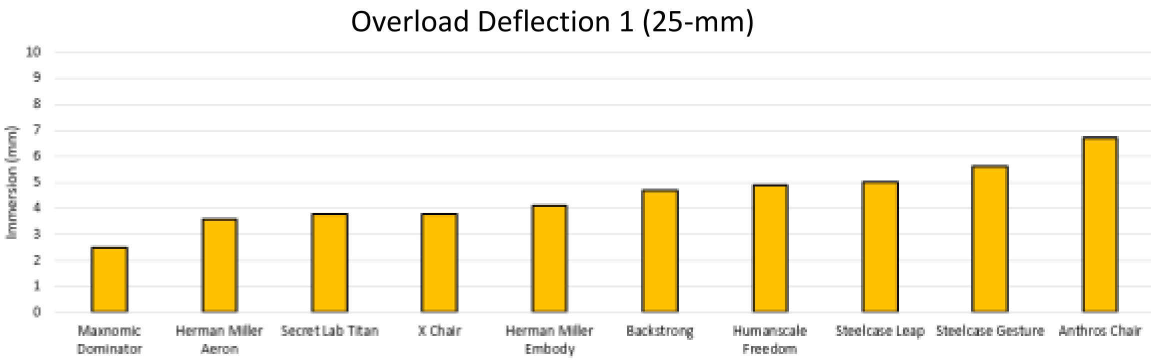

Figure 6. Overload Deflection 1 sorted least to greatest using the 25-mm LCI

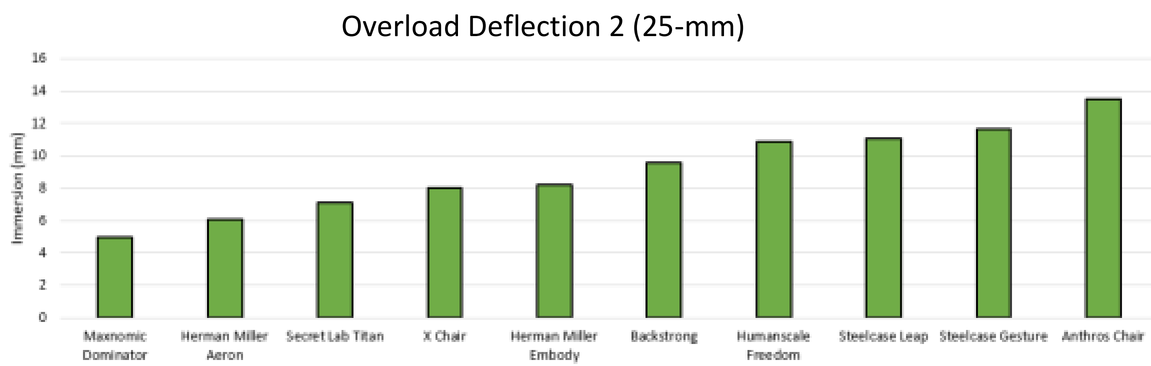

Figure 7. Overload Deflection 2 sorted least to greatest using the 25-mm LCI

Figure 8. Secret Lab Titan with the 40-mm LCI 300 seconds after nominal load was applied

Figure 9. Secret Lab Titan with the 25-mm LCI 300 seconds after nominal load was applied

Figure 10. Maxnomic Dominator with the 40-mm LCI 300 seconds after nominal load was applied

Figure 11. Maxnomic Dominator with the 25-mm LCI 300 seconds after nominal load was applied

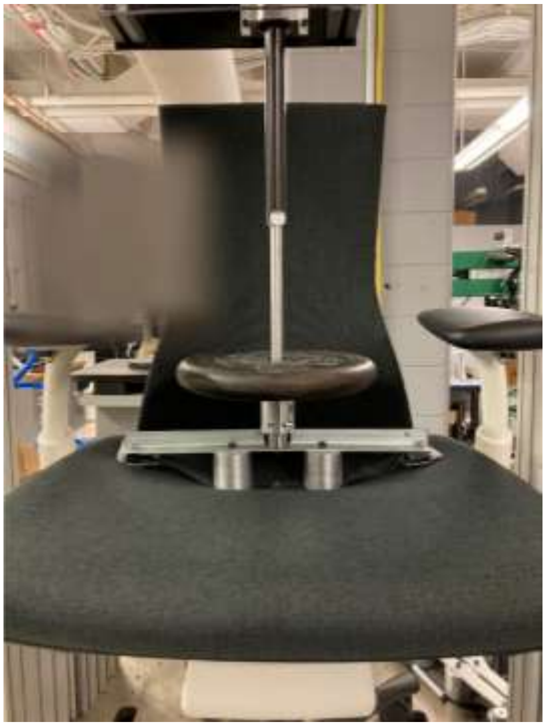

Figure 12. Herman Miller Embody with the 40-mm LCI 300 seconds after nominal load was applied

Figure 13. Herman Miller Embody with the 25-mm LCI 300 seconds after nominal load was applied

Figure 14. Herman Miller Aeron with the 40-mm LCI 300 seconds after nominal load was applied

Figure 15. Herman Miller Aeron with the 25-mm LCI 300 seconds after nominal load was applied

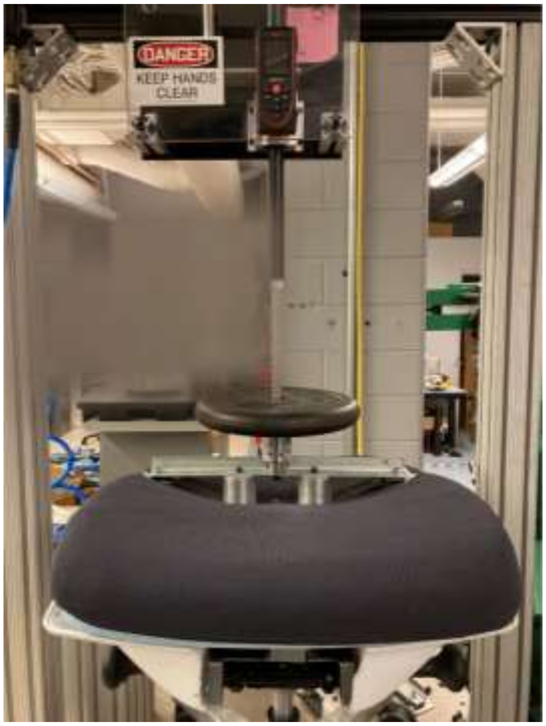

Figure 16. Anthros Chair with the 40-mm LCI 300 seconds after nominal load was applied

Figure 17. Anthros Chair with the 25-mm LCI 300 seconds after nominal load was applied


Figure 18. X Chair X3 with the 40-mm LCI 300 seconds after nominal load was applied

Figure 19. X Chair X3 with the 25-mm LCI 300 seconds after nominal load was applied


Figure 20. Humanscale Freedom with the 40-mm LCI 300 seconds after nominal load was applied


Figure 21. Humanscale Freedom with the 25-mm LCI 300 seconds after nominal load was applied


Figure 22. Steelcase Gesture with the 40-mm LCI 300 seconds after nominal load was applied


Figure 23. Steelcase Gesture with the 25-mm LCI 300 seconds after nominal load was applied

Figure 24. Steelcase Leap with the 40-mm LCI 300 seconds after nominal load was applied

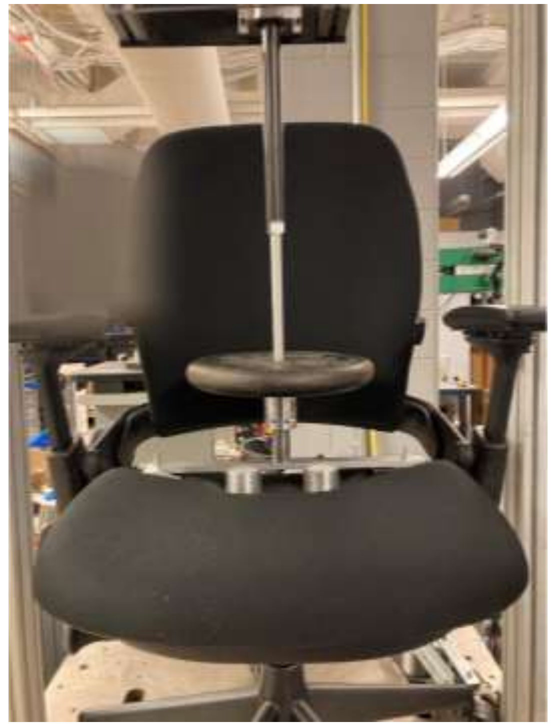

Figure 25. Steelcase Leap with the 25-mm LCI 300 seconds after nominal load was applied

Figure 26. All33 Backstrong with the 40-mm LCI 300 seconds after nominal load was applied.

Figure 27. All33 Backstrong with the 25-mm LCI 300 seconds after nominal load was applied

5mm & 10mm Force Deflection Testing

Test Overview and Methodology

Force Deflection is a test that characterizes the cushion's surface properties. Figure 36 shows a visualization of the Force Deflection test procedures from ISO 16840-6:2015 Clause 20 that were modified for office chair testing. This method based upon ASTM D5672-03 and is applied in 16840-6 before and after simulated aging to measure the surface effect of aging, which is the earliest indication of how the cushion might age.

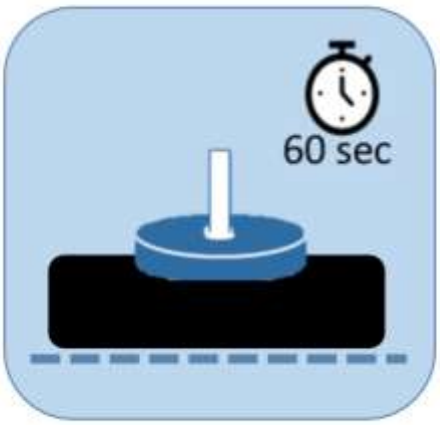

Figure 28. (left) An 8-in diameter disk compresses the cushion by 10% of the total cushion thickness* for 60 seconds. Average force is measured at 60 seconds. *This test normally compresses a cushion by 10% of its total thickness. Since obtaining a cushion thickness for the office chairs was not feasible, the test was run twice: once with a 5mm compression and second time with a 10mm compression.

The main outcome of this test is the average force, which indicates the amount of force exerted by the cushion at 60 seconds. A cushion that requires a higher average force to produce a 5mm or 10mm compression may indicate a stiffer cushion surface.

Results

5mm and 10mm Force Deflection results can be seen in Table 4 and Figures 29-30.

Table 4. Force Deflection forces at 60 seconds with a 5mm & 10mm compression

	Average Force (N) (5mm)	Average Force (N) (10mm)
Secret Lab Titan	185	304
Maxnomic Dominator	101	213
Herman Miller Embody	40	82
Herman Miller Aeron	25	51
Anthros Chair	8	17
X Chair X3	25	84
Humanscale Freedom	43	125
Steelcase Gesture	23	94
Steelcase Leap	10	29
All33 Backstrong	87	180

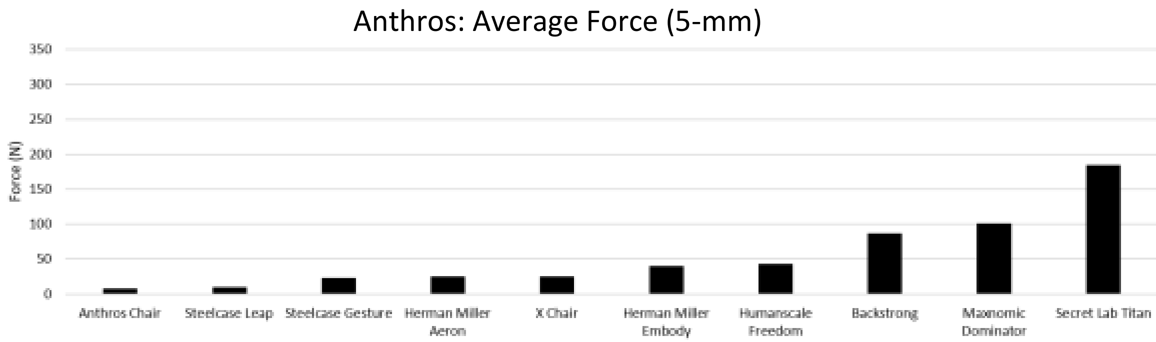

Figure 29. Average force 60s after application of a 5mm IFD sorted least to greatest

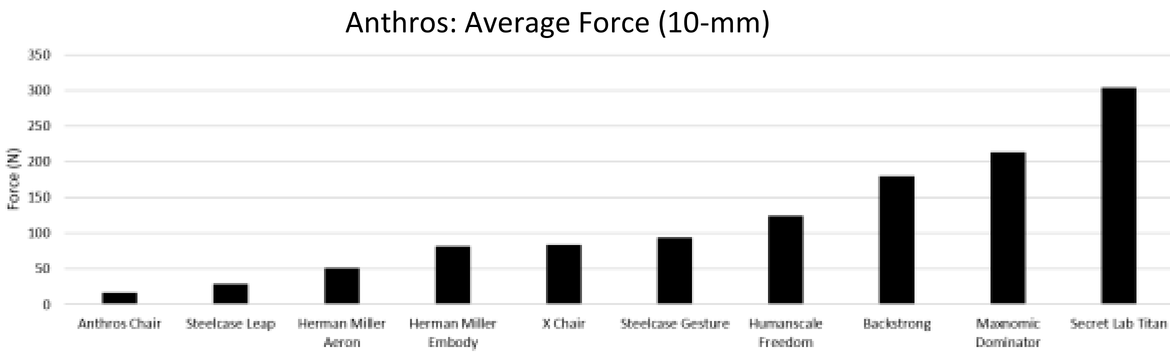

Figure 30. Average force 60s after application of a 10mm IFD sorted least to greatest

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Horizontal Stiffness

Test Overview and Methodology

Horizontal Stiffness is a test that characterizes a cushion's response to slight horizontal movements in the forward direction, indicating resistance to pelvic movement. Figure 31 shows a visualization of the Horizontal Stiffness test procedures from ISO 16840-2:2018 Annex C that were followed.

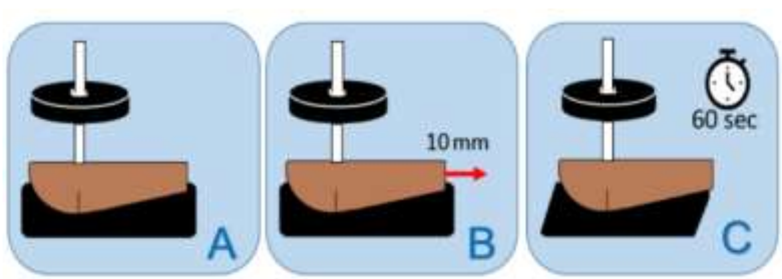


Figure 31. A: The cushion is loaded with a rigid cushion loading indenter to 500N; B: The loaded indenter is pulled 10 mm in the forward direction and the Peak Force (N) to pull the indenter is measured; C: The position is held and after 60 seconds the pull force (N) is again recorded.

Two key outcomes of this test as defined in ISO 16840-2:2018 Annex C are Peak Force (N) and Force at 60 seconds (N). The Peak Force is the maximum horizontal force required to displace a loaded cushion indenter forward 10 mm. The Force at 60 seconds is the final force measured after the 60 second hold time after displacement.

In addition to the procedures and outcomes outlines in ISO 16840-2:2018 Annex C, we attached a shear sensor on the lowest basepoint on one side of the indenter (simulating the ischial tuberosity) at the interface between the indenter and the cushion to obtain Shear Force (N) at 60 seconds after displacement. Measurements of interface shear is NOT part of ISO 16840-2:2018 Annex C and is being provided as a supplemental outcome.

Results

Horizontal Stiffness test results can be seen in Table 5 and Figures 32-34.

Table 5. Peak Horizontal Force (N), Horizontal Force at 60 seconds (N), Shear Force at 60 seconds averaged over three trials with a 10 mm pull.

	Peak Horizontal Force (N)	Horizontal Force at 60 seconds (N)	Shear Force at 60 seconds (N)
Secret Lab Titan	287	234	17.1
Maxnomic Dominator	171	140	21.2
Herman Miller Embody	243	211	16.1
Herman Miller Aeron	260	226	23
Anthros Chair	227	182	7.2
X Chair X3	167	138	16
Humanscale Freedom	254	198	13
Steelcase Gesture	208	172	12.9
Steelcase Leap	228	190	10.5
All33 Backstrong	246	212	10

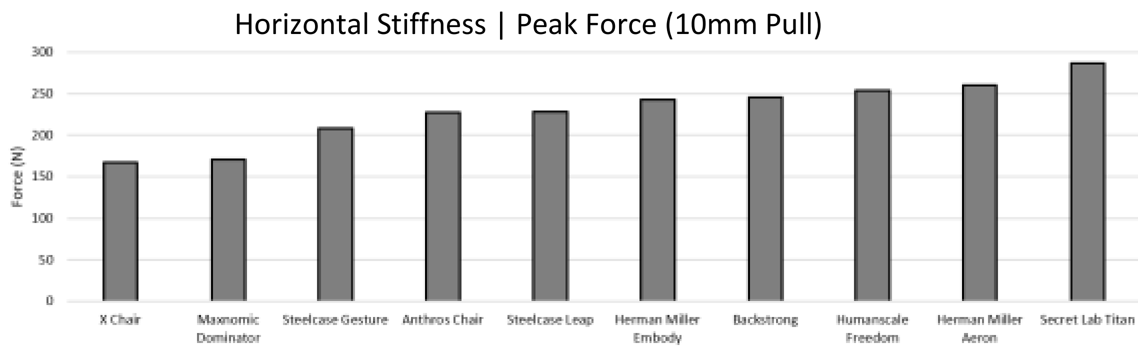


Figure 32. Peak Horizontal Force sorted least to greatest for Horizontal Stiffness with a 10mm pull

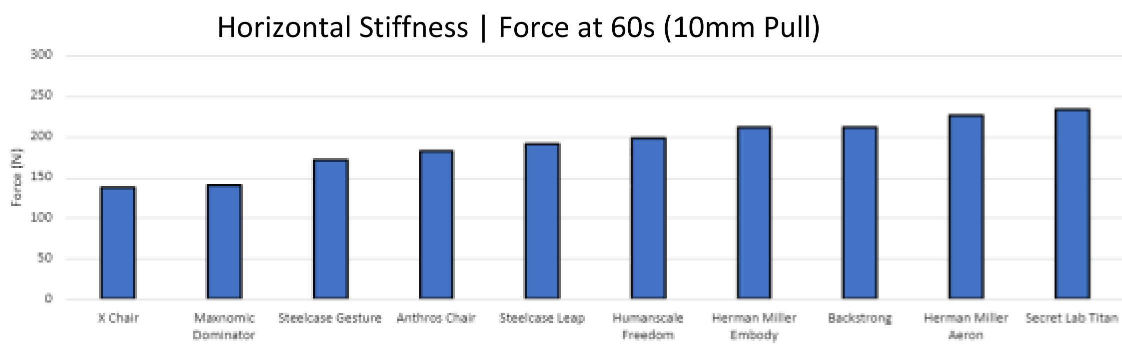


Figure 33. Horizontal Force at 60 seconds sorted least to greatest for Horizontal Stiffness with a 10mm pull

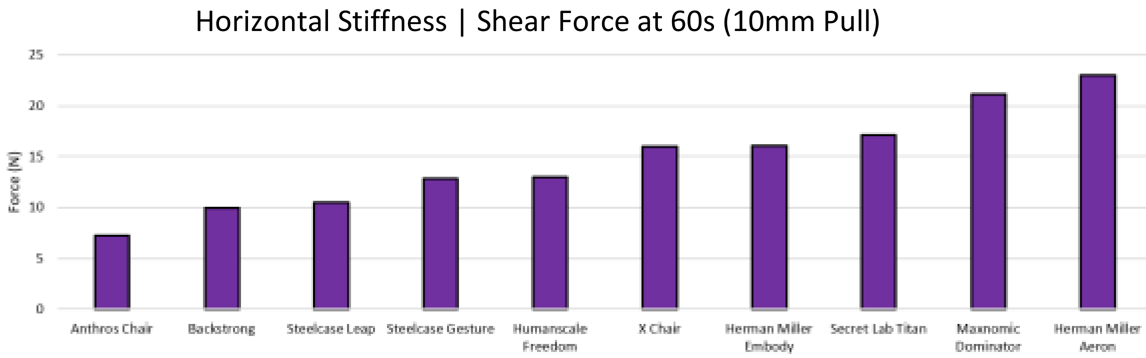


Figure 34. Shear Force at 60 seconds sorted least to greatest for Horizontal Stiffness with a 10mm pull

A higher Peak or Final Force, meaning a higher "Horizontal Stiffness" outcome, may offer more stability as individuals make slight shifts on the cushion. However, there is an increased chance of tissue deformation due to shear forces between the seat cushion and buttocks, therefore a noteworthy combination is high horizontal stiffness values and low shear force.

Pressure Mapping

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. Figure 35a shows a visualization of the Pressure Mapping test procedures from ISO 16840-6:2015 Clause 14 that were followed. This method is not a validated and standardized test method and is intended to be used to compare pressure mapping metrics before and after simulated aging.

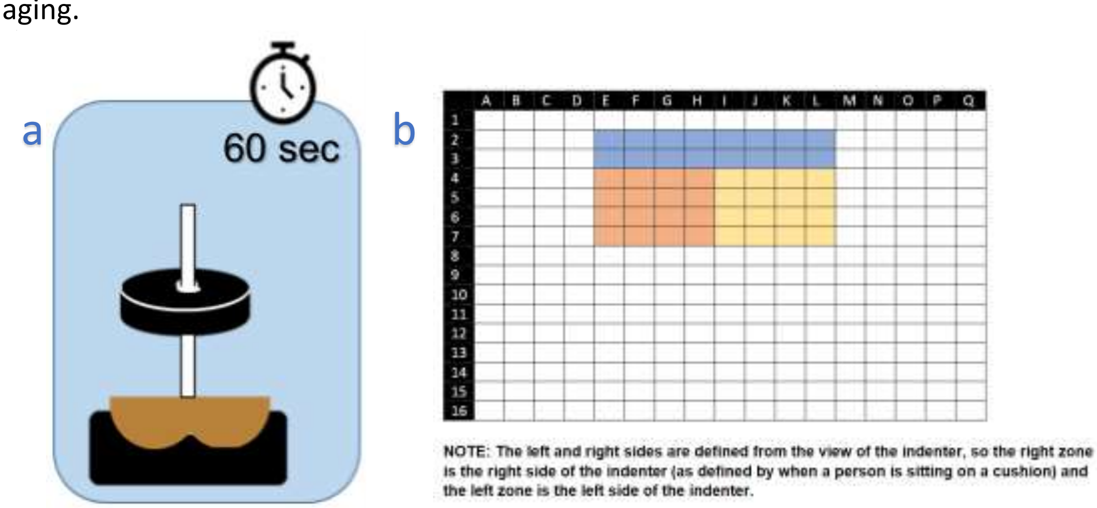


Figure 35. a: The cushion is loaded with a rigid cushion loading indenter and load totaling 500N and pressure map placed at the interface between the cushion and indenter records for 60 seconds. b: Guidance on interpretation of

the pressure map and base zones. Representation of a pressure map that shows Right (orange) and Left (yellow) Base Zones as well as sacral (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 related the base zones highlighted in Figure 35b including: Peak Pressure Index for the right and left base zones; Total force; Percent total pressure for the right, left and center base zones; dispersion index; and contact area. For more information on these metrics please reference ISO 16840-6:2015 Clause 14. 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. Maximum recorded value is 200 mmHg.

Results

Pressure Mapping test results can be seen in Figures 36-48. Additional figures and detailed data can be found in Appendix A and accompanying Pressure Mapping Excel files.

	Dispersion Index (%)	PPI – Left Base Zone (mmHg)	PPI – Right Base Zone (mmHg)	Contact Area (mm^2)
Secret Lab Titan	62%	158	175	51649
Maxnomic Dominator	68%	110	107	58997
Herman Miller Embody	52%	163	173	55070
Herman Miller Aeron	51%	196	172	41767
Anthros Chair	34%	69	64	100342
X Chair X3	55%	125	130	66515
Humanscale Freedom	48%	95	94	77241
Steelcase Gesture	56%	115	115	80282
Steelcase Leap	43%	100	104	82267
All33 Backstrong	59%	138	140	58448

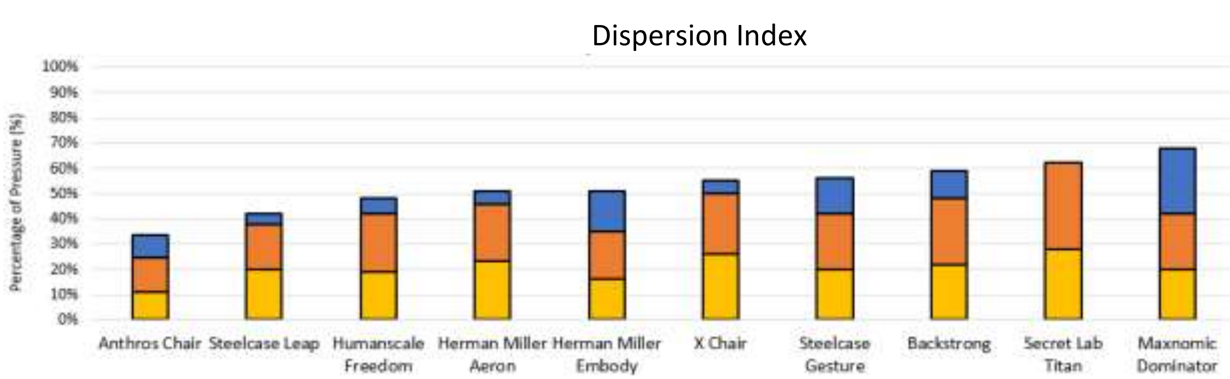


Figure 36. Percentage of force seen on the Left Base Zone (LBZ) (yellow), Right Base Zone (RBZ) (orange) and Rear center zone (CZ) (blue) sorted least to greatest

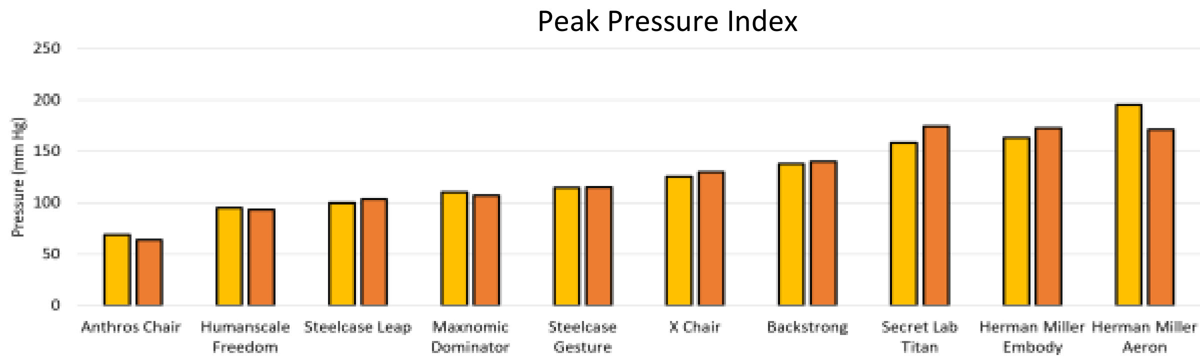


Figure 37. Peak pressure index of the Left Base Zone (LBZ) (yellow) and Right Base Zone (RBZ) (orange) sorted least to greatest

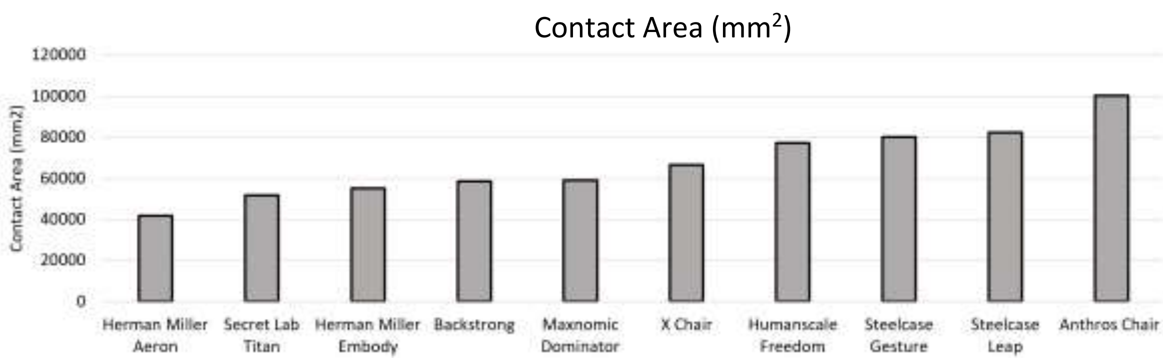


Figure 38. Contact Area sorted least to greatest

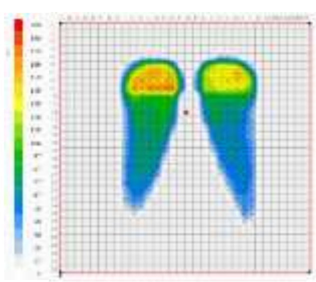


Figure 39. Lateral Stability test pressure map for Secretlab Titan 60 seconds after load application

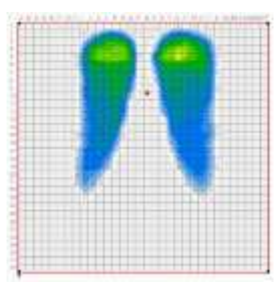


Figure 40. Sample Pressure Mapping output for Mxanomic Dominator 60 seconds after load application

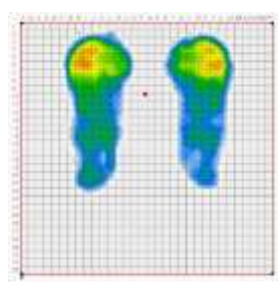


Figure 41. Sample Pressure Mapping output for Herman Miller Embody 60 seconds after load application

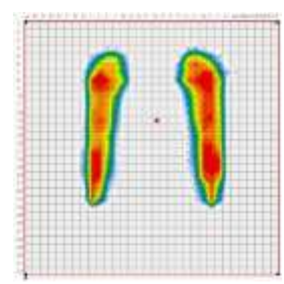


Figure 42. Sample Pressure Mapping output for Herman Miller Aeron 60 seconds after load application

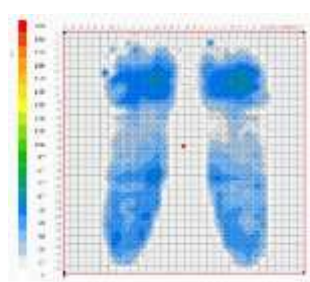


Figure 43. Lateral Stability test pressure map for Anthros chair 60 seconds after load application

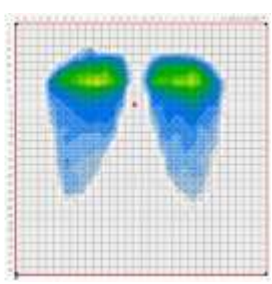


Figure 44. Sample Pressure Mapping output for X Chair X3 60 seconds after load application

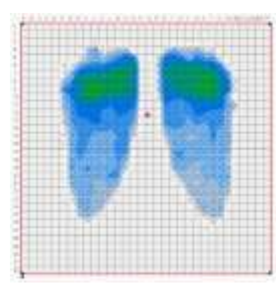


Figure 45. Sample Pressure Mapping output for Humanscale Freedom 60 seconds after load application

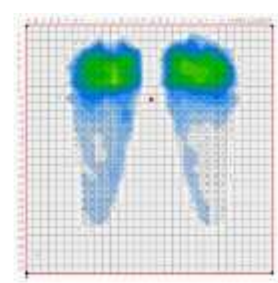


Figure 46. Sample Pressure Mapping output for the Steelcase Gesture 60 seconds after load application

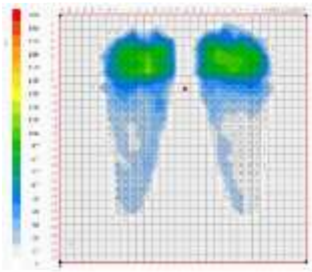


Figure 47. Sample Pressure Mapping output for the Steelcase Leap 60 seconds after load application

Figure 48. Sample Pressure Mapping output for the All33 Backstrong 60 seconds after load application

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 49 shows a visualization of the Lateral Stability test procedures in the ISO 16840-13 standard that were followed.

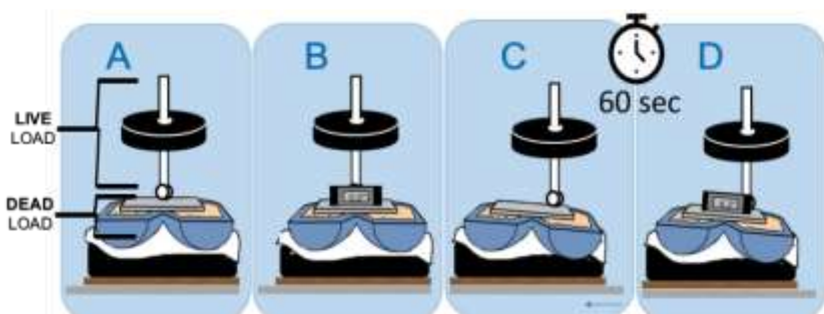


Figure 49. A: The cushion is loaded with a live load (the (60%) portion of the load that translates in the horizontal plane to shift the center of mass relative to the test cushion) and dead load (the (40%) portion of the total load, including the rigid cushion loading indenter, that does not translate 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 (this is a deviation from ISO 16840-13). 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.

A second version of this test was conducted using a shear sensor placed under the IT of the RCLI. Shear Force (N) and Interface Pressure (mmHg) recordings were taken after 60 seconds of the tilt application and averaged over three trials.

Results

Lateral Stability test results can be seen in Table 6 and Figure 56. Figures 49-60 show the nature of the cushion's support during a lateral tilt event via distribution of pressure at 60s. Lateral Stability with shear results can be seen in Table 7 and Figures 61-62.

Table 6. Average lateral tilt (degrees) of five trials at each time point

	Lateral tilt (°) at 60s					
	10s	20s	30s	40s	50s	60s
Secret Lab Titan	3.9	3.9	3.9	3.9	3.9	3.9
Maxnomic Dominator	3.7	3.7	3.8	3.8	3.8	3.9
Herman Miller Embody	3	3	3	3	3	3
Herman Miller Aeron	3.5	3.5	3.5	3.5	3.5	3.5
Anthros Chair	5.1	5.3	5.4	5.4	5.4	5.5
X Chair X3	2.7	2.7	2.8	2.8	2.8	2.8
Humanscale Freedom	4.7	4.9	4.9	5	5	5
Steelcase Gesture	4.8	4.9	5	5	5	5.1
Steelcase Leap	3.9	4	4	4.1	4.1	4.2
All33 Backstrong	5.2	5.3	5.4	5.4	5.4	5.4

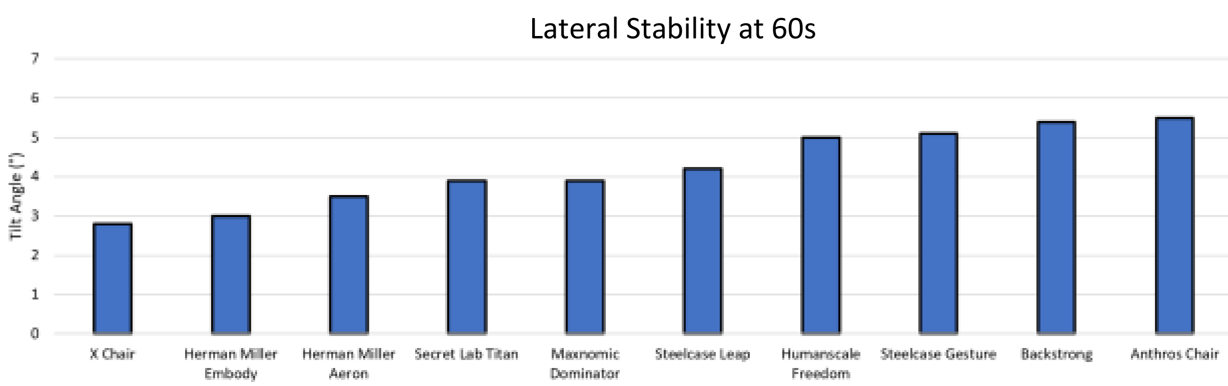


Figure 50. Change in Lateral Tilt Angle at 60 seconds sorted least to greatest

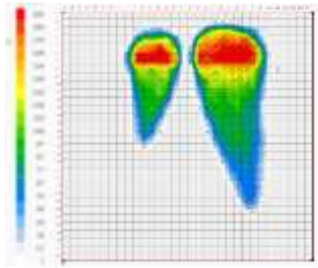


Figure 51. Lateral Stability test pressure map for Secretlab Titan 60 seconds after weight shift application

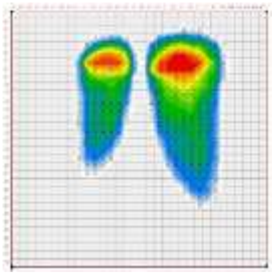


Figure 52. Lateral Stability test pressure map for Maxnomic Dominator 60 seconds after weight shift application

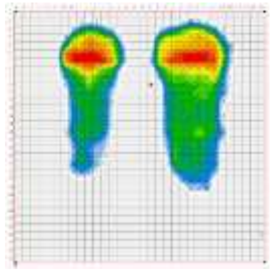


Figure 53. Lateral Stability test pressure map for Herman Miller Embody 60 seconds after weight shift application

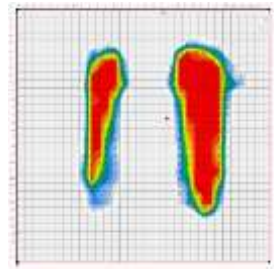


Figure 54. Lateral Stability test pressure map for Herman Miller Aeron 60 seconds after weight shift application

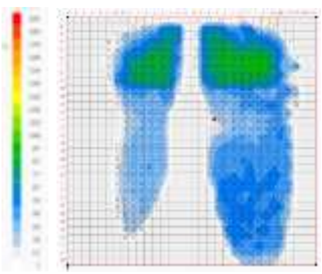


Figure 55. Lateral Stability test pressure map for Anthros chair 60 seconds after weight shift application

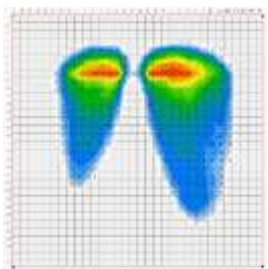


Figure 56. Lateral Stability test pressure map for XChair 60 seconds after weight shift application

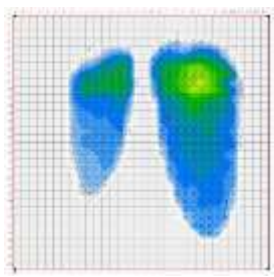


Figure 57. Lateral Stability test pressure map for Humanscale Freedom 60 seconds after weight shift application

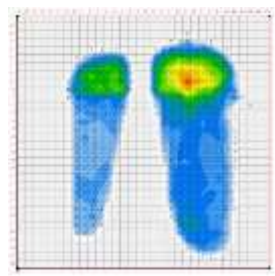


Figure 58. Lateral Stability test pressure map for Steelcase Gesture 60 seconds after weight shift application

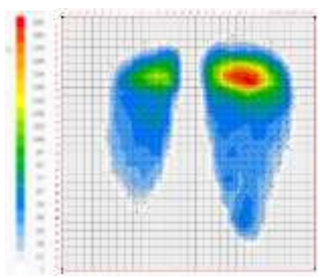


Figure 59. Lateral Stability test pressure map for Steelcase Leap 60 seconds after weight shift application

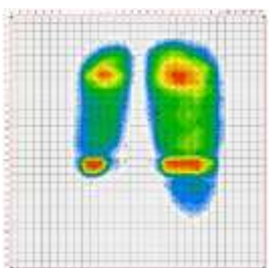


Figure 60. Lateral Stability test pressure map for All33 Backstrong 60 seconds after weight shift application

Table 7. Shear Force and Interface Pressure of three trials at 60 seconds

	Lateral tilt (°) at	
	Shear Force (N)	Interface Pressure (mmHg)
Secret Lab Titan	7	139
Maxnomic Dominator	8	145
Herman Miller Embody	-3.6	109
Herman Miller Aeron	-16.7	140
Anthros Chair	0.1	61
X Chair X3	7.6	150
Humanscale Freedom	1	109
Steelcase Gesture	10.4	155
Steelcase Leap	12.5	153
All33 Backstrong	9.9	160

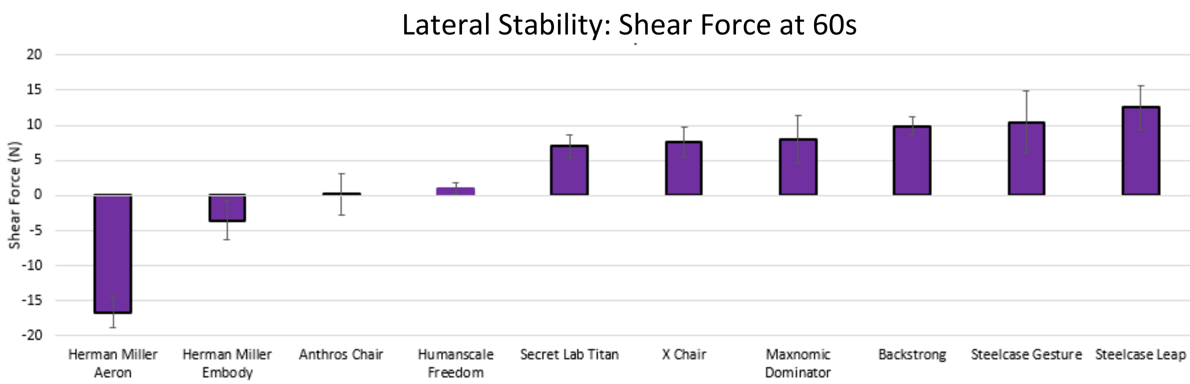


Figure 61. Shear Force from the shear sensor at 60 seconds sorted least to greatest

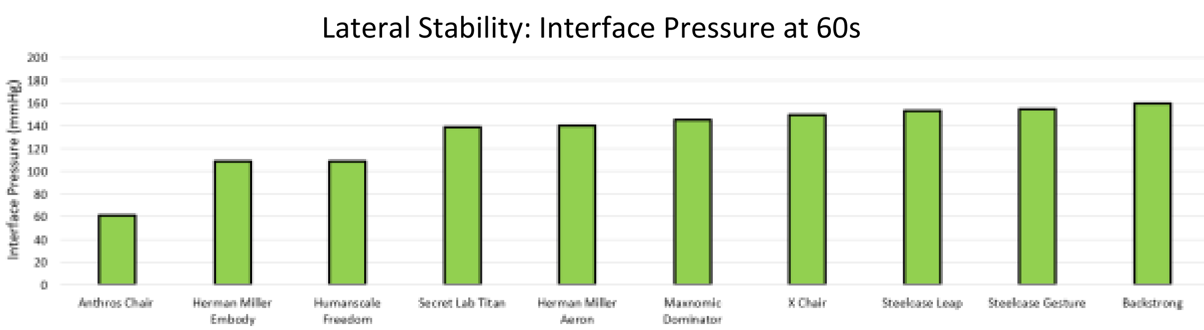
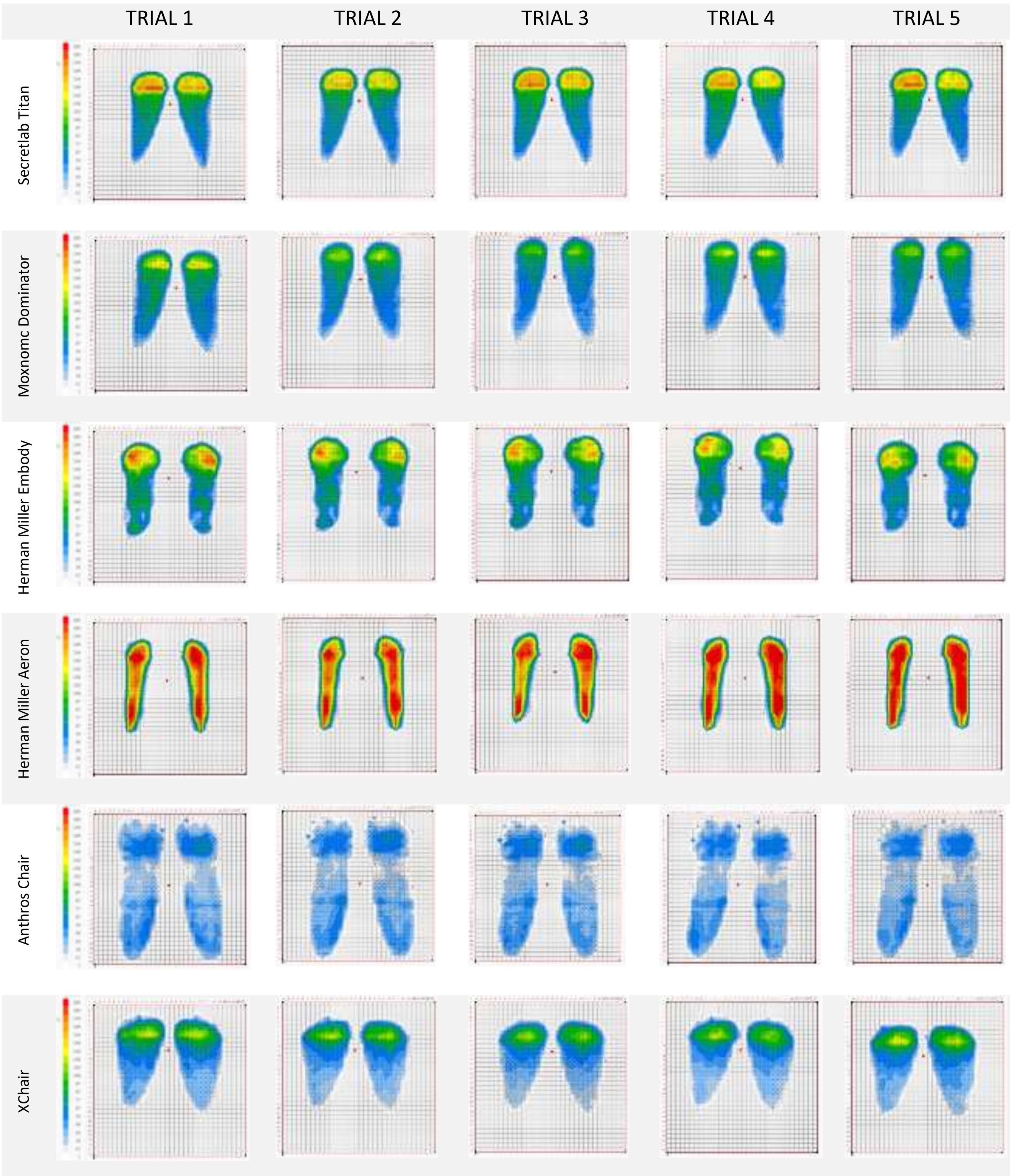
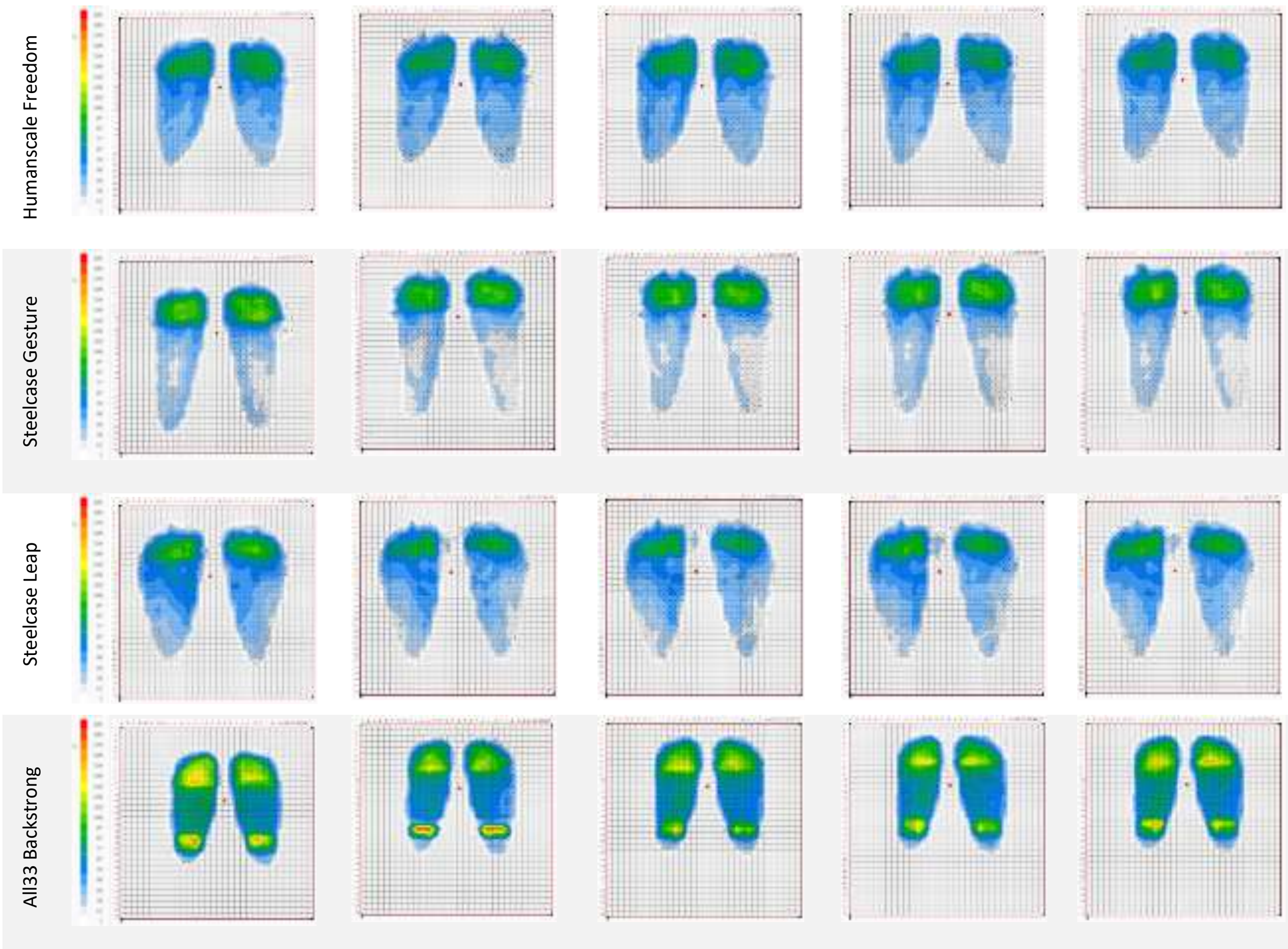


Figure 62. Interface pressure from the shear sensor at 60 seconds sorted least to greatest

APPENDIX A: Pressure Mapping




Humanscale Freedom
Steelcase Gesture
Steelcase Leap
All33 Backstrong