Leap Seating Outperforms Other Leading Chairs

Michigan State University research study validates Leap performance claims.

Background

Recent research has given us a new understanding about how the human torso, spine and pelvis move and interrelate in a seated environment. We believe these findings will radically change the way chairs are designed for the workplace in the future. In an effort to provide a healthier way to sit today, the Leap chair incorporates new design concepts and new technologies, based on the new research, with features like the Live Back™, Natural Glide™ system, and separate upper and lower back controls.

But does the Leap chair really provide better fit, movement and support than other leading work chairs on the market today? Is it really a healthier way to sit?

To find out, Steelcase commissioned Tamara Reid Bush and Robert Hubbard, Biomechanical Design Research Laboratory, Michigan State University, and Steve Reinecke, Innovative Ergonomic Solutions, to evaluate the Leap design against three other leading work chairs on the market. Their findings (attached) were reported at the Human Factors and Ergonomics Society 43rd Annual Meeting in Houston, September 27 - October 1, 1999.

The Study: "An Evaluation of Postural Motions, Chair Motions, and Contact in Four Office Chairs"

The goal of this study was to use the most recent biomechanical models and tools to measure people and work chairs in terms of fit, movement, and support during changes in spinal inclination and curvature. Testing was performed with four office chairs in a simulated keyboarding workspace, with fourteen subjects ranging from petite, light women to tall, heavy men.

Equipment: A video-based system was used to measure the positions and motions of the subjects and the chairs. A Lordosimeter measured changes in lumbar (lower back) spinal curvature. A state-of-the-art pressure mapping system was used to measure the distribution of contact pressures between the subjects and the backs of the chairs. Torso positions relative to the keyboard and desktop were evaluated against changes in recline angle and lumbar curvature. Based on the contact areas between the subject's back and the seat back, the amount and quality of support was evaluated for all four chairs.

Bottom-Line: Leap has the best overall performance of all chairs tested.

Motion Results

- **Leap performed best in keeping users oriented to their work when changing postures**
  Because of the importance of maintaining contact with the work task, the movement of the hands and head when reclining were monitored. (Typically when users recline, they are pulled away from their work, which increases the likelihood of eyestrain and wrist strain.) Of the four chairs tested, Leap demonstrated a significant reduction in travel of the wrist and head while still achieving an equivalent range of recline. For example, Leap reduced the horizontal travel of the wrists by 78% compared to the other chairs. Thus Leap allows users to recline – taking pressure off the discs and pelvis – yet maintain contact with the work task.
- **Leap showed the highest correlation between chair movement and body movement, while providing a more even distribution of motion between the upper and lower back**
  How well the chair moved and provided support to the torso during movement was also monitored. Leap moved with people very well, showing the highest correlation between chair movement and body movement. The motions between the upper and lower regions of the back were also more evenly balanced.

Pressure Results

- **Leap provided the most consistent pressure distribution for all test conditions, and reduced shoulder pressure when reclining.**
  Users were able to maintain contact with the chair and the upper and lower back while maintaining constant lower back support. Unlike other chairs which showed high pressures along the spine and shoulders, Leap showed the most consistent pressure mappings for all test conditions. The patterns showed a wider, nearly square shape pressure map, stretching from the shoulders to the buttocks, vs. a tall thin rectangular shape. More consistent pressure distribution minimizes stress, fatigue and discomfort to the individual.

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An Evaluation of Postural Motions, Chair Motions, and Contact in Four Office Seats

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The goal of this study was to use biomechanical procedures and models to measure people and office chairs in terms of fit, movement, and support during changes in recline and spinal curvature. Testing was performed with four office chairs in a simulated keyboarding workspace with fourteen subjects ranging from petite, light women to tall, heavy men.

Postures, body motions and chair motions were measured with a video-based system. A Lordosimeter measured changes in lumbar spinal curvature. Torso positions relative to the keyboard and desktop were evaluated for changes in recline angle and lumbar curvature. Pressure distributions were measured on the back of the chairs and related to changes in torso posture (back inclination and lumbar curvature). Based on the contact areas between the subject's back and the seat back, the amount of support was evaluated for changes in recline angle and lumbar curvature.

Chair D, the LEAP chair had the best overall performance. LEAP was found to move with people as they moved their spine from flexion to extension. During recline motions LEAP demonstrated a reduction in travel of the wrist and head as compared to the other chairs and a reduction in the pressure necessary to recline the seat, specifically in the shoulder region. The LEAP chair also provided a consistent pressure map for all test conditions, confirming that the chair maintained contact with the torso.

Introduction

The design and evaluation of seating has been limited by the available technologies to measure the mechanical interaction between a chair and its user. For many years, measuring the torso, while sitting, has been performed by two standardized measurement manikins provided by American National Standards Institute (ANSI)[1] for office seating, and the Society of Automotive Engineers (SAE)[2] for vehicle seating. Most office and automotive seat backs recline about a single point; this motion can be measured with the available manikins. However, both the ANSI and the SAE manikins do not represent the natural anatomic movements of the upper torso (thorax) relative to the lower torso (pelvis) that occur with spinal articulation.

Current tools that are useful for seat design and evaluation include the biomechanical models[3, 4], that have been developed at Michigan State University (MSU). In addition to the reclining of the entire torso, these biomechanical models also represent the motions of the thorax relative to the pelvis, which occur with spinal articulation. For product evaluation in terms of biomechanical models and manikins, it was necessary for new measurement protocols to be developed. Bush, et al.[5] developed measurement methods for human seated postures associated with reclining and spinal articulation. These measurement methods of human movement in seated positions were used to obtain data from people for the evaluation of product performance, specifically office seats.

The goal of the present study was to use the recently developed procedures and models to measure people and office chairs in terms of fit, movement, and support during changes in recline and spinal curvature.

Experimental equipment

The equipment used in the study included three primary systems:

1. Qualisys video-based motion system that measured the positions and motions of the subjects and the chairs.
2. Tekscan pressure measurement system that measured the distribution of contact pressures between the human subjects and the seat backs.
3. Lordosimeter that measured the spinal curvature in the lumbar region of the subjects.

Data collection from all three systems was synchronized and data acquisition occurred for a duration of eight seconds at twelve data samples per second (12 Hz).

Motion System. The positions and motions of the subjects and the chairs were measured using a five camera Qualisys video system. Reflective targets were attached using a medical adhesive to skeletal landmarks of the subjects and to reference points on each of the chairs.

Pressure Mapping System. Contact pressures between the seat backs and the subjects' torsos were measured with a Tekscan pressure system. Two pressure mats were used during the testing with each mat used for about half of the subjects. The mats were equilibrated and their calibration was checked before testing with each subject. The calibration was always stable within less than 5 pounds. There were pressure readings at the edge of the mat due to the attachment of the mats to the seat back. These pressures were eliminated in data processing.

Lordosimeter. The Lordosimeter consisted of several thin layers of material with an overall thickness of 5 mm. It was 25 mm wide and 230 mm long. A lycra covering was used to minimize any adhesion to the subjects' backs. The lower end of the Lordosimeter was attached to the sacrum at the level of the posterior superior iliac spine (PSIS) with medical tape. The top portion of the Lordosimeter was held in place against the back by a strip of lycra fabric attached to the skin on both sides. As the subject's lumbar curve changed, the Lordosimeter, held close to the back, measured the change in spinal curvature.

Methods

Subject Sampling. The subjects were sampled based on height and weight criteria. Six categories were developed including petite (short), light females; petite, heavy females; mid-sized females and males by height and weight; tall, light men; and tall, heavy men, Table 1. These categories were based on a combination of Natick Data[6] and Steelcase criteria. Two subjects were tested within each of the anthropometric categories. A total of fourteen subjects were tested for this project with an age range between 20 and 51. Two of the subjects did not acceptably fit a height and weight category. The chairs, Figure 1, were selected by Steelcase to include the LEAP chair and three competing chairs. The following is a brief summary of the unique features of the chairs that were significant to this study:

Chair A. The seat back of the Chair A was a stiff shell, covered by a layer of foam, while the other three chairs had seat backs that were more compliant. Chair A had an adjustable seat back height and adjustable seat pan depth. The armrests were attached to the seat pan base and could be adjusted vertically and translated laterally.

Chair B. Chair B was the only chair that allowed a side to side rocking motion, this motion was not evaluated in this testing. The seat back of Chair B was a flexible plastic grid covered by a layer of foam. Chair B armrests were attached to the seat pan base and only adjusted vertically. The height of the seat back could also be adjusted vertically.

Chair C. Three sizes of Chair C were used to accommodate the range of subjects according to the sizing guidelines from the manufacturer. This resulted in the medium size Chair C chair being used by all of the subjects except the petite, light women who used the small size and the tall, heavy men who used the large size. Among the tested chairs, C chairs were unique with their mesh material for the seat pan and seat back. Chair C's armrests were attached to and moved with the seat back. The Chair C armrests were adjustable in and out by rotating about a pivot located near the seat back and they were adjustable up and down by slides on the sides of the seat back. The seat pan and seat back had a 2:1 ratio when reclining, so the seat back moved twice as much as the pan during recline.

Chair D, the LEAP. Chair D had a unique reclining motion in which the seat pan glided forward as the seat back reclined. Chair D had a foam-covered, flexible plastic back with a lumbar tension adjustment. Chair D seat pan depth was adjustable. The armrests were attached to the seat pan base and were the most adjustable, combining translation (found with Chair A) and rotation (found with Chair C) in addition to height adjustment.

The construction of the seat backs of all of the chairs, except the Chair A, allowed the measurement of seat back deflections that resulted from contact with the subjects' back.

Testing protocol

The subjects went through an orientation where the terminology of recline and lumbar lordosis (erect posture) and kyphosis (slouched posture) were demonstrated and explained. Chair stations were set up with instruction boards on the operation of each chair. For testing and reference purposes, each chair was assigned a letter (A, B, C, D) and the manufacturer and chair name were not disclosed to the subject.

A qualified individual assisted the subject with the chair functions and demonstrated each of the chair adjustments. As the subject was rotated through chair stations (every ten minutes), the subject gained familiarity with each chair. After rotating through all four chairs, the assistant readjusted each chair and the subject was asked to repeat the chair adjustments on their own. The second adjustment typically occurred in less than five minutes for each chair.

After the orientation period, the subject was asked to change into the testing attire. This attire consisted of a pair of athletic shorts, a tight fitting tank top and a pair of low-heeled shoes such as tennis shoes.

Table 1: Subject categories.

Category	Approximate Percentile	Stature (cm)	Weight (kg)
Short Light Female	2%-5%	147-152	50.0-54.5
Short Heavy Female	2%-5%	147-152	72.3-76.8
Average Female	50%	160-165	59.0-63.5
Average Male	50%	173-178	75.5-80.0
Tall Light Male	95-98%	185-190	70.5-75.0
Tall Heavy Male	95-98%	185-190	98.0-102.5

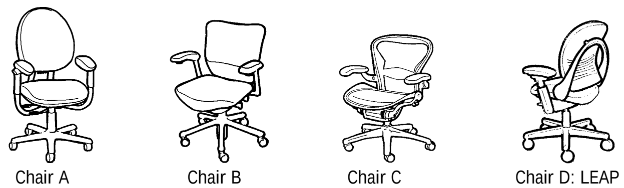


Figure 1: Test chairs selected by Steelcase.

Definition of Test Trials

Upright Recline (UR) - The subject was seated in the test chair and the seat back was locked in the full forward position. The subject was then instructed to move from lordosis to kyphosis, repeating the motion for the entire test period of 8 seconds.

Mid Recline (MR) – The seat back was in the unlocked condition (allowed to move freely) and the subject was positioned at a recline angle that was half of the full range of recline of that chair. The subject was then instructed to hold that recline angle and move from lordosis to kyphosis, repeating the motion for the entire test period of 8 seconds.

Full Recline (FR) – The seat back was in the maximum recline position that could be maintained by the subject. The subject was then instructed to hold that recline angle and move from lordosis to kyphosis, repeating the motion for the entire test period of 8 seconds.

Dynamic Recline (DR) – The seat back was in the unlocked condition. The subject began with the seat back in the most upright recline position and then reclined to the maximum recline attainable and then back to the upright position. The reclining motion was repeated for the entire 8 second trial.

Data Collection

After the subject was fitted with the lordosimeter and the targets, the test chair and desk and a simulated computer monitor and keyboard were brought into the calibrated space. The subject was seated in the test chair, (A, B, C, or D) and was asked to adjust the chair for a keyboarding task. In some cases, such as adjusting the armrest height of Chair C or the lumbar tension in Chair D, a test assistant helped the subject make the adjustments.

The order of test chairs was randomized and within each chair, the test conditions were randomized. The subject was given a chance to readjust the chair before each test condition. For example, many subjects lowered the chair slightly for the tests that occurred in the full recline position.

The lordosimeter, pressure and motion data were synchronized and all data were collected at 12 Hz for 8 seconds. Each condition was performed two times; due to the lengthy test procedure, the first and second trial were performed one right after the other to reduce the test time.

Results

Selecting subjects from the different anthropometric categories assured that a wide range of individuals would be tested. However, the test data were not analyzed by different anthropometric categories, rather the data from all subjects were pooled. Eleven of the twelve categorized subjects were analyzed in terms of the motion data. One subject was a petite heavy woman and the chest targets were lost for the majority of tests due to the chin obscuring the targets from the cameras, therefore the majority of these data were lost. All fourteen subjects' pressure data were analyzed.

Dynamic Recline Test Conditions: Motion Results

In the dynamic recline test condition, each subject was asked to start in an upright recline position and then recline the chair to the maximum recline position and repeat this motion for the duration of the test.

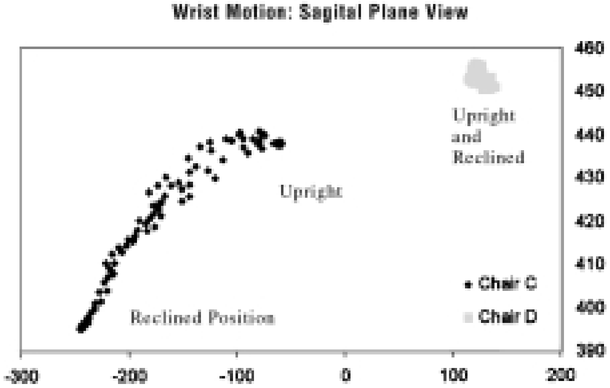
The total recline range of each chair was measured for each subject and then averaged. The recline ranges were as follows; Chair A, 14˚, standard deviation (std) 1˚, Chair B, 21˚, std 3˚, Chair C, 21˚, std 4˚, Chair D 20˚, std 1˚. Chair A had the smallest range of recline, 6 to 7 degrees less than that of the other chairs. Thus when comparing the motion of the wrist and head, it must be noted that Chair A pro-vided smaller overall body movements because of the restricted recline range.

Because of the importance of maintaining contact with the work task, the movement of the hands and head during seat recline were monitored. Compared to Chair B and Chair C during dynamic recline, Chair D reduced the horizontal travel of the wrists by 78% (from 175 mm to 38 mm) and reduced the vertical motion of the wrists in half (from 30 mm to 15 mm). Figure 2 shows wrist movements for a single subject in Chairs C and D. The offset in the horizontal direction is due to differences in the initial starting points.

The horizontal motion of the head was reduced in Chair D by 15% to 25% compared to Chairs B and C. The vertical motion of the head was reduced between 32% and 41%. The subjects achieved an average recline range of 20 degrees in all three chairs; it was the design of Chair D, including the seat pan glide mechanism, and the location of armrest attachment, that provided the reduced head and wrist motion.

Thus, of the three chairs with similar recline ranges, Chairs B, C and D, Chair D (LEAP) performed the best in maintaining reach and vision zones so contact was not lost with the keyboard or desk, and the focal point was not disrupted.

Figure 2: Motion of wrist in side view, a comparison between Chair C and Chair D. Subject 6.



Movement Between Lordosis and Kyphosis: Motion Results

Three recline positions were selected, upright, mid and full recline. The subject was placed in one of these conditions and then asked to move from a kyphotic position to a lordotic position, repeating the motion.

When comparing the curve traces of the lordosimeter, the thorax motion, and the number of cycles over the 8 second test period, the subjects were consistent in their movement patterns across all four seats. Since the motion pattern and ranges were consistent, particularly between Chairs C and D, comparisons could be made between seat back responses and posture changes.

The comparisons were made between all four chairs to establish how well the seat moved and provided support to the torso during movement. Since Chair A had a rigid seat back, it did not provide a measurable amount of seat back flexibility or motion when the subjects changed their posture from lordosis to kyphosis.

Chair B showed a decrease in the average range of spinal articulation as the seat moved from an upright position to either a mid-recline, or fully reclined position. This decrease in spinal motion range was due, in part, to the difficulty the petite subjects had trying to maintain contact with the floor.

Not only was the flexion of the spine measured, but the motions of the thorax and pelvis were also measured. The motion of the thorax and pelvis, when combined were relatable to the amount of spinal flexion from lordosis to kyphosis. This combined measurement of the thorax and pelvis was termed postural openness.

Changes from lordosis to kyphosis were then compared to the response of the chair. The ability of the seat back to flex and follow the motion of the back was measured at the upper and lower regions of the chair for Chairs C and D, and measured in the upper region of Chair B. The lower region of Chair B could not be measured and appeared to be stiffer than the upper section.

The seat back flexibility was measured by creating two vectors between three targets and measuring the angular deviation from a reference position over time. For Chairs C and D, there were four targets on the seat back. This calculation was performed twice, once with the upper three targets and once with the lower three targets.

Almost twice as much chair flexion occurred in the upper region of Chair C as compared to the lower region. In Chair D, the motions between the upper and lower regions of the chair were more evenly distributed, with the bottom portion of the chair showing a slightly larger angle change.

Table 2: Correlation coefficients between chair movement and body movement.

Upright Recline	r^2	r^2	r^2
	Chair B	Chair C	Chair D
Average	0.27	0.62	0.88
STD	0.28	0.27	0.10
Mid Recline			
Average	0.19	0.67	0.66
STD	0.21	0.24	0.25
Full Recline			
Average	0.44	0.83	0.88
STD	0.15	0.12	0.11

A linear regression was performed on these data and a coefficient of determination was obtained. This coefficient provided an assessment of how well the subject and seat back motions correlated. Table 2 lists the coefficients of determination for all three recline angles and the three chairs that had a flexible back.

In all recline conditions Chair B showed the lowest correlation. In the Mid and Full recline positions Chair D and Chair C provided similar correlations. However, in the Upright recline, Chair D was able to move with the body with a higher correlation, 0.88 as compared to 0.62 from the Chair C.

Chair D and Chair C performed well with regard to the ability to move with the back during spinal articulation from flexion to extension. Chair B had some ability to flex and move with the back, but to a lesser degree as compared to Chairs C and D. Due to the rigid back, there was no measurable ability of the seat back to flex with the body for Chair A.

Pressure Results

Three investigators, Bush, Hubbard, and Reinecke, independently assessed the pressure distribution mappings of all the test chairs during the various test conditions. While each subject moved through the test condition, pressure patterns of 96 still frames made up a dynamic pressure support movie. To evaluate the maps each investigator reviewed the maps and noted changes in the support patterns as the subject moved. Observations were made on the magnitude of force, amount of support contact area, and location of support to the subject's anatomical locations.

The following describes the overall trends seen in the pressure distributions for all chairs.

Chair A: Pressure Map Overview. Chair A had the least consistent pressure readings and the most asymmetrical patterns for all test conditions. These readings typically did not exhibit uniform continuous contact with the seat, but rather a "spotty" localized contact. This seat back displayed the most contact with the sides of the buttocks, resulting in a pear shaped pressure mapping for some individuals. When the subjects were in kyphotic postures, there was a round contact zone in the lower region of the seat back and when the subjects moved into a lordotic posture, this contact zone shifted to the upper portion of the seat back. Thus, in an erect posture, there was little to no contact with the seat back in the lumbar region.

Chair B: Pressure Map Overview. Chair B consistently displayed high pressure zones at the top edge of the seat back along the subjects' upper thoracic regions, specifically in the reclined condition and in the lordotic postures. Several subjects showed high pressures across the lumbar region of the chair where the contour break line was in the seat back. In the fully reclined condition and the dynamic recline condition, the petite subjects showed contact only at the shoulder region, this is because their buttocks were pulled away from the seat back to maintain contact with the floor.

Chair C: Pressure Map Overview. Chair C showed a uniform pressure map in all test conditions. The subjects were able to maintain contact over the thoracic and lumbar regions of the back. Chair C showed symmetrical mappings laterally, although the pressures were primarily concentrated at the midline of the body with a narrow lateral distribution. High pressures were seen along the spine, which suggested a hammocking effect of the mesh seat fabric. The overall shape of the pressure map was a tall thin rectangle.

During the dynamic recline test condition, high pressures were seen in the shoulder region of the chair, especially for the lighter subjects.

Chair D: Pressure Map Overview. Chair D consistently provided uniform, symmetrical pressure distributions. The subjects were able to maintain contact with the chair and the upper and lower back while maintaining lumbar support constantly. The pressure mappings did not show high localized pressure zones, but rather uniformed even distribution. The patterns showed a wider, square shape pressure map stretching from the shoulders to the buttocks. The pressures were laterally similar with minimal pressures on the spinous processes.

During the dynamic recline conditions high pressure spots rarely appeared in the shoulder region across the subject sample.

In addition to the independent analysis made by the three investigators, quantitative measures of contact between the human subjects and the seat backs were developed based on the pressure readings. The pressure maps were analyzed with the following goals in mind.

1. The center of pressure (COP) was interpreted as the location of the resultant force that supported the subject's back. As the subjects changed spinal curvature from lordosis to kyphosis, the range of movement of the center of pressure indicated whether the seat back maintained contact with the subject's back. The center of pressure moved away from areas where support was lost and if the pressure patterns shifted large amounts, the COP would have a larger travel path.
2. The total area of the pressure distribution was interpreted as a measure of the compatibility between the seat back shape and the subjects' backs. The greater the contact area, the better the fit. As the subjects changed their spinal curvature from lordosis to kyphosis, the change in the area indicated the ability of the seat back to provide distributed support for these changes of posture.

Table 3: Averaged vertical movement of Center of Pressure.

	Chair A	Chair B	Chair C	Chair D
Recline	mm	mm	mm	mm
Upright	305	330	305	203
Mid	254	254	254	203
Full	305	229	305	203

Table 3 shows the vertical movement of the COP. Chair D had the overall lowest movement of the center of pressure. Chair D data is significantly different at a 95% confidence level using a paired t-test when compared to the mean from Chair C. Thus, between Chair C and D, the COP has a smaller vertical travel path in Chair D. This relationship means that the pressures in Chair D were consistently and continuously being provided during postural changes, more so than in the Chair C.

Table 4: The average maximum and minimum contact area during movement from lordosis to kyphosis. (cm^2)

	Chair A		Chair B		Chair C		Chair D	
	Max	Min	Max	Min	Max	Min	Max	Min
Upright	690	380	658	393	710	426	722	464
Mid	716	535	761	535	819	613	806	581
Full	793	581	780	548	922	651	851	651

The second method that was used to analyze the contact of the seat back with the subject was the evaluation of the overall contact area. Table 4 displays the average maximum and minimum contact areas for all four chairs and all three recline angles. All the seat backs provide an increasing amount of contact area as the seat is reclined. Chair C and Chair D provide the largest contact areas for both the maximum and minimum values, which is congruent with the comments from the reviewers. These numbers indicate that Chairs C and D are consistently providing support to the subject through postural changes, however data from Table 3 shows that Chair D is providing more stable pressures patterns during postural changes.

Summary

Chair D (LEAP) allowed sufficient ranges of movement in terms of spinal flexion and extension, and recline. Of the four chair tested, the LEAP provided the least amount of disturbance to the hand and head position while still achieving an equivalent range of recline. The LEAP also provided the most consistent pressure mappings across all trial conditions and reduced shoulder pressures during recline, specifically for the petite, light, and mid-sized women. Overall the LEAP and Chair C both provided the ability to move with the subject during spinal articulation from lordosis to kyphosis. However, the LEAP provided a more consistent COP position with smaller vertical travel than Chair C. The LEAP also allowed equal motion in the lumbar and thoracic regions of the seat back while Chair C primarily allowed motion along the thoracic region of the seat back.

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