



VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

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**ŽMOGAUS ERGONOMINIO SLĖGIO Į SĖDIMAŽĮ PAVIRŠIŲ
NUSTATYMO TYRIMAS**

**RESEARCH OF HUMAN ERGONOMIC PRESSURE ADJUSTMENT TO
THE SITTING SURFACES**

Master's degree Thesis

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Pavadinimas **Žmogaus ergonominio slėgio į sėdimąjį paviršių nustatymo tyrimas**
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Anotacija

Šiame magistro baigiamajame darbe sudaryta ergonominių sėdimos darbo vietos tyrimų metodika, skirta matuoti spaudimą į sėdimą pagrindą. Remiantis mokslininkų tyrimais sukurtas mobilus spaudimo matavimo kilimėlis, kaip stendas tyrimams atlikti. Jutiklinis kilimėlis sukurtas naudojant FSR 402 serijos jutiklius, iš kurių sudaryta matrica 4×4. Matavimo ir duomenų atvaizdavimo programa sukurta naudojant Matlab programos paketą Simulink. Sukurtas jutiklinis kilimėlis yra patvarus, pigus, neinvazinis, tinkamas jėgos į sėdimą pagrindą matavimams. Ergonominiai tyrimai atlikti analizuojant 16 tyrimo dalyvių, ant trijų skirtingų kėdžių. Kiekvienas tyrimo dalyvis atvaizdavo 6 dažniausias sėdimos darbo vietos laikysenas. Ergonominiai tyrimai parodė tolygų spaudimo pasiskirstymą sėdint ant minkšto paviršiaus nepriklausomai nuo sėdėjimo laikysenos ar tyrimo dalyvių fiziologijos. Sėdėjimas ant kieto paviršiaus parodė dideles spaudimo jėgos vertes sukoncentruotas į du taškus atitinkančius sėdimuosius kaulus (ischial tuberosity).

Darbą sudaro 5 dalys: įžanga, literatūros apžvalga, analitinė dalis, eksperimentinė dalis, išvados ir literatūra. Darbo apimtis: 50 puslapių, 23 iliustracijos, 4 lentelės, 39 literatūros šaltiniai. Atskirai pridedami darbo priedai.

Prasminiai žodžiai: Spaudimo matavimo kilimėlis, FSR, Simulink, ergonominiai tyrimai, skirtingas sėdėjimo pagrindas

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Annotation

In this research, ergonomic test methodology of seated workplace created. Referring to review of other author's studies adjustable pressure-measuring mat designed as a stand for pressure measurements. Sensing mat build using Interlink FSR402 sensors in matrix 4×4. The program of measurement reading and visualization created in Matlab package Simulink. Created pressure measurement mat is robust, low cost and non-intrusive suitable for seated pressure evaluation. Ergonomic study made taking pressure measurements of 16 participants on the three different seats. Each participant represented six common seated workplace positions. Ergonomic study showed equal distribution of pressure when seated on the soft cushion regardless sitting position or body anatomy of test participants. Hard seat surface shows higher pressure values and concentration in two points representing sitting bones (ischial tuberosity).

Structure: introduction, literature review, analytical part, experimental part and conclusions, references. Research work consists of: 50 pages, 23 pictures, 4 tables and 39 bibliographical entries. Appendixes included.

Keywords: Pressure sensing mat, FSR, Simulink, ergonomic tests, different sitting surface.

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GLOSSARY AND ABBREVIATIONS

etc. – et cetera, (and similar other things);

FSR – force sensitive resistor;

LT – laterally tilted;

PCB – printed circuit board;

WRMSD – work related muscular skeletal disorder;

$\bar{a}$ – mean value of measurements;

BMI – body mass index, kg/m^2 ;

C – multiplication coefficient, depending on each test participant weight.

h – height, m;

k – calculated factor, equal to 0,005;

m – mass, kg;

n – number of sensors, equal to 16;

V – measured voltage, V;

w – calibration weight, g;

x – calculated factor, equal to 1,5;

x_i – measurement of force in grams from each sensor, g.

INTRODUCTION

Ergonomics is the scientific study of people at work. Ergonomics is highly relevant to preventive and occupational medicine, management of musculoskeletal injuries and rehabilitation.

With the introduction of the computer, office workers are now sitting for the majority of the day. Moreover, people sit to watch television or drive in average 6 hours per day. Many adults spend 70% of their waking hours sitting and little or no time exercising. Most people experience pain in the back, neck, and shoulder at some time.

Most common posture of the office environment is sitting, moreover extended sitting in uncomfortable seats or positions can cause lower work effectivity, fatigue and other health problems. Therefore, analysis of sitting posture is necessary due to its relevance in chronic diseases, back pain, analysis of correct sitting posture and comfortable seat.

Object of research

In this research, the methodology for ergonomic analysis of seated workplace created. Adjustable pressure-measuring mat designed to perform measurements of pressure distribution over seated surface. This research analyses:

- Sensors quantity and spacing for relevant ergonomic pressure analysis;
- Force of body distribution on the seat;
- Pressure distribution of people with different physique regarding sitting surface and position;
- Gender dependency on pressure distribution.

Aim and tasks of the work

The aim of the work create methodology for ergonomic analysis of seated workplace. The main tasks are:

- Analyze literature of pressure measurements, hardware used for seated pressure measurements and existing examples of seated workplace ergonomic analysis.
- Create adjustable pressure measuring mat.
- Perform ergonomic tests with people of different physique in different postural positions.
- Collect results of tests and analyze it in respect of sitting surface and pressure distribution.

- Write conclusions.

Scientific novelty of the work

Researches on pressure measurements mostly made for laying position, measuring pressure of the body on a bed like surfaces. The analysis for sitting position mostly made for car or agricultural vehicle seats to find most comfortable materials and designs. Moreover, measurements of seated pressure distribution mostly concern disable people to study causes and prevention of pressure ulcers. The aim of this research is to measure pressure on the different sitting surfaces in office work environment with people of different physical characteristics. These measurements would help to find comfortable sitting surfaces depending on person anatomy.

Topicality of the problem

Increased seated time matches with grow of work related musculoskeletal disorders of the upper extremities (WRMSDs). Office workers, affected by WRMSD experience pain in the back, neck, shoulder and functional impairment (Plantard *et al.* 2015). Moreover, manufacturers typically do not design chairs to accommodate the dimensions of the individual user. Without proper design, sitting will require greater muscular force and control to maintain stability and equilibrium, which in turn lead to greater fatigue and discomfort, and is likely to lead to poor postural habits (Maria Lis *et al.* 2007). Overall, it is very important that sitting surface would be individually adjusted depending on person anatomy and carried work.

Experimental methods

Created adjustable pressure measuring mat of 4×4 sensor matrix. Signal conditioning and matrix interface visualized with MATLAB package *Simulink*. Ergonomic analysis made on three different chairs with 16 test participants. Tested 6 most common seated office workplace positions imitating realistic environment. Acquired data normalized regarding test participants weight and dispersion of sensor values calculated to illustrate performed ergonomic tests.

Scientific value of research

Ergonomic study showed high-pressure distribution on soft sitting surface regardless sitting position or body anatomy of participants. However, on hard surface pressure is highly concentrated in two points representing sit bones (ischium tuberosity). Moreover, pressure is more concentrated for male due to body anatomy of pelvis. Research represents high concentration of pressure regarding hard-seated surface, low body mass and positions, like crossed legs, resulting in discomfort, higher risk of fatigue in short time and low work efficiency.

Work approbation

In March 20th of 2018 presented poster „Research of Human Ergonomic Pressure Adjustment to the Sitting Surface“ in 61st Open readings Conference 2018 (Appendix A.1).

In April 24th of 2018 oral presentation „Research of Human Ergonomic Pressure Adjustment to the Sitting Surface“ in 21st Conference for Lithuanian Junior Researchers „Science – Future of Lithuania“ (Appendix A.2).

1. LITERATURE REVIEW

Traditionally, sitting position analyzed by the medical personal when patient seated on hospital chair. Patient is observed and questioned for comfort feeling, while this analysis can take to one hour it is not enough accurate for too short time to gather enough information and low reliable questionnaire. For sitting posture analysis cameras in an office setting can be used, however it can be influenced by test subject awareness and uncomfortable feeling of being watched (Marschall *et al.* 1995).

More reliable and less privacy affected way to monitor sitting posture is pressure measurement over sitting surface. Method suggested by Kamiya *et al.* (2009) involves four pressure sensors on the seat yet number of sensors is not enough to acquire complete sitting posture information. Nevertheless, increased number of sensors will increase the cost of analysis due to that solution of low cost sitting posture analysis is still in demand (Kamiya *et al.* 2009).

1.1. Seated posture analysis

For measurements of seated comfort different studies were made using electromyography, motion tracking systems, spinal shrinkage, subjective comfort or discomfort ratings and pressure distribution measurements of the seat pan and the backrest (Zemp *et al.* 2015). Overviewed studies regarding WRMSD showed that self-report questionnaire is not a reliable method to measure postural load. The challenge to develop quick and inexpensive techniques for assessing exposure to postural load at seated office workplace position is still in demand (Heinrich *et al.* 2004). Pressure measurements of the sitting surface and in some cases, backrest too is one of the most common methods to analyze or compare different chairs or sitting positions because of cheap and easily applied measurement systems (Zemp *et al.* 2016a).

Another study of Zemp *et al.* (2015), aimed to analyze the influence on back pain regarding sitting behavior in office environment. For the study, a textile pressure mat of 64 sensor matrix placed on the seat pan and used to identify sitting positions of 20 office workers. Experiment participants divided in two groups regarding of existing back pain. In conclusion, static sitting position resulted in back pain. In addition, study system showed the importance of comparison between subjects with and without back pain (Zemp *et al.* 2015).

Zemp *et al.* (2016b), determined most meaningful pressure parameters for different office chairs. It was found that sensor mat has to be calibrated for specific chair because chair material properties and geometry influences the measurements. The most important pressure parameters in the seat pan are total contact area, pressure force and pan's maximum and mean gradient, which defined by the geometrical addition of the pressure derivative of the two sensor mat directions (Zemp *et al.* 2016b).

Commercial product for seated pressure measurements I-Scan System developed by *Tekscan* consists of 2000 pressure sensors and can accurately measure and analyze pressure between surfaces. Commercial products like smart cushions are *DARMA* and *SENSIMAT*, which measures and monitors pressure on sitting surface, recognizes postures and sitting habits. Both products have 6 sensors and similar deployment. *DARMA* system consists of fiber optic sensors, which are more sensitive and accurate compared to pressure sensors. Proposed mat can track sitting time, position, heartbeat and respiration as well as can provide stand-up reminders and posture advice. While *SENSIMAT* is more focused on wheelchair users providing reminders to the user via mobile device when to move and can track progress over time.

1.2. Sensors mat designs

Many studies made for limited mobility people in wheelchairs to analyze and prevent development of pressure ulcers. Normally people voluntarily or subconsciously change their posture or shift weight to bring the pressure down under the threshold. Bony body parts, like sit bones exposed to high-pressure levels. Regarding comfort of seated people, Chung-Huang *et al.* (2014) proposed an active seating cushion (Fig. 1.1), in which the interface pressure can be changed with different supporting shapes. The modular system with height-adjustable support surface elements was developed. Four-element module was autonomous and included force sensors, position sensors, linear actuators, signal conditioners, driving circuits, and signal processors. Supporting area of the element 3×3 cm could provide 49 N pushing force with displacement resolution less than 0.1 mm and the force sensor error less than 1% in the 2000 g range. Finally, created modularized system was capable of actively managing interface pressure in real time (Chung-Huang *et al.* 2014).

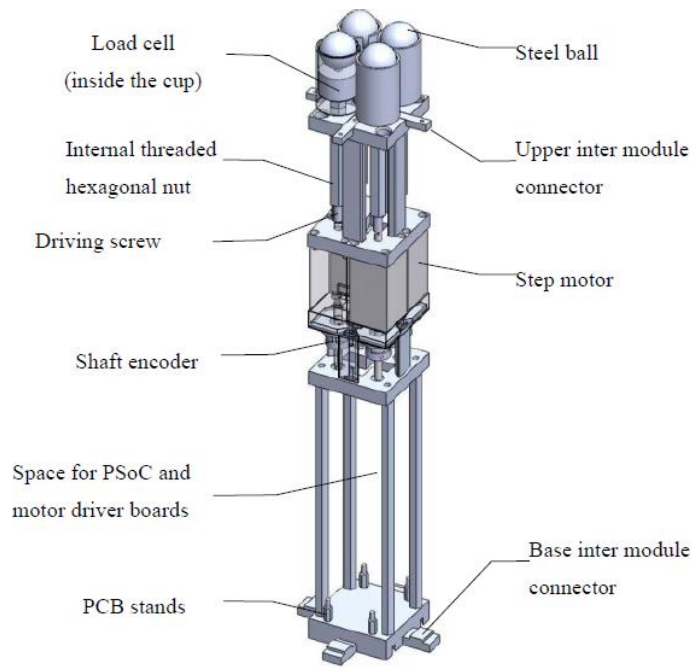


Fig. 1.1. The mechanical design of a module unit (Chung-Huang *et al.* 2014)

Cheap but high resolution and high accuracy textile pressure mat was presented by Saenz-Cogollo *et al.* (2016), where a single layer of a 100% cotton fabric stitched with silver coated polyester threads and treated at specific spots with polystyrene sulfonate-doped poly-3,4-ethylenedioxythiophene (PEDOT:PSS). Developed system (Fig. 1.2) is very thin and flexible textile device, robust, uses minimum amount of expensive material, quickly installed and rolled up for transportation. Has high variability in resistance because different sensels not equally absorb conductive polymer. Moreover, used polymer PEDOT-PSS, which known for its piezoresistivity can be affected by thermoelectric and humidity-sensitive properties, which can cause pressure measurement variability (Saenz-Cogollo *et al.* 2016).

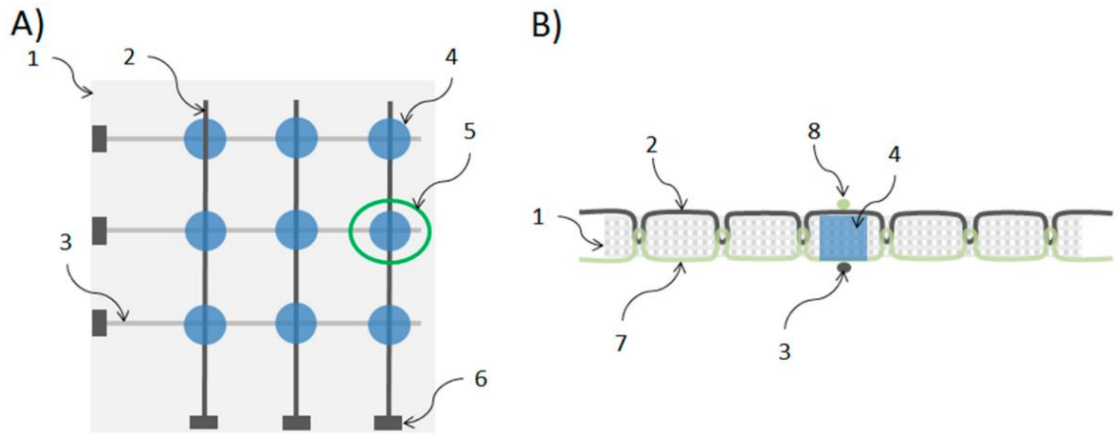


Fig. 1.2. Scheme of a textile pressure sensor. **(A)** Top view: (1) base fabric, (2) top conductive path, (3) bottom conductive path, (4) conductive polymer treated zone, (5) single sensing element or sensel, and (6) connector or electrical contact for measuring; **(B)** Transversal view of (5 of panel A) illustrating the relation between the base fabric (1), the conductive threads (2 and 3), the non-conductive threads (7 and 8) and polymer-treated zone (4) (Saenz-Cogollo *et al.* 2016)

The study of Chenglu *et al.* (2017) was to develop a smart mat system to unobtrusively acquire information of pressure distribution. Smart mat (Fig. 1.3) was an array of pressure sensors build of seven-layer structure. For signal transfer to acquisition circuit as well as conducting each sensor the conductive layers were used. Sensor layer consist of pressure sensor array. All system surrounded by protective layers preventing the electrical device from contacting directly with environment.

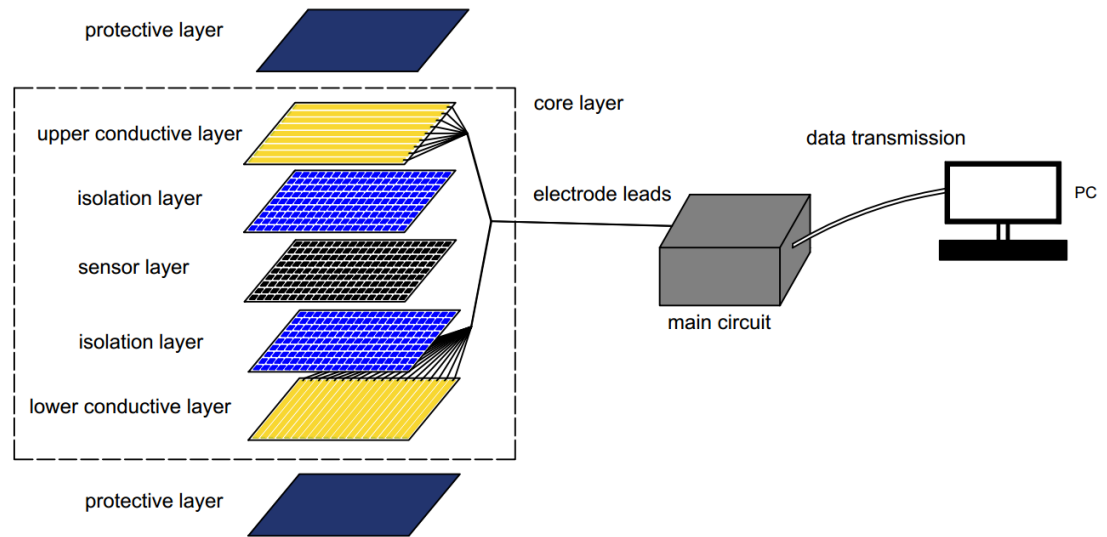


Fig. 1.3. System overview (Chenglu *et al.* 2017)

Smart mat system records pressure distribution and changes without interference to the laying subject. For this reason conductive and sensor layers are less than 2mm thickness. Conductive layers are out of cotton with surface printed conductive lines made of silver powder. Sensor layer is a linen cloth with measurements of 32×32 cm, where each sensor 6×6 mm size. Pressure sensor made of flexible material *velostat*, which features response and relaxation time at the level of millisecond. In conclusion, created smart mat able to sense the pressure change caused by body applied on it (Chenglu *et al.* 2017).

Another smart cushion presented by Yu *et al.* (2010) installed with pressure sensors for chronic back pain prevention (Yu *et al.* 2010). Monitoring system for wheelchair users proposed by Arias *et al.* (2016) could be adapted to office workers. Sensing mat was able to detect pressure relief tilts and gives reminder for posture change (Arias *et al.* 2016). System created by Barba *et al.* (2015) detects user position change using 8 pressure sensors placed on seat and 8 on the backrest (Barba *et al.* 2015).

Furthermore, textile based sensor mat called *Smart Cushion* developed by Xu *et al.* (2013) used binary pressure data distribution represented by gray scale image applied for posture recognition (Xu *et al.* 2013). Capacitive textile sensor array cushion proposed by Meyer *et al.* (2010) for measurements of human body pressure distribution. Used sensing mat consisted of 19 pressure sensors adopted to recognize sitting position. System was robust, low cost and non-intrusive with comparable results to commercial pressure measurement systems (Meyer *et al.* 2010).

1.3. Force sensitive resistors (FSR)

Activity recognition system proposed by Ma *et al.* (2014) uses pressure measurements acquired from smart cushion system. Smart cushion system made out of 4 FSR pressure sensors (approximately one sensor 45×38 mm) purchased from Interlink Electronics embedded in cushion textile. Analyzed measurement model recognize fatigue or nonfatigue regarding seated position. Sensors laced in extremes of the chair to detect pressure data when person swings to the sides or front and back. Data analyzed in MATLAB showed that people suffering from fatigue in the sitting position maintain stable posture with low activity. Moreover, study showed that people get tired after approximately one hour of sitting and fatigue of seated position can be observed using pressure sensor on a chair like surface. (Ma *et al.* 2014)

Ma *et al.* (2017) proposed sensing module with FSR-406 pressure sensors by Interlink is easily deformable on the chair surface. Using Arduino DUE sensors data collected and processed and results sent to smartphone using wireless connection. Few pressure sensors individually connected to processing unit making system more cost economic and less power consuming (Ma *et al.* 2017).

In the work of Fard *et al.* (2013) used Interlink Electronics force sensing resistors (FSR-part no. 400), for seated pressure measurements. Matrix of 64 sensors (Fig. 1.4) was used over are of 30 × 40 cm. Sensors fixed on Plexiglas sheet with a same size PCB board on the other side for sensor wiring. Data from the sensors acquired every 320ms with a sampling rate of 3 Hz and processed in MATLAB. Using mean values of measured pressure from sensor matrix, it was possible to make recognition for straight, crossed legs and stretched legs sitting positions (Fard *et al.* 2013).



Fig. 1.4. Pressure sensor array (Fard *et al.* 2013)

Force sensing resistors (FSRs) are suitable for medical applications due to their thin and flexible construction and ability to operate at low pressures. Parmar *et al.* (2016) FSR described as low accuracy sensors, but on the other hand more suitable for compression therapy as it is small, thin, low cost and can be easily integrated in textile structures. The Interlink FSR approximately linearly responds in resistance with applied force change. In the study, different types of pressure sensors were tested and Interlink FSR showed long time to reach steady state and high drift values, as a result of slow response. On the other hand, sensor showed high consistency during pressure application and high repeatability. Fast and accurate response compared to other tested sensors when dynamic force is applied is a characteristic highly suitable for pressure measurements of sitting surface (Parmar *et al.* 2016).

1.4. Overview

Current research involves analysis of different types of seat cushion system. Up to a certain point, it is based on reviewing other authors research works aimed to study pressure measurement distribution for workplace ergonomics, ulcer prevention purposes and sensing mat designs. Summary of analog created sensing mats and their specifications shown in table 1.

Table 1.1 Comparison of different existing systems and their parameters

Studies	Matrix	Pressure measuring range, N/cm ²	Max. Pressure, N/cm ²	Contact area, cm ²	Sampling frequency, Hz
Medilogic	43×43	0 - 2.75			100
Min et al. 2016	16×16	0 – 1.3	1.36		0.083
Junrong et al. 2013		0.2 – 10			60
Anderson et al. 2013	48×48	0.14 - 2.7	1.68	1168	
Fard et al. 2013	8×8			1200	3
Zemp et al. 2015		0-6			10
Jawad et al. 2017	4×4			505.25	77

For pressure measurements on the sitting surface basic requirements for hardware described in study of Casey *et al.* (2011). The interfaces between two continuum phases one of which is living tissue

and the other biomedical device of non invasive pressure measurement, the following features for the device should be completed:

- sensor measurement range of applied pressure 0-100 kPa;
- permit fast, convenient and intuitive calibration checking in the target application environment;
- measurement errors should be less than 1% of full scale;
- allow easy compensation for ambient pressure and temperature variations;
- easily interfaced to microcontrollers;
- have similar compliance to that of the target tissue;
- be low profile (<2 mm high) with very small footprint (<1 cm²).

In addition, electrical characteristics of high accuracy, high sensitivity, low drift, linearity, fast response time and low hysteresis desirable in all sensors (Casey *et al.* 2011).

Review of literature showed FSR sensors suitability for pressure measurement on sitting surface. Moreover, quantity of sensors can be as little as eight, to obtain critical data of pressure distribution. Average measured pressure value do not exceed 4.5 N/cm². Sampling frequency used in studies varies a lot depending of study purpose. Pressure measurement over long time used for fatigue detection or pressure ulcer prevention require low sampling frequency, due to minor movements. While, pressure measurement for posture detection require high sampling frequency.

2. ANALYTICAL PART

Prolonged uncomfortable sitting position at work or daily bases can cause physical fatigue due to higher muscle activity to maintain right posture. This can lead to mental and physical problems and lower the efficiency and safety of work. Fatigue can be detected by increased pressure value and concentration on particular points of the buttocks. Early detection of wrong sitting posture or increased pressure can prevent from medical conditions such as decreased immune system, endocrine disorders, cardiovascular diseases, etc. (Nakane *et al.* 2011). High pressure indication can be closing pressure of arterial capillaries, which is 33 mmHg (31.99683 kg/cm²), any higher values in measured place exerted on the capillaries can cause an impediment in the flow (Jun *et al.* 2016).

75% of mass is supported on a seat. In seated position fatigue and discomfort originates in regions of high interface pressure on the buttocks due to bone anatomy of the pelvis (Fig. 2.1). These regions include coccyx, ischium tuberosity (sit bones) and sacrum (Anderson *et al.* 2016). Rectangular area formed by highest pressure is approximately 6.4×8.9 cm, which can differ depending on people physique.

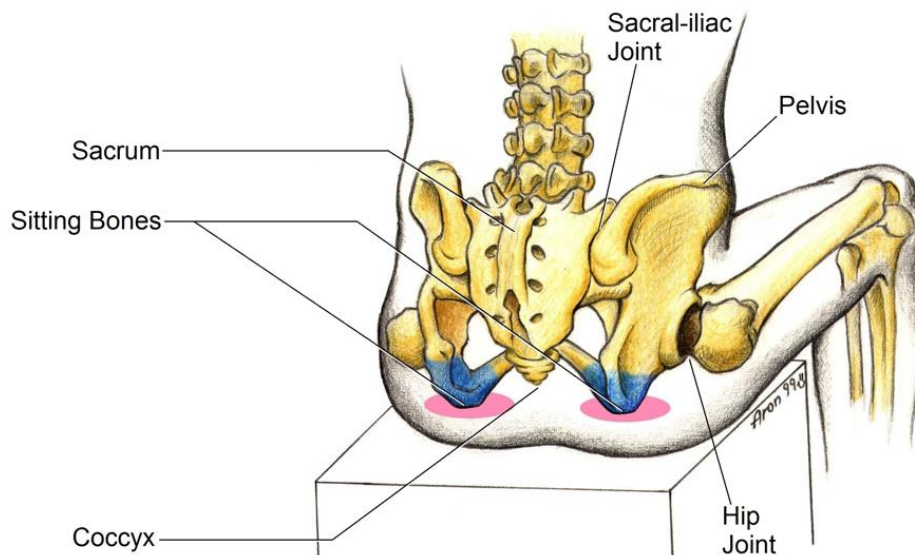


Fig. 2.1. Anatomy of pelvis (Cole 2007)

2.1. Sitting positions

There are no ideal position to sit for prolonged time or chair design that would allow prolonged sitting in one position. However, the main objective of relaxing or working in seated position is to remove

weight from lower body and maintain a stable posture. In this way, muscles not directly involved with the work can be relax.

Best-seated posture requires the least postural stress and muscles not stressed to maintain equilibrium in seated position. Sitting position like crossing and uncrossing legs let to distribute pressure in different places of buttocks and pump blood through its tissues. Upright position with head and torso vertically aligned, and knees flexed in 90° , known to be most suitable position for seated workplace. On the other hand, to maintain the torso straight causes increased muscular activity, which can lead to fatigue and lower back pain. Sitting postures close to neutral (upright position) require lower muscle force than lean forward positions. Abduction hip position can influence the sitting comfort by twisting the pelvis in an anterior tilt. Moreover, hip open position lowers the force of the muscles needed to maintain seated position (Bertolaccini *et al.* 2016).

In workplace environment, most of the seated postures adjusted to computer work. Most common position is lean forward, which can stress lower back area. While pelvis rotates backwards to compensate position to keep torso erect. In result, ligaments of posterior spine stretched, buttocks muscles shortened and normal lumbar lordotic curve lost. Afterwards, body tends to sit, stand and walk leaning forward, which requires higher lower back muscle force to keep upper body in balance (Haynes *et al.* 2008).

Lower back is normally lordotic, which is very important to keep this curve in seated positions, because it reduces pressure between the vertebrae. Rotational movements of the pelvis can affect lumbar vertebrae. Forward rotation of the pelvis, natural lordosis increases to maintain torso in upright position, floor supports 25% of body weight, center of the mass moves in from of sit bones resulting in higher seated pressure distribution. Rotating pelvis backwards flattens the lumbar spine and can increase the kyphosis, mass of upper body moved behind sit bones. This position supported by large, inclined backrest can be suitable for resting. Prolonged incorrect and uncomfortable sitting positions requiring high lower back muscle force or compressing vertebrae can lead to posture disorders (Fig. 2.2).

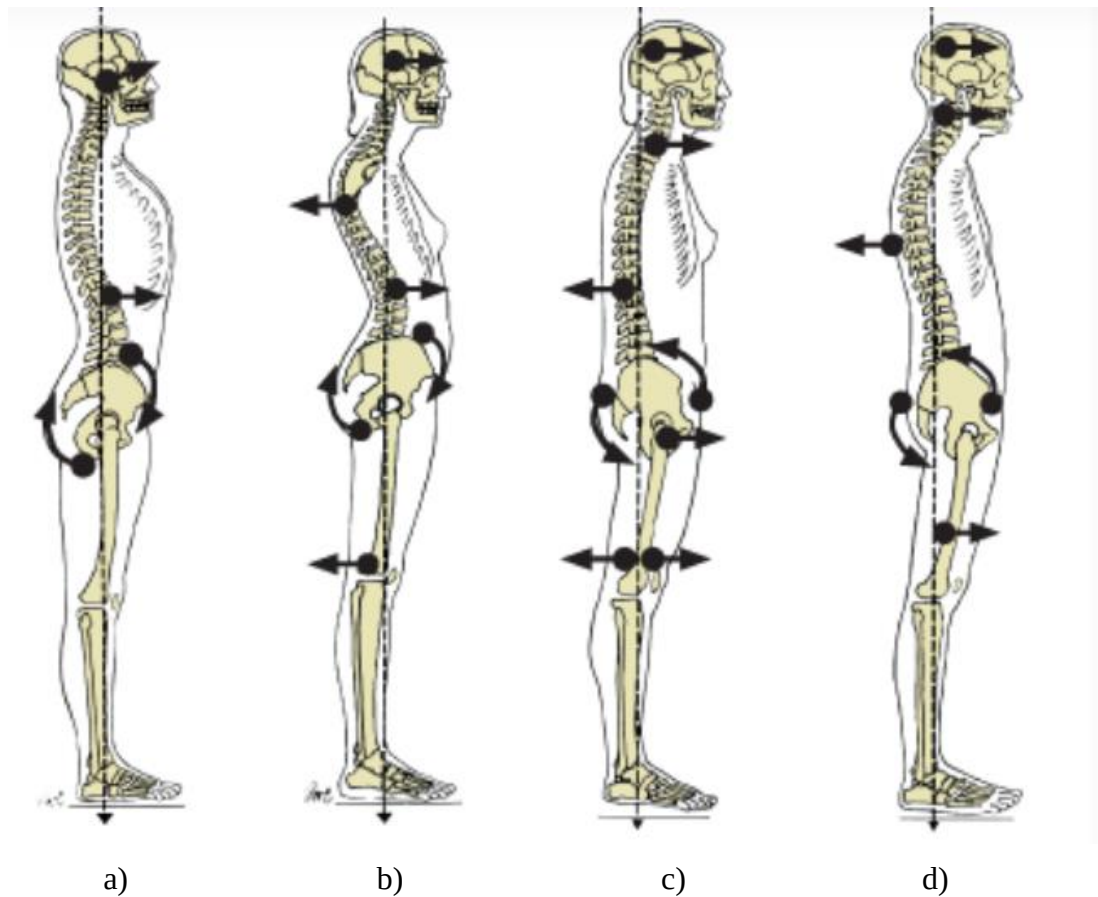


Fig. 2.2. Lumbar curvature disorders a) lordosis; b) kyphosis; c) flat back; d) sway back (Bertolaccini *et al.* 2016)

Lumbar curvature disorders can affect posture and sitting position leading to serious health issues. Lordosis with increased anterior lumbar curve can be caused of lean forward sitting position. Flat back indicated with decreased anterior lumbar curve can be caused by reclined sitting position without backrest support.

2.2. Chair design for supported sitting posture

Seat with easy adjustable parts can increase comfort and lower fatigue by supporting different sitting positions. Seat height should be adjustable for user physique to maintain 90 degrees knee angle. This would prevent leg from swelling. Regardless the height of the chair, swelling can occur due to prolonged sitting and low leg muscle activity. In addition, too high chair can cause pressure in popliteal

fold (underside of knees), increase pressure on the sitting nerve or reduce blood circulation in buttocks tissue (CU Ergo).

Seat pan cushions and contouring can distribute pressure from sit bones to larger area increasing comfort and support better posture. Needless over cushioning can cause movement constrain, lower blood circulation and compression under thighs, resulting in discomfort. Seat pan angled in 5-10 degrees, promotes to maintain contact with backrest and relaxes lower back muscles. Seat depth should not exceed the length of the femur otherwise, backrest of the chair won't be used. Unsupported back during prolonged sitting can cause fatigue due higher muscle activity to maintain upright position without support (Bertolaccini *et al.* 2016).

Backrest supports torso weight, if backrest is low it supports only lumbar region, which helps to maintain natural curvature of the spine. Higher backrests can support shoulder region and in utmost support neck and head, which is not practical in workplace environment due to restricted movements. Additional lumbar support pad can reduce force of lower back muscles and maintain natural lumbar lordosis, which supports healthy disc spacing and position in spinal column (Grondin *et al.* 2013).

Moreover, active seats with balance disk require lower muscle activity in inclined position while seated on static seat.

Comparing different positions regarding seat height, torso inclination or hips abduction less muscles activity observed in torso lean forward position.

2.3. Ergonomic measurements of seated workplace

One of the ways to monitor pressure distribution over sitting position and recognize the fatigue moments can be pressure measurement of the sitting surface to track highest pressure points (Nakane *et al.* 2011).

To find better conditions of required comfort seated in different chairs body pressure information is essential. Measured pressure distribution between body and seat surface can present information about seated comfort. In Lee *et al.* (2007) study hip pressure ratio evaluated as measurement parameter, which showed association with lower overall ratings (Lee *et al.* 2007).

Moreover, men and women require different seat adjustments, because of different pelvis structure and shape (Fig. 2.3). Female pelvis adapted for childbirth defined as lower, wider and more circular than male. Female sacrum also wider and tilted anteriorly with more supporting area in a sitting position (Delavier *et al.* 2014).

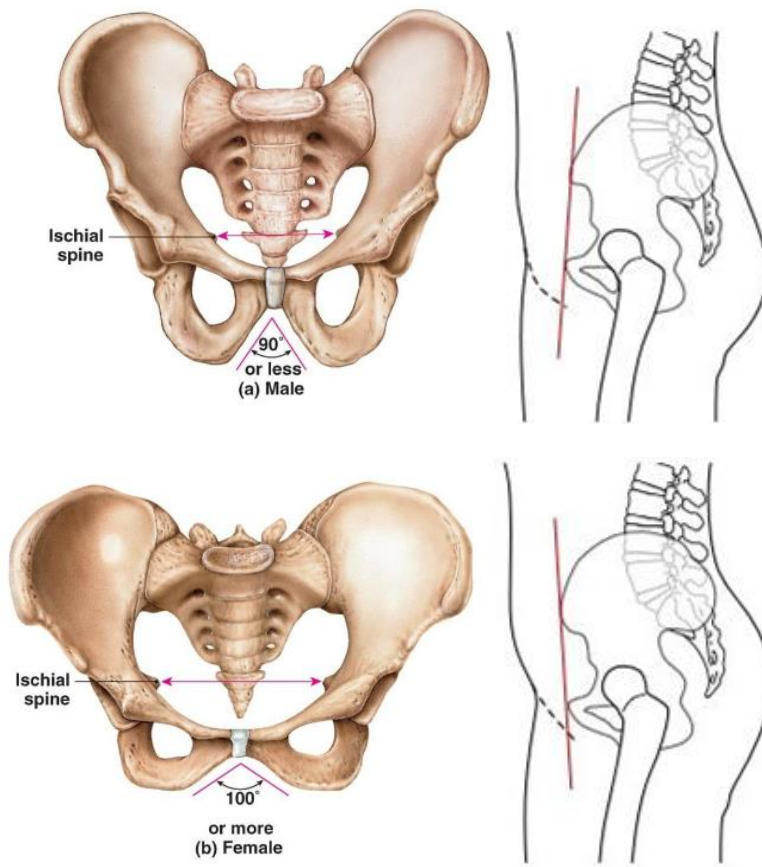


Fig. 2.3. Male (upper) and female (down) pelvis and rotation angle side view
(Delavier *et al.* 2014)

Postural disorders can be observed with pressure distribution measurements over sitting surface. If there is spinal inclination to right or left, pressure more concentrates in that side, as center of mass is shifted and more mass supported on particular buttocks area. Lordosis can be indicated with pressure concentrated in front of sit bones while, flat back can be see with pressure concentrated behind sit bones (CU Ergo).

3. EXPERIMENTAL PART

Methodology for ergonomic seated workplace measurements performed using pressure measuring mat. Robustness and usability for measurement hardware tested. For ergonomic measurements evaluated 16 test participants to find dependency of pressure distribution regarding body physique. Moreover, different seats evaluated for comfort in seated workplace position. Pressure distribution regarding gender and body mass assessed for influence on comfort in sitting position.

3.1. Methodology

Test of seated workplace ergonomics included three different types of seat: soft and adjustable office chair with backrest and armrests, static chair with cushion and backrest and hard sitting surface without cushion or backrest (Fig. 3.1). Test participants were 8 male and 8 female, age range 23-37. As the research aims to imitate natural office environment, regarding nowadays highly frequent work related musculoskeletal disorders of the upper extremities, 7 of participants have a slight formation of kyphosis or scoliosis. Relevant evaluation of participants mass and height dependency, chosen body mass index (BMI), which ranged from 19.4 kg/m² until 27.8 kg/m².

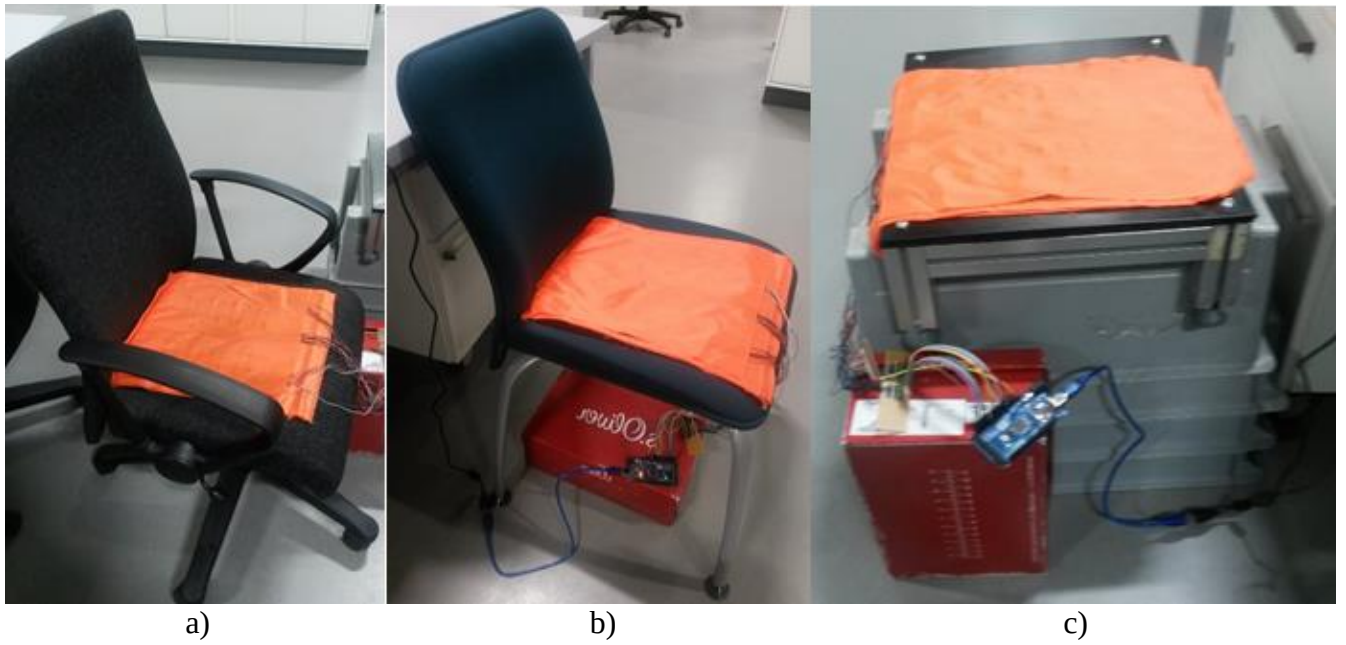


Fig. 3.1. Experimental chairs a) office chair with backrest and armrests; b) static chair with cushion and backrest; c) and hard sitting surface

During the measurements sensor mat was placed 10 cm from chair backrest. Test participants were measured sitting upright with legs bended in 90° angle, then reclined, laterally tilted (LT) right and left in approximately 30° angle and leg crossing positions (Fig. 3.2) referring to Zemp *et al.* (2016a).



Fig. 3.2. Sitting positions, on different chairs a) upright; b) reclined; c) laterally tilted (LT) right; d) laterally tilted left; e) right leg over left leg; f) left leg over right

Pressure distribution measurement of each position was taken after 30 seconds of sitting time. Each test participant was seated on office chair and taking upright sitting position for 30 seconds, then data

was recorded after changing to another position and recording data again. Afterwards, changing to the static chair with cushion and repeating process of measurements. Finally, test participant seated on hard surface measurements followed with same positions and measurements.

3.2. Adjustable pressure sensing mat

Sensor mat made out of force sensitive resistors (FSR-part no. 402, obtained from Interlink Electronics website), which approximately linearly responds in resistance with applied force change.

The matrix of sensors (4×4) was used for measurements. Each sensor fixed with adhesive tape on a mat, with sensing area 23×22 cm. Spacing between rows was 3 cm, spacing between columns – 5 cm. Sensor mat placed 10 cm from backrest of the chair. PCB board used for connecting sensors with 5 V input. Sensors connected as voltage divider with known resistance value of 3.3 k Ω , as sensor manufacturer recommends. Single-in-line (SIL) resistors used to connect output signal pins. For voltage supply and output measurements the Arduino MEGA 2560 microcontroller was used (Fig. 3.3). As only 16 sensors used no multiplexers needed to read the signal and supplied voltage is enough.

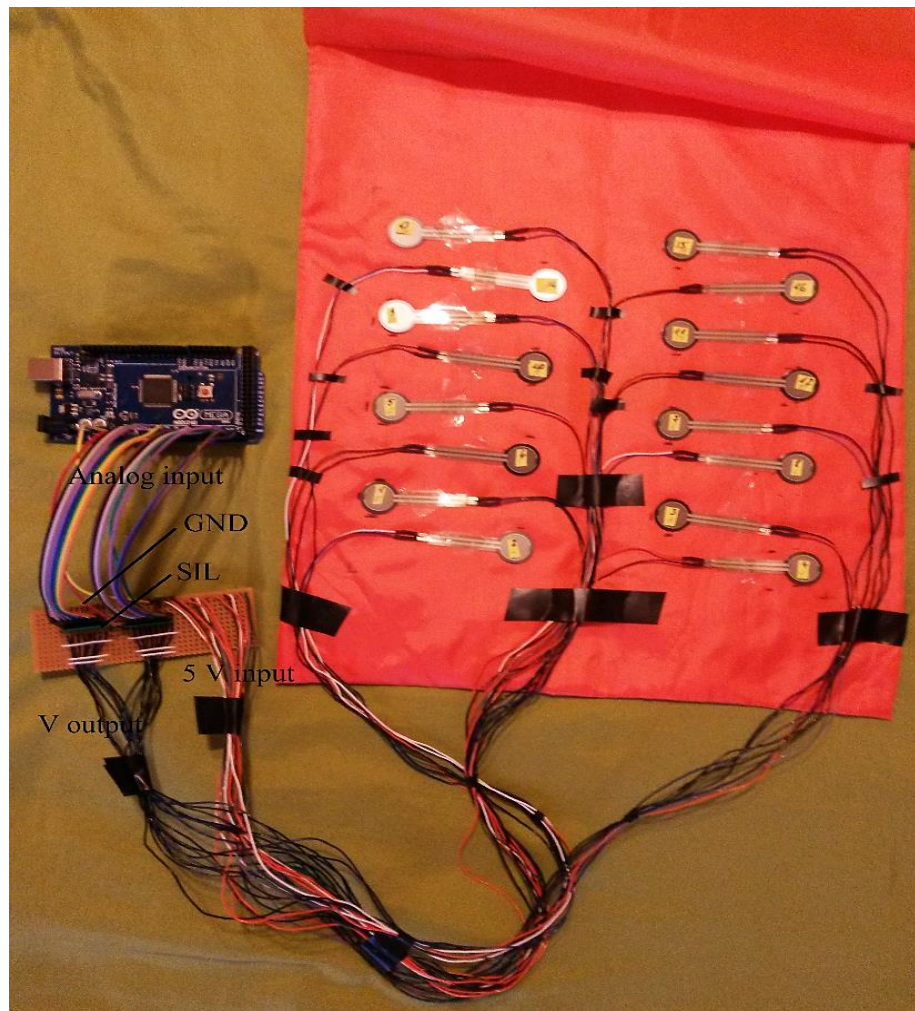


Fig. 3.3. Sensor mat and sensor connections

Sensors were calibrated with fixed weight of 120 g and 220 g, placing the weight in the center of sensing area. Voltage was measured using oscillograph giving 2,1 V and 2.6 V accordingly, values of each sensor was fluctuating, but did not overcome 10% of difference. Voltage dependency on applied mass was calculated using equation (3.1):

$$V = k \times w + x \quad (3.1)$$

Where, V – measured voltage, V; k - calculated factor; w – calibration weight, g; x – calculated factor. Applied formula for equation system (3.2), helped to find calculated factors.

$$\begin{cases} 2.1 = k \times 120 + x \\ 2.6 = k \times 220 + x \end{cases} \quad (3.2)$$

Where, k - calculated factor equals to 0.005 and x – calculated factor equals to 1.5.

In this case, all sensors were calibrated same way assuming that voltage change over the weight is linear, by formula (3.1). Sensor triggered by the weight no less than 100 g.

To evaluate and approve the chosen spacing of the sensors following tests were made. Sensor position was changed moving each sensor on a mat 2 cm closer to the center of the seat, resulting that some of the sensors had very little of pressure and did not reflected the movements of seated human body. Another test made by placing sensor mat 3 cm from chair front edge and 20 cm from backrest, obtained data did not reflected highest pressure points, but clearly visualized leg crossing positions. This show, having small number of sensors can represent critical data of most pressure places. Having more sensors that can cover all sitting surface can represent data of leg position more detailed. Furthermore, small spacing between sensors can result in very low readings of particular places where pressure is low.

The program of measurement reading and visualization created in MATLAB package *Simulink* (Fig. 3.4). The data from all 16 sensors obtained in 10 Hz sampling frequency and converted from voltage change to grams of force. The measured value from each sensor visualized as a square colored matrix (Fig. 3.5) corresponding to sensor placement in sensor mat. The data measured over time is stored in Matlab workspace, where it can be reused for further examinations.

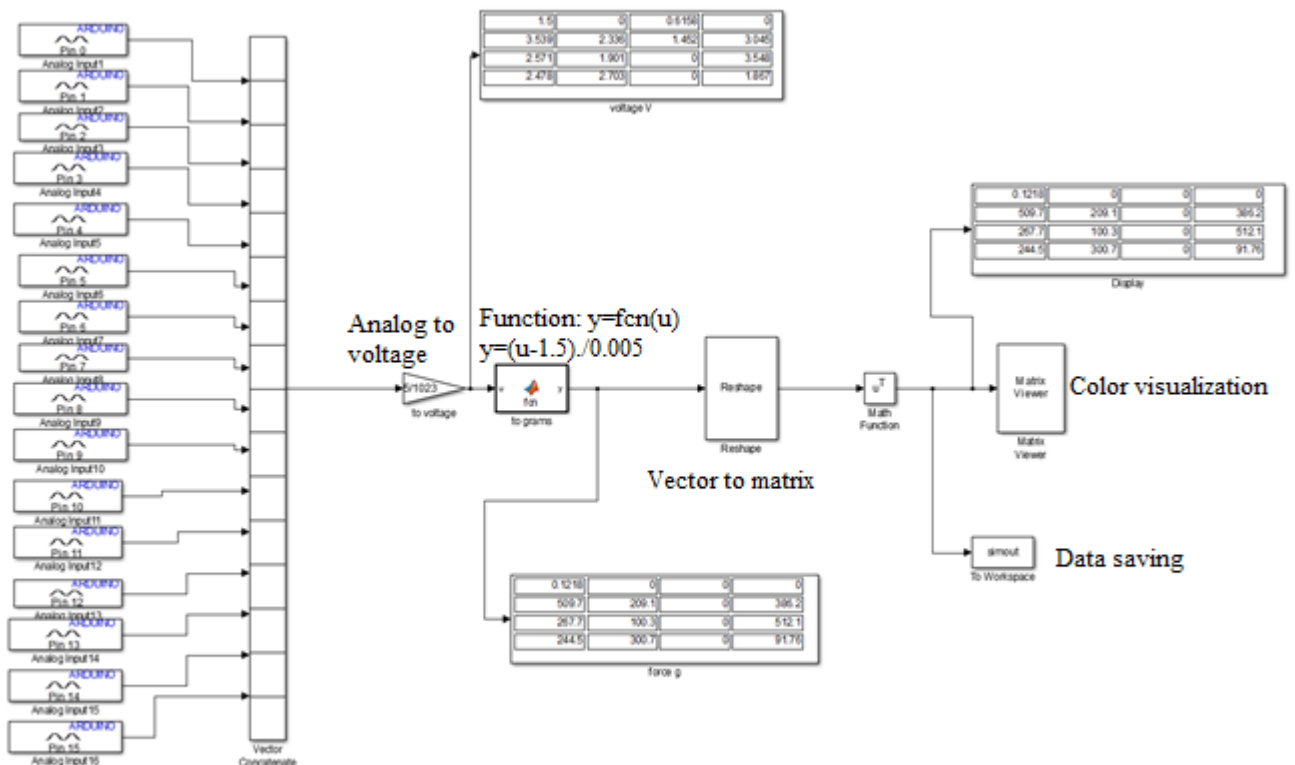


Fig. 3.4. Simulink program for data readings

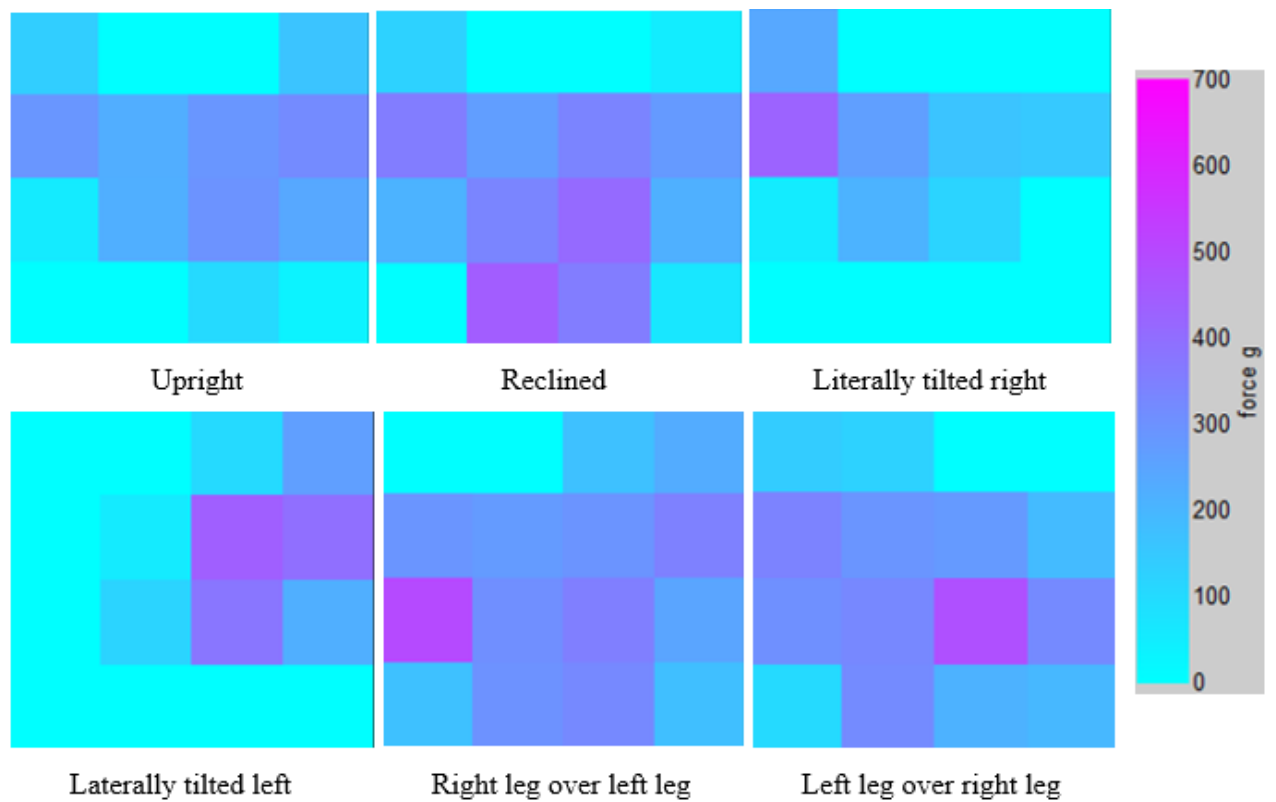


Fig. 3.5. Measured data in *Simulink* interface

Figure above illustrates Simulink visualization of measured data from sensor mat. Each square represents FSR sensor and obtained measured values of pressure. Images represent view from under seated chair.

Measured value can change from 20 g to 60 g depending on the sitting surface (hard or soft), because of this reason mat can be used for comparison of pressure of different parts, but not precise measurements of the weight.

3.3. Results and discussion

Measurements indicated highest pressure points under the sit bones (ischial tuberosity). For participants with lower BMI (under 20 kg/m^2) the pressure on hard seat surface concentrates in two points under sitting bones and compared to seat with cushion the force of pressure increases by 100 g. On the other hand, participants with higher BMI (from 27.5 kg/m^2) on the hard seat surface distribute pressure on surrounding points (Fig. 3.6).

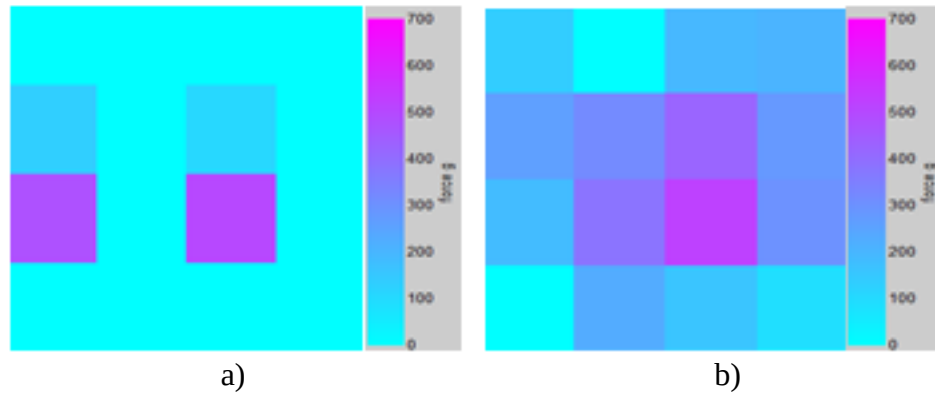


Fig. 3.6. Upright position pressure distribution on hard surface a) low BMI (20,3 kg/m²); b) high BMI (27,7 kg/m²)

Furthermore, pressure distribution regarding different seated positions and seat surfaces show big difference of body mass index influence (Fig. 3.7). Comparing test participants with high BMI and low BMI, 19.44 kg/m² and 27.74 kg/m² accordingly pressure distributes over wider area for high BMI test participant. As a result, of boney part of pelvis more exposed to the sitting surface for participants with lower BMI. Presumably, test participants with higher BMI values can sit longer on hard surface seats in different positions not experiencing fatigue or discomfort as fast as participants with low BMI can.

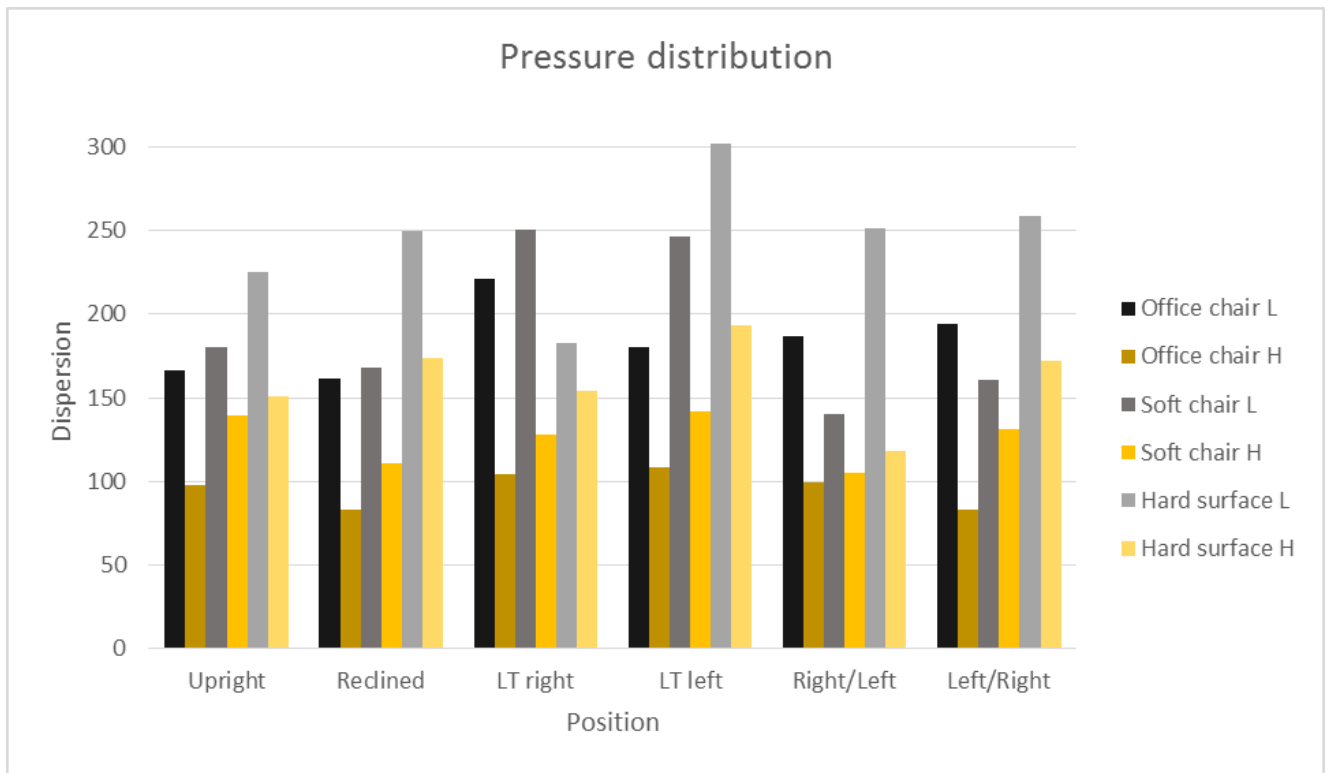


Fig. 3.7. Pressure distribution comparing low BMI and high BIM test participants on three chairs in all positions

Moreover, participants with higher BMI has very high pressure force values up to 780 g while seated on hard surface compared to other participants. On the other hand, on the seats with cushions pressure force values are lower and close to all the other participants, reaching average values up to 400 g.

Furthermore, participants suffering from spinal curvature disorders that are invisible, seated pressure distribution indicate right or left side higher-pressure values following in majority positions, while seated on hard surface (Fig. 3.8). Same participants seated on the cushion decrease the difference in pressure distribution value and problematic points are relatively indistinguishable.

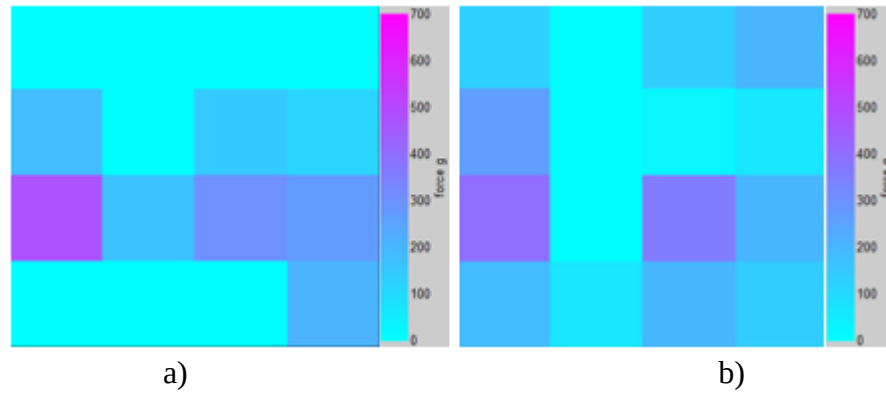


Fig. 3.8. Pressure distribution in upright position a) participant with spinal curvature disorder;
b) healthy test participant

Regarding the comparison of the seat surface and design office chair seated pressure measures 40-70 g lower values compared to static chair in all measured positions. In critical positions, LT right, left or crossed legs adjustable office chair distributes pressure in bigger area while static chair with cushion concentrates it in one/two points as well as increasing the value in 40-90 g (Fig. 3.9).

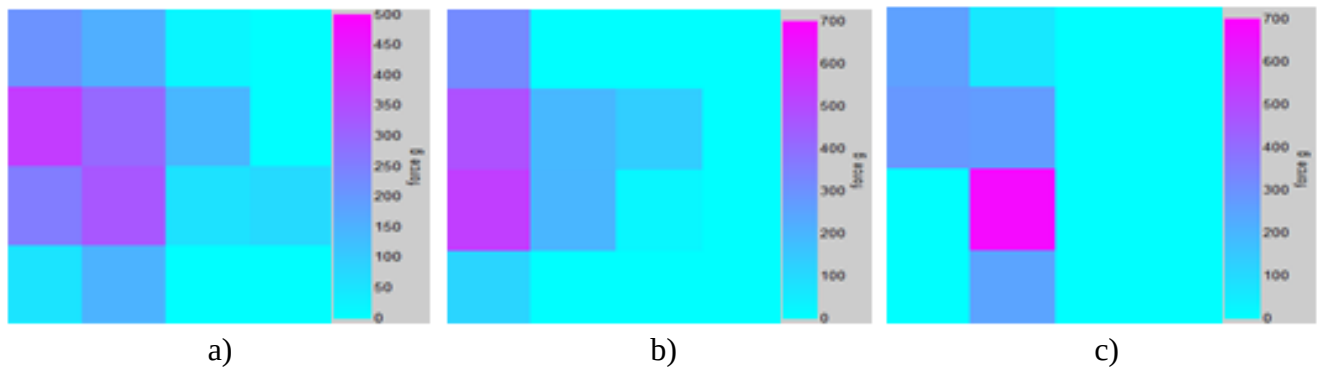


Fig. 3.9. Laterally tilted right position, pressure distribution on a) office chair; b) soft chair; c) hard surface

In relined position office chair distributes pressure, only low values (250-350 g) measured while, on the static chair highest pressure points are shifted back with the same pressure value. Furthermore, on hard seat surface in reclined position pressure is still concentrated on the sitting bones and pressure value increases, surrounding points distribute low values of pressure (200-350 g) (Fig. 3.10).

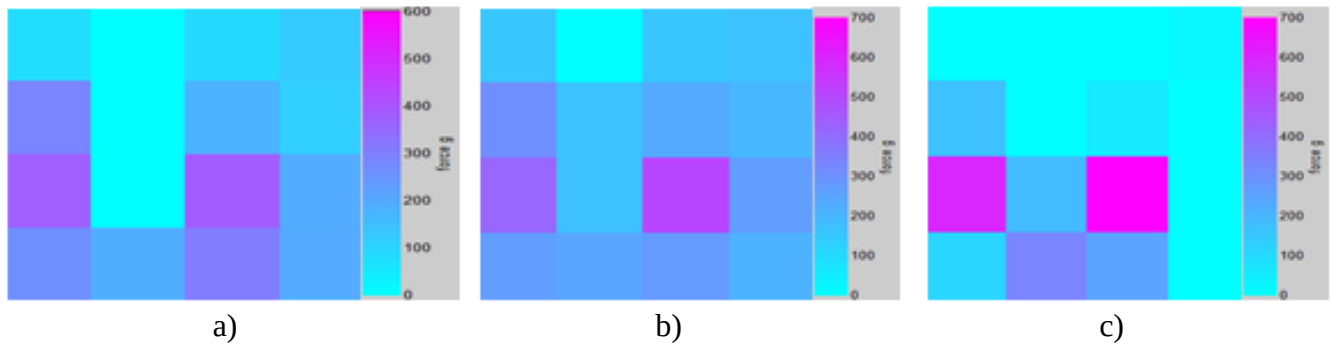


Fig. 3.10. Reclined position pressure distribution a) office chair; b) soft chair; c) hard surface

Leg crossing positions pressure distributes on two sitting bones while, on the adjustable office chair pressure is distributed gradually, the static chair shows slight increase of pressure in one side, which leg is lifted. Moreover, hard seat surface measurements shows high difference of pressure concentration under the lifted leg up to 100-200 g more than under other sitting bone (Fig. 3.11).

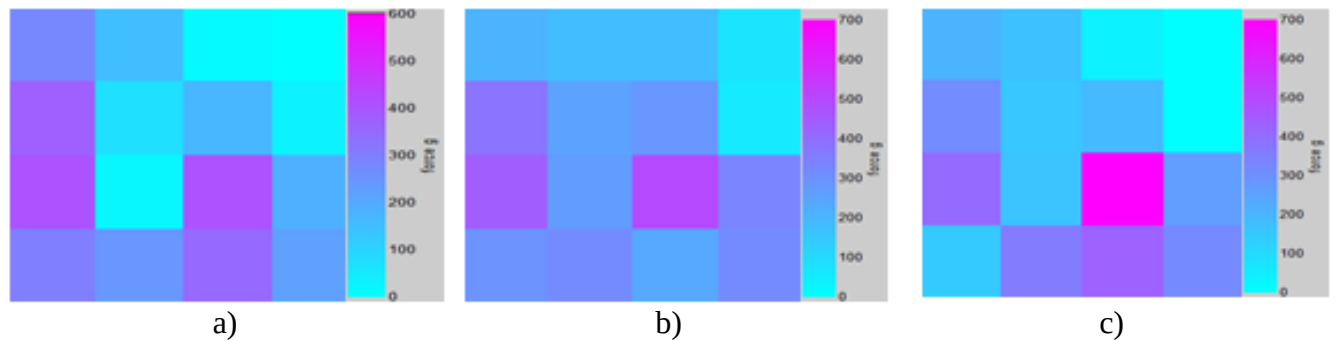


Fig. 3.11. Left leg over right a) office chair; b) soft chair; c) hard surface

Measurement of pressure distribution on hard surface has a huge peak of dispersion equal to 1400 g. It cause can be bad measurement or drift of sensor value. For faulty reason this measurement is not interpreted. Comparing test participants by BMI, clear pattern of pressure distribution change not observed. In the graph (Fig. 3.12) can be seen analysis of different seats, which shows higher measured pressure concentration on hard surface as bony part of the buttocks is not supported by cushion. Moreover, pressure distributed more on the office chair compared to soft chair. Although analyzed data is fluctuating, pressure concentration of office chair has pattern to decline with increase of BMI. Soft chair pressure distribution is fluctuating randomly. Pressure distribution regarding test participants height did not shown any dependency.

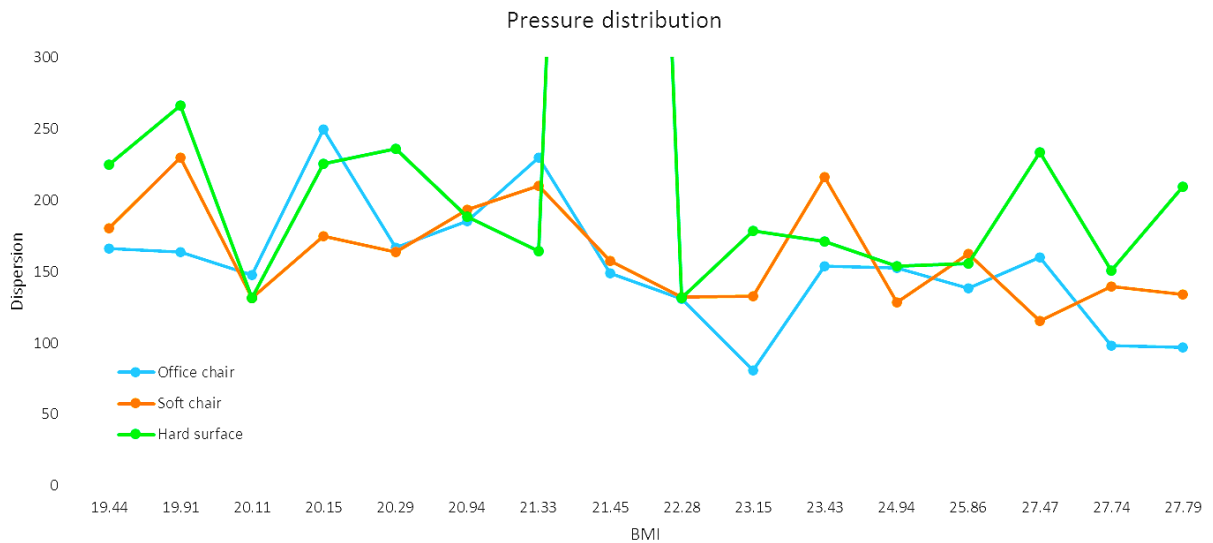


Fig. 3.12. Pressure distribution comparing different seats regarding test participants BMI

Comparing pressure distribution over different sitting surfaces in critical position like, crossed legs where pressure less distributed, due to reduced buttocks area on sitting surface. In comparison of male and female participants with different BMI (Fig. 3.13), can be noticed that male pressure is more concentrated regarding female and only distrusted when BMI increases over 27 kg/m². Difference of male and female pressure distribution occur from different skeletal structure in pelvis area. On hard surface seat all participants experience high concentration of the pressure indicating low comfort of sitting. Pressure better distributed over office chair and soft chair surfaces.

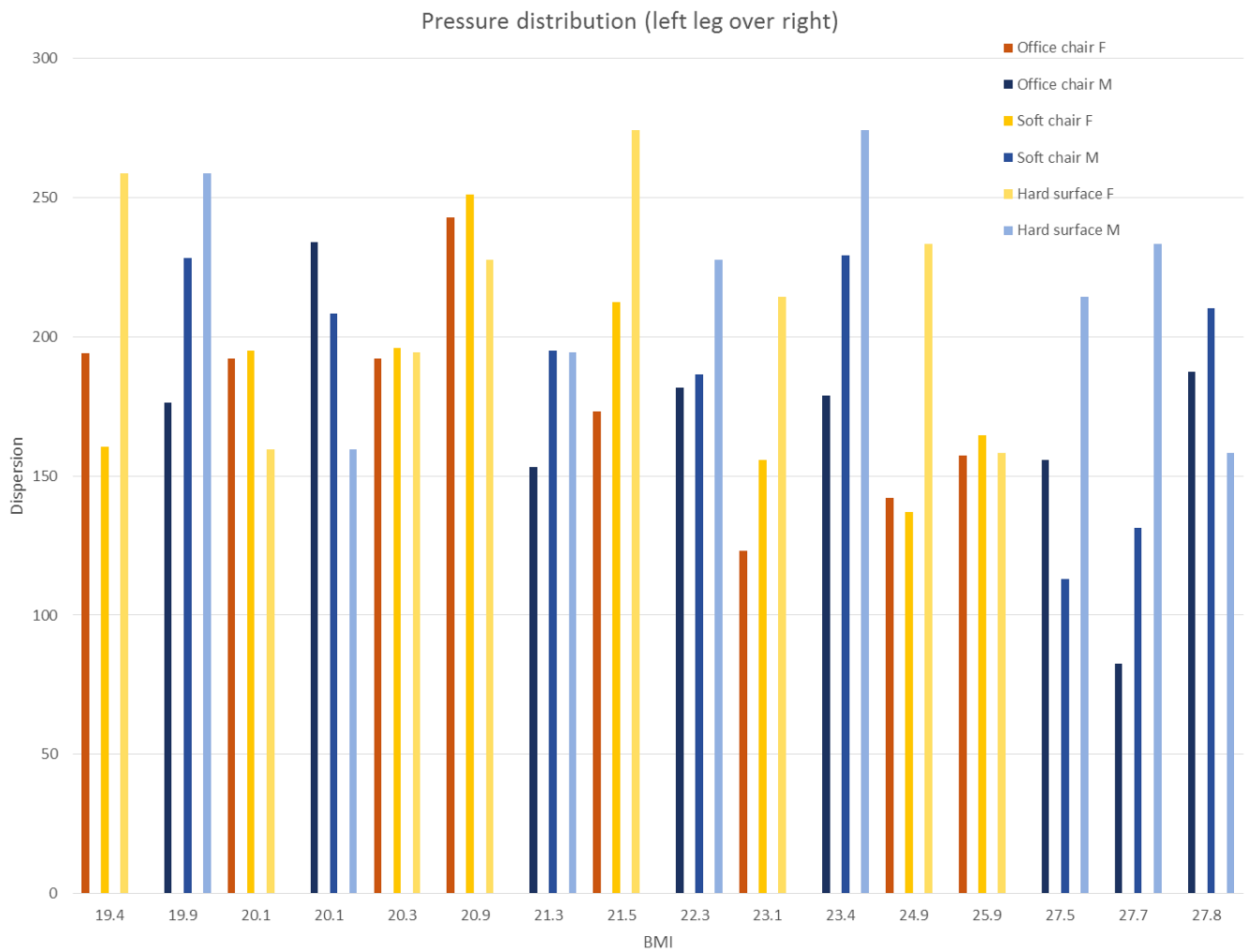


Fig. 3.13. Pressure distribution comparing in crossed leg position

In the graph below (Fig. 3.14), compared male and female test participants with close BMI values, 19.9 kg/m² and 20.1 kg/m² accordingly, it shows that female distributes more pressure on soft or hard surfaces than male. According to human anatomy, female has wider pelvis bones and higher concentration of subcutaneous fat in buttocks and hips area compared to male. Regarding the sitting position male test participant concentrates more pressure upright and reclined positions in particular on hard or soft chairs.

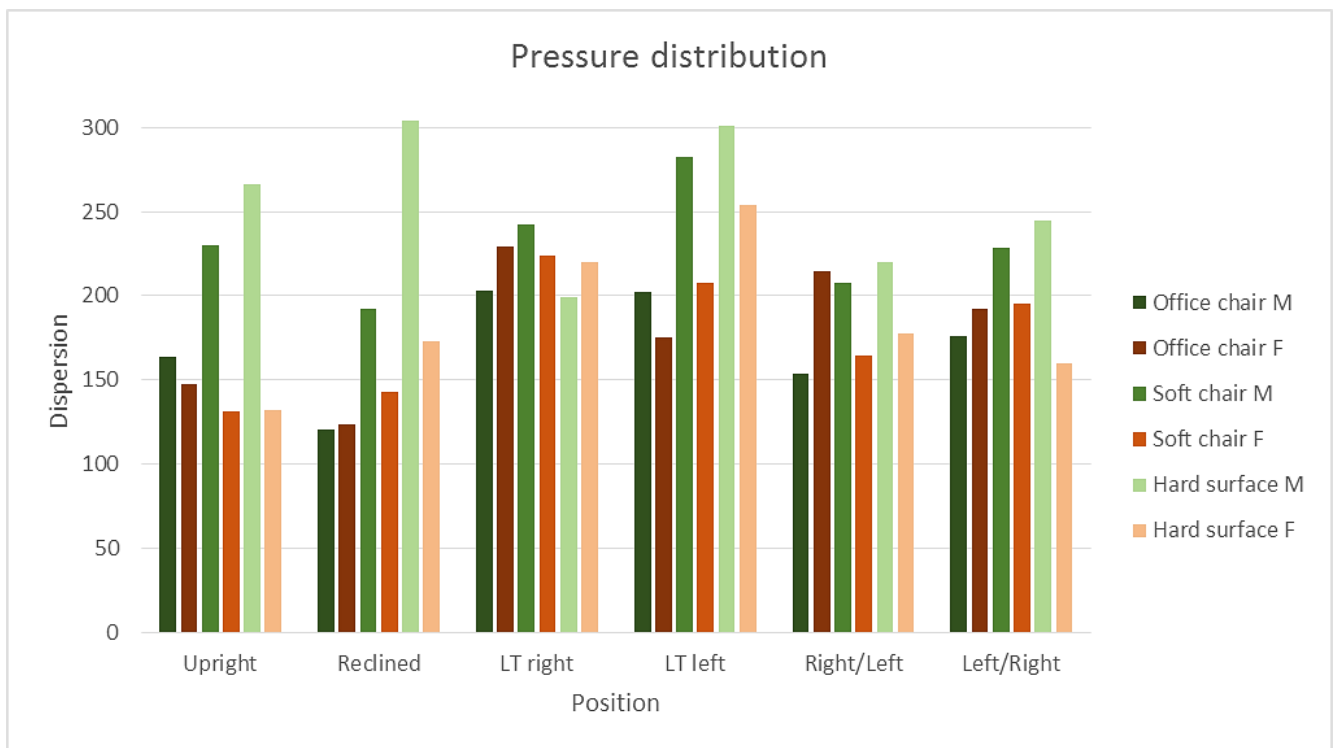


Fig. 3.14. Pressure distribution comparing male and female of similar BMI values, in different position, on three different chairs

Pressure distribution of male and female test participants regarding the height shown in the graph below (Fig. 3.15). Comparing two participants of similar height and BMI male: 182 cm and 23.43 kg/m² and female: 180 cm and 23.15 kg/m², to see if the length of the legs have influence on pressure distribution. According to human anatomy, female legs are shorter, nevertheless it does not have impact on pressure distribution regardless seated position or surface. Seated male pressure is more concentrated because of sharper pelvis bones and lower subcutaneous fat layer in buttocks area. It is possible that pressure distribution over the legs area for male and female participants can defer regarding the length of the legs, however it was not measured and pressure distribution over buttocks area dependency does not illustrate difference in leg length.

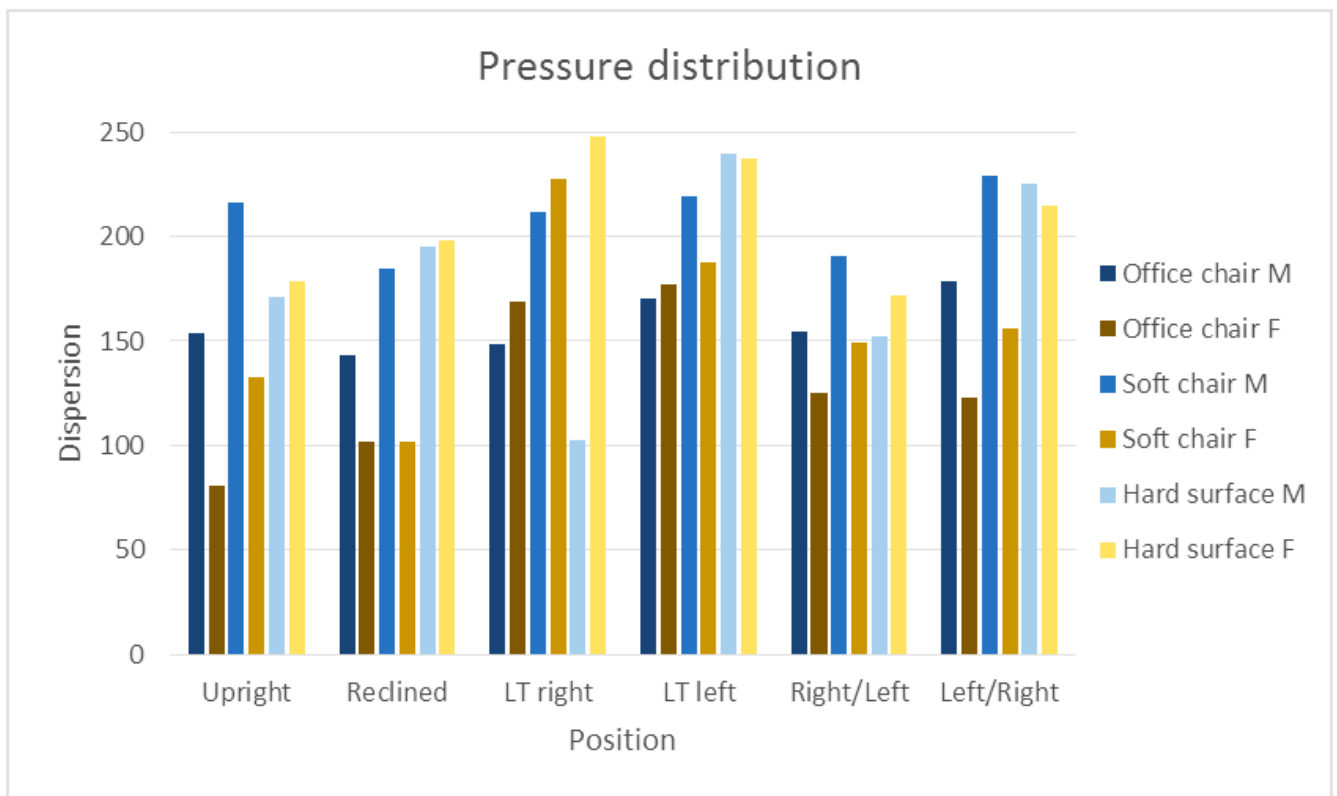


Fig. 3.15. Pressure distribution comparing male and female of similar BMI values and similar height, in different position, on three different chairs

Normal BMI for healthy person is from 18.5 kg/m^2 until 25 kg/m^2 , which make average of 21.75 kg/m^2 . Taking test participants with similar deviation from average of 1.68 kg/m^2 and 1.64 kg/m^2 for male and female accordingly. We can test if a female body anatomy satisfies pressure distribution better than male with higher BMI. Male with 23.43 kg/m^2 and female with 20.11 kg/m^2 BMI comparison (Fig. 3.16) show body mass distribution very similar, although male pressure is more concentrated especially in critical positions over hard surface.

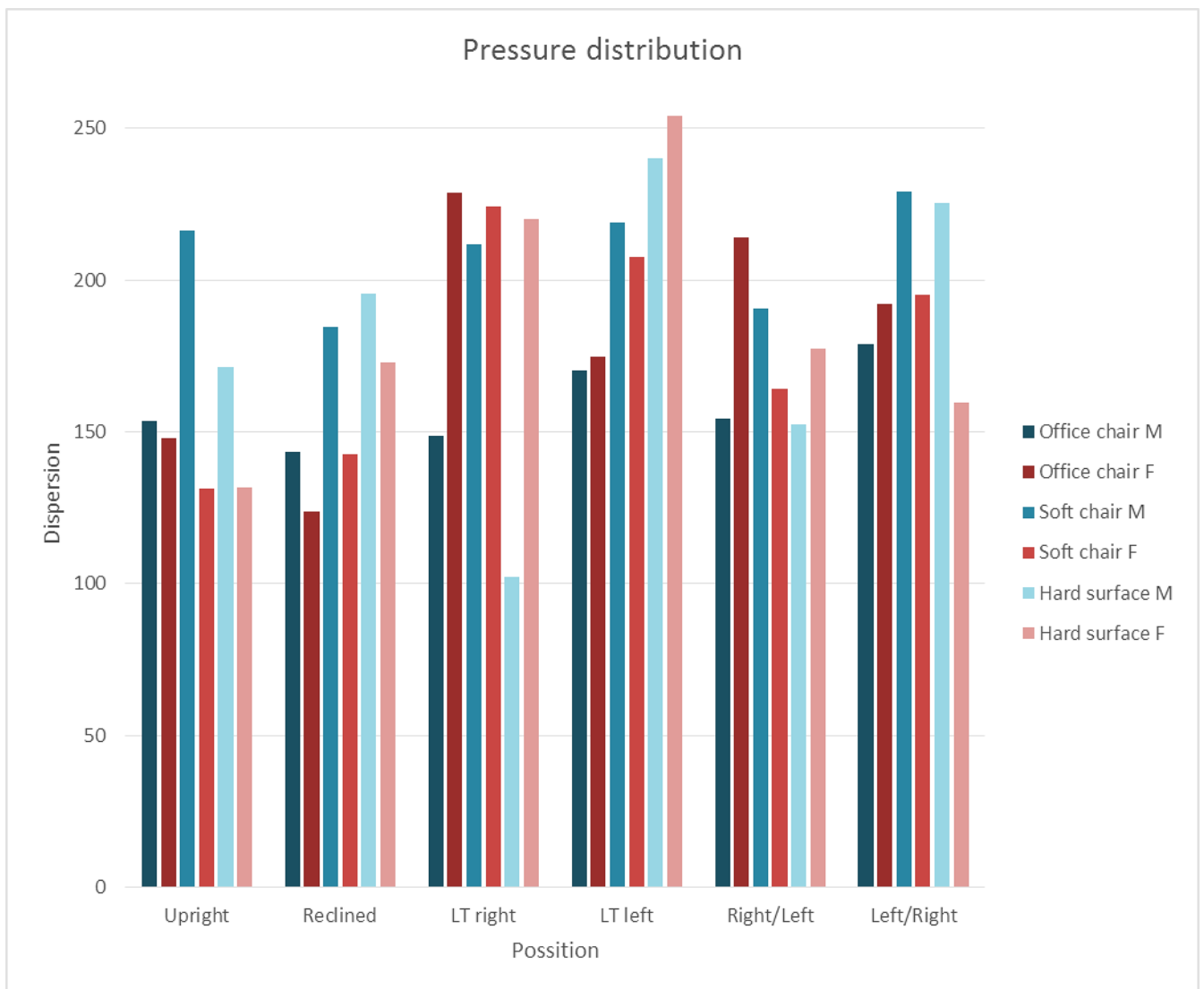


Fig. 3.16. Pressure distribution of male and female, in different position, on three different chairs

Regarding acquired data we can assume that female body anatomy is more efficient compared to male with higher BMI. Male seated on hard surfaces exposed to higher discomfort than female. Moreover, male faster experience fatigue in sitting position and need additional attention when choosing seat. Confirming this assumption would require experiments with more test participants.

3.4. Statistical calculations

Data measured from each sensor is acquired in matrix of 4×4. Measured resistance change values from sensors transformed to grams of force. Examples, of acquired one measurement matrix shown in the table 3.1.

Table 3.1 Pressure distribution measurement matrix

160.2	129.6	179.7	178.5
309.3	217.6	248.2	211.5
188.3	249.4	212.7	244.7
61.22	177.3	127.2	102.8

For ergonomic workplace analysis, test participants of different weight tested. To have comparable data of pressure distribution, data normalized depending on test participant weight, as shown in equation 3.3:

$$C = \frac{100}{m} \quad (3.3)$$

Where, C – multiplication coefficient depending on each participant weight; m – mass of test participant, kg.

Calculated C coefficient is multiplied to each sensor data. As example, test participant of 75 kg mas, measured pressure distribution shown in table 3.1, its multiplication coefficient equals to 1.33, in conclusion normalized pressure distribution matrix shown in table 3.2.

Table 3.2 Normalized pressure distribution measurement matrix

213.066	172.368	239.001	237.405
411.369	289.408	330.106	281.295
250.439	331.702	282.891	325.451
81.4226	235.809	169.176	136.724

To evaluate test participants of different physique chosen body mass index (BMI) representing height and mass. Calculation of BMI shown in formula 3.4.

$$BMI = \frac{m}{h^2} \quad (3.4)$$

Where, BMI – body mass index, kg/m^2 ; m – mass, kg ; h – height, m .

To compare pressure distribution of different test participants on different seats dispersion calculated from each normalized matrix. Firstly, arithmetic mean calculated using formula 3.5:

$$a_e = \frac{1}{n} \sum_{i=1}^n x_i. \quad (3.5)$$

Where, x_i ($i = 1, 2, \dots, n$) measured pressure from each sensor; n – number of sensors equal to 16.

Dispersion represents two meanings: first, it compares the variation of the measured values among themselves, and second, it shows the variation around the average measurement (Bowley 1939). If the difference between the value and average is high, then dispersion will be high meaning that pressure is very concentrated in couple of points and others are zeros or measure very low values. Otherwise, low dispersion shows high distribution of pressure over seated surface, meaning more comfortable sitting. Formula of dispersion shown below:

$$D_e = \frac{1}{n} \sum_{i=1}^n (x_i - a)^2 \quad (3.6)$$

Where, x_i ($i = 1, 2, \dots, n$) separate measured results from one sensor; a – mean value of measurement from all 16 sensors.

Calculated values of dispersion presented in the tables 3.3 and 3.4.

Table 3.3 Parameters of test participants and dispersion of measurements on office chair

No.	Height, m	Weight, kg	Coef., C	BMI, kg/m ²	Age	Back disorders	Office Chair					
							Upright	Reclined	LT right	LT left	Right/ Left	Left/ Right
1	1.80	63.0	1.59	19.44	24	Yes	166	162	221	180	187	194
2	1.79	63.8	1.57	19.91	24	Yes	163	121	203	202	153	176
3	1.77	63.0	1.59	20.11	23	-	148	124	229	175	214	192
4	1.74	61.0	1.64	20.15	23	-	250	198	235	280	228	234
5	1.66	55.9	1.79	20.29	33	-	167	91	195	241	166	192
6	1.65	57.0	1.75	20.94	24	-	186	130	180	228	223	243
7	1.85	73.0	1.37	21.33	28	-	230	93	162	159	150	153
8	1.63	57.0	1.75	21.45	29	-	149	89	201	225	163	173
9	1.82	73.8	1.36	22.28	25	Yes	131	111	172	179	157	182
10	1.80	75.0	1.33	23.15	24	Yes	81	102	169	177	125	123
11	1.82	77.6	1.29	23.43	24	Yes	154	144	149	170	154	179
12	1.74	75.5	1.32	24.94	25	Yes	152	102	165	161	160	142
13	1.72	76.5	1.31	25.86	24	Yes	138	99	151	151	146	157
14	1.85	94.0	1.06	27.47	37	-	160	131	173	174	140	156
15	1.83	92.9	1.08	27.74	25	-	98	83	105	108	99	83
16	1.67	77.5	1.29	27.79	28	-	97	151	220	219	171	188

Table 3.4 Dispersion of measurements on soft chair and hard surface

No.	Soft chair						Hard surface					
	Upright	Reclined	LT right	LT left	Right/ Left	Left/ Right	Upright	Reclined	LT right	LT left	Right/ Left	Left/ Right
1	180	168	251	247	140	160	225	250	183	302	251	259
2	230	192	243	283	208	228	266	304	199	301	220	244
3	131	143	224	207	164	195	132	173	220	254	177	160
4	175	153	215	248	195	208	226	239	238	204	243	264
5	164	156	225	258	188	196	236	227	179	238	285	194
6	193	152	211	270	211	251	188	231	220	263	195	228
7	210	165	223	278	207	195	164	184	238	204	232	197
8	158	126	244	290	164	212	1409	295	220	297	1031	274
9	132	135	213	220	169	187	132	132	219	196	135	202
10	133	102	228	188	149	156	179	198	248	238	172	214
11	216	184	212	219	190	229	171	195	102	240	152	225
12	128	93	207	208	136	137	154	187	218	219	211	233
13	163	126	213	211	169	165	155	199	174	210	167	158
14	115	117	197	171	104	113	234	233	177	198	192	191
15	139	111	128	142	105	131	151	174	154	194	118	172
16	134	147	202	205	152	210	209	238	281	202	287	283

Presented tables show parameters of 16 test participants including multiplication coefficient C required for data normalization and information of spinal curvature disorders. Measured pressure dispersion indicated for each chair and sitting position. This data used to illustrate pressure distribution in the graphs.

CONCLUSIONS AND DISCUSION

In this research, tests of ergonomic pressure measurements in seated workplace performed. Obtained results:

1. Created adjustable pressure measuring mat is robust, low cost and non-intrusive suitable for seated pressure evaluation;
2. Quantity and spacing of the sensors sufficient for ergonomic studies;
3. Pressure is highly distributed while sitting on soft cushion seat regardless body mass or sitting position;
4. Ergonomic pressure measurements on sitting surface can show spinal curvature disorders;
5. Pressure distribution depending the height of test participants was not found;
6. Measurements of male ergonomic pressure show high concentration resulting in discomfort and fast fatigue compared to female;
7. Measurements show possible evaluation of the chair regarding comfort and adjustability for people with different physique.

Future works

For better evaluation of sitting positions, sensors on backrest of the chair should be included in the measurements. Moreover, adding more sensors covering all seat surfaces would let to represent leg position in details. Furthermore, sensor mat for measurements should be easily fixed on any type of surface to avoid slips or bends of the mat. To better analyze fatigue and time when it occurs, measurements of seated test participant should be longer. To analyze dependency of pressure distribution regarding gender more participants needed. For sophisticated ergonomic study, the outcomes of the measurements should be reviewed and interpreted by physiotherapist.

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APPENDIX

A.1. APPENDIX. POSTER



Research of human ergonomic pressure adjustment to the sitting surface

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Introduction

Analysis of human fatigue in a seated working place based on pressure measurements is not widely investigated. Most papers of pressure measurements [1] made to prevent development of pressure ulcers for disable people in wheelchairs [2]. The motivation for this topic comes from fatigue behavior of human tests and ergonomics of seated working places. Sitting in uncomfortable chair requires greater muscular force and control to maintain stability and equilibrium, which leads to fatigue and discomfort [3].

Methods

Pressure sensing is done with Interlink Electronics force sensing resistors (FSR-part no. 402), which increase the resistance with increasing force applied on the sensing area. Sensor connected with resistor of known value creates voltage divider, where drop of input voltage corresponds to weight applied on the sensor. The matrix of sensors (4x4) was used for measurements. The measuring matrix is fixed with sensing area 24x22 cm. Sensor wires connected on PCB boards, resistors with fixed value of 3.3 k Ω single-in-line (SIL), for voltage supply and output measurements the Arduino MEGA 2560 microcontroller were used (Fig. 1). The program of measurement reading and visualization is created in Matlab package Simulink. Values of sensors are visualized as color matrix corresponding to sensor placement.

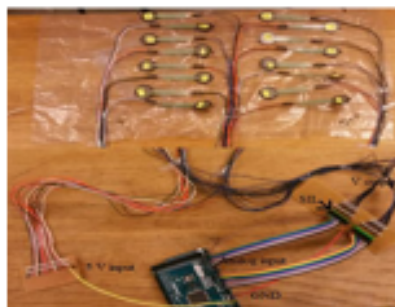


Fig. 1. Measuring mat and sensor connections

Results

Obtained results (Fig. 2) were corresponding to change of the position of analyzed person. Sensor mat was placed 8 cm from chair backrest and 16 cm front edge. Highest pressure points were under the sit bones (ischial tuberosity).

Another test was made by placing sensor mat 3 cm from chair front edge and 20 cm from backrest, obtained data did not reflect highest pressure points, but clearly visualized leg crossing positions. Results show, having small amount of sensors can represent critical data of most pressure places.

Having more sensors that can cover all sitting surface can represent data of leg position more detailed. Furthermore, small spacing between sensors can result in very low readings of particular places where is low pressure. Spacing of the sensors also depends on tested body anatomy for important data reflection.

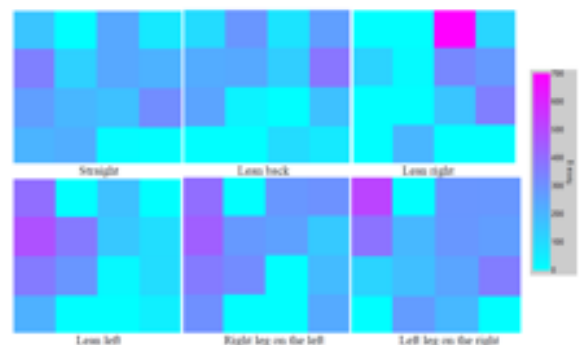


Fig. 2. Measuring mat and sensor connections

Discussion

Measured value can change from 20 g to 60 g depending on the sitting surface (hard or soft), because of this variation precise tests has to be performed on different surfaces. For this reason mat can be used for comparison of pressure of different parts, but not precise measurements of the weight. Humans of different body physique should be tested to find optimal spacing of the sensors.

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A.1. APPENDIX. ARTICLE

RESEARCH OF HUMAN ERGONOMIC PRESSURE ADJUSTMENT TO THE SITTING SUFACE

Abstract. In this research, the adjustable pressure-measuring mat designed referring to review of other authors studies. Hardware is build using Interlink FSR402 sensors in matrix 4×4. The program of measurement reading and visualization created in Matlab package Simulink. Created pressure measurement mat is robust, low cost and non-intrusive suitable for seated pressure evaluation. Sensor spacing tests illustrate that, having small amount of sensors can represent critical data of most pressure places. Ergonomic study made taking pressure measurements of 16 participants on the three different seats. Each participant represented six common seated workplace positions. Ergonomic study showed equal distribution of pressure when seated on the soft cushion regardless sitting position or body anatomy of test participants. Hard seat surface shows higher pressure values and concentration in two points representing sitting bones (ischial tuberosity).

Keywords: pressure sensing mat, FSR, Simulink, ergonomic tests, different sitting surface.

Introduction

With the introduction of the computer, office workers are now sitting for the majority of the day. Many adults spend 70% of their waking hours sitting and little or no time exercising. Increased seated time matches with grow of Work related musculoskeletal disorders of the upper extremities (WRMSDs) (Plantard et al. 2015). Most office workers affected by WRMSD experience pain in the back, neck or shoulder and functional impairment.

For measurements of seated comfort different studies were made using electromyography, motion tracking systems, spinal shrinkage, subjective comfort or discomfort ratings and pressure distribution measurements of the seat pan and the backrest (Zemp et al. 2015). Overviewing the studies regarding WRMSD self-reports questionnaire is not a very reliable method to measure postural load. The challenge to develop quick and inexpensive techniques for assessing exposure to postural load at seated office work position is still in demand (Heinrich et al. 2004). Pressure measurements of the sitting surface and in some cases, backrest too is one of the most common methods to analyse or compare different chairs or sitting positions because of cheap and easily applied measurement systems (Zemp et al. 2016a).

The influence on back pain regarding sitting behavior in office environment was analysed by Zemp et al. (2015). A textile pressure mat of 64 sensor matrix was placed on the seat pan and used to identify sitting positions of 20 office workers. It was found that static sitting position resulted in back pain In addition, study system showed the importance of comparison between subjects with and without back pain.

Zemp et al. 2016b) determined most meaningful pressure parameters for different office chairs. It was found that sensor mat has to be calibrated for specific chair because of chair material properties and geometry influences the measurements. The most important pressure parameters in the seat pan are total contact area, pressure force and it's, maximum and mean gradient, which defined by the geometrical addition of the pressure derivative of the two sensor mat directions.

Textile-based sensor mat called Smart Cushion developed by Xu et al. (2013) using binary pressure data distribution represented by grey scale image applied for posture recognition was easily foldable for transportation and adjustable for different surfaces. Meyer et al. (2010) proposed capacitive textile sensor array cushion for measurements of human body pressure distribution. Used sensing mat consisted of 19 pressure sensors placed over seat and backrest. Created sensing system was able to recognize seated workplace positions.

Sensing mat systems for disable people in wheelchairs can be easily adopted for seated workplace ergonomic and pressure measurements. Fard et al. (2013) presented system for monitoring of surface pressure in prevention of pressure ulcers. 8×8 matrix of pressure sensors used in system allowed continuous monitoring of body pressure distribution on sitting surface. Another smart cushion presented by Yu et al. (2010) installed with pressure sensors for chronic back pain prevention. Monitoring system for wheelchair users proposed by Saenz-Cogollo et al. (2016) was able to detect pressure relief tilts and give reminder for posture change.

Commercial product for seated pressure measurements I-Scan System developed by Tekscan consists of 2000 pressure sensors and can accurately measure and analyse pressure between surfaces. Other products like smart cushions are DARMA and SENSIMAT measures and monitors pressure on sitting surface, recognizes postures and sitting habits. Both products have 6 sensors and similar deployment. DARMA system consists of fibre optic sensors, which are more sensitive and accurate compared to pressure sensors. Mat can track sitting time, position, heartbeat and respiration as well as provide stand-up reminders and posture advice. While SENSIMAT is more focused on wheelchair users providing reminders to the user via mobile device when to move and can track progress over time. Ma et al. (2017) proposed sensing module with

FSR-406 pressure sensors by Interlink is easily deformable on the chair surface. Using Arduino DUE sensors data collected and processed and results are sent to smartphone using wireless connection. Few pressure sensors are individually connected to processing unit making system more cost economic and less power consuming. Parameter comparison of different studies and commercial created sensor mats presented in table 1. Current research involves analysis of different types of seat cushion system. Up to a certain point, it is based on reviewing other authors research works aimed to study pressure measurement distribution for workplace ergonomics, ulcer prevention purposes and sensing mat designs.

Table 1. Represents comparison of different existing systems and their parameters

Studies	Matrix	Pressure measuring range	Max Pressure	Contact area (cm ²)	Sampling frequency (Hz)
Medilogic	43×43	0 - 2.75(N/cm ²)			100
Min et al. 2016	16×16	0 – 1.33(N/cm ²)	1.36(N/cm ²)		0.083
Junrong et al. 2013		0.2 – 10(N/cm ²)			60
Anderson et al. 2013	48×48	0.14 - 2.7(N/cm ²)	1.68(N/cm ²)	1168	
Fard et al. 2013	8×8			30x40	3
Zemp et al. 2015		0-60 (kPa)			10
Jawad et al. 2017	4×4			23.5x21.5	77

In this research, the adjustable pressure-measuring mat designed and used to perform ergonomic analysis of seated workplace. Sensor mat is cheaper than commercial products moreover, it is flexible easily adjustable to different seat designs. Research analyses the robustness and usability of created sensor mat, and applies it to explore human pressure distribution on different surfaces (different size of seat cushions and design of chair).

2. Methodology

Pressure measurements were performed by force sensing resistors (FSR-part no. 402, obtained from Interlink Electronics website), which approximately linearly responds in resistance with applied force change. In the study of Parmar et al. (2017) different types of pressure sensors were tested and Interlink FSR force sensing resistors showed high consistency during pressure application and high repeatability. These sensors gave fast and accurate response compared to other tested sensors when dynamic force is applied, therefore, they are highly suitable for pressure measurements of sitting surface. Sensor connected with resistor of known value creates voltage divider, where drop of input voltage corresponds to force applied on the sensor.

The matrix of sensors (4×4) was used for measurements. Each sensor was fixed with adhesive tape on a mat, with sensing area 23×22 cm. Spacing between rows was 3 cm, spacing between columns was 5 cm. Two separate PCB boards were used for easier sensor adjustment and mobility. One PCB board connects sensors with 5 V input, another with single-in-line (SIL) resistors of 3.3 kΩ value and output signal pins. For voltage supply and output measurements the Arduino MEGA 2560 microcontroller was used (Fig. 1). As only 16 sensors used no multiplexers needed to read the signal and supplied voltage is enough.

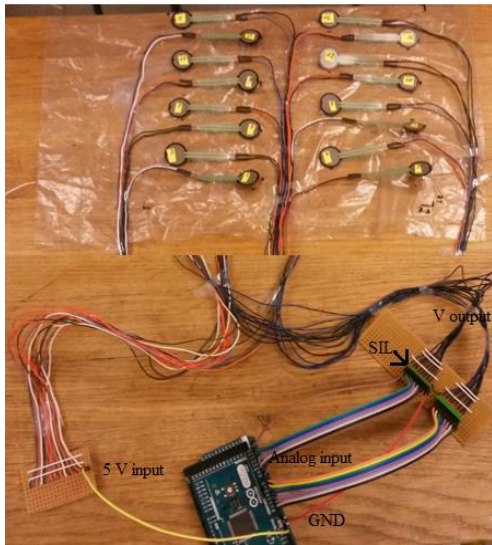


Fig. 1. Sensor mat and sensor connections

Sensors were calibrated with fixed weight of 120 g and 220 g, placing the weight in the centre of sensing area. Voltage was measured using oscillograph giving 2,1 V and 2.6 V accordingly, values of each sensor was fluctuating but did not overcome 10% of difference. In this case, all sensors were calibrated same way assuming that voltage change over the weight is linear, by formula:

$$V = km + x$$

,where V – measured voltage, V; k - calculated factor equal to 0.004; m – weight, g; x – calculated factor equals to 1.5. Sensor triggered by the weight no less than 100 g.

To evaluate and approve the chosen spacing of the sensors following tests were made. Sensor position was changed moving each sensor on a mat 2 cm closer to the center of the seat, resulting that some of the sensors had very little of pressure and did not reflected the movements of seated human body. Another test made by placing sensor mat 3 cm from chair front edge and 20 cm from backrest, obtained data did not reflected highest pressure points, but clearly visualized leg crossing positions. This show, having small number of sensors can represent critical data of most pressure places. Having more sensors that can cover all sitting surface can represent data of leg position more detailed. Furthermore, small spacing between sensors can result in very low readings of particular places where low pressure is.

The program of measurement reading and visualization created in Matlab package Simulink. The data from all 16 sensors obtained in 10 Hz sampling time and converted from voltage change to grams of force. The measured value from each sensor visualized as a square colored matrix corresponding to sensor placement in sensor mat. The data measured over time is stored in Matlab workspace, where it can be reused for further examinations.

Test of seated workplace ergonomics included three different types of seat: soft and adjustable office chair with backrest and armrests, static chair with cushion and backrest and hard sitting surface without cushion or backrest. Test participants were 8 male and 8 female, age range 23-37. As the research aims to imitate natural office environment regarding nowadays highly frequent work related musculoskeletal disorders of the upper extremities 7 of participants have a slight formation of kyphosis or scoliosis. Relevant evaluation of participants mass and height chosen body mass index (BMI), which ranged from 19.4 kg/m² until 27.8 kg/m².

During the measurements sensor mat was placed 10 cm from chair backrest. Test participants were measured sitting upright with legs bended in 90° angle, then reclined, laterally tilted (LT) right and left in approximately 30° angle and leg crossing positions referring to Zemp et al. 2016a. Pressure distribution measurement of each position was taken after 30 seconds from seated time. Each person was seated on office chair and taking all position for 30 seconds then data was recorded after changing to another position and recording data again. Afterwards changing to the static chair with cushion and repeating process of measurements and finally sitting on hard surface following with same positions and measurements.

4. Results and discussion

Measurements indicated highest pressure points under the sit bones (ischial tuberosity). For participants with lower BMI (until 20 kg/m²) the pressure on hard seat surface concentrates in two points under sitting bones and compared to seat with cushion the force of pressure increases by 100 g. On the other hand, participants with higher BMI (from 27.5 kg/m²) on the hard seat surface distribute pressure on surrounding points. Moreover, participants with higher BMI has very high

pressure force values up to 780 g while seated on hard surface compared to other participants, but pressure on the seats with cushions pressure force values are lower and close to all the other participants reaching average values up to 400 g. Furthermore, participants suffering from spinal curvature disorders that are invisible seated pressure distribution indicates right or left side higher pressure values following in all measured positions in case of hard surface seat, while seated on the cushion the difference decreases and problematic points are relatively indistinguishable.

Regarding the comparison of the seat surface and design office chair seated pressure measures 40-70 g lower values compared to static chair in all measured positions. In critical positions, LT right, left or crossed legs adjustable office chair distributes pressure in bigger area while static chair with cushion concentrates it in one/two points as well as increasing the value in 40-90 g (Fig. 2.). In reclined position office chair cushion distributes pressure and only low values (250-350 g) are measured while on the static chair highest pressure points are shifted back with the same pressure value. Furthermore, on hard seat surface in reclined position pressure is still concentrated on the sitting bones increasing the pressure value, surrounding points distributes insufficient values up to 200-350 g.

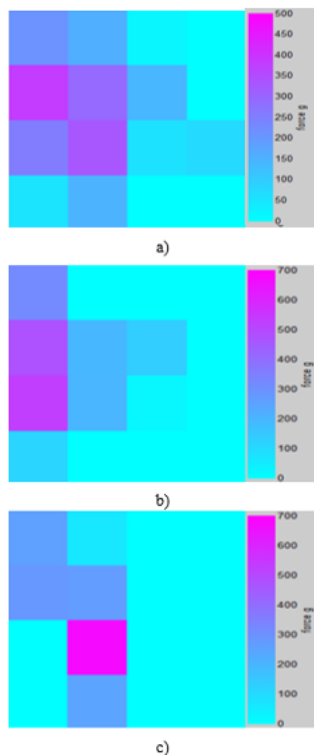


Fig. 2. Pressure distribution in laterally tilted right position with measuring scale: a) on soft and adjustable office chair; b) static chair with cushion; c) hard sitting surface

Leg crossing positions pressure distributes on two sitting bones while on the adjustable office chair pressure is distributed gradually, the static chair shows slight increase of pressure in one side which leg is lifted. Moreover, hard seat surface measurements shows high difference of pressure concentration under the lifted leg up to 100-200 g more than under other sitting bone.

Conclusions

Created pressure measurement mat compared to analysed studies and commercial products is robust, low cost and non-intrusive suitable for seated pressure evaluation and further ergonomic analysis.

These tests illustrate that, having 16 sensors is possible to represent critical data of most pressure places.

Spacing of the sensors was tested and the places with highest pressure like sitting bones where measured regardless of different body anatomy of participants. Ergonomic study shows equal distribution of pressure when seated on the soft cushion regardless sitting position or body anatomy of participants.

Hard seat surface shows higher pressure values and concentration in two points which means high risk of body fatigue in shorter sitting time.

Measurements of participants with higher BMI value indicates distribution of pressure even on the hard seat surface therefore discomfort and body fatigue occur after longer seated time compared to participants with lower BMI equal to 19.4-20.2 kg/m².

Measured value can change from 20 g to 60 g depending on the sitting surface (hard or soft), because of this reason mat can be used for comparison of pressure of different parts, but not precise measurements of the weight.

For better evaluation of sitting positions, sensors on backrest of the chair should be included in the measurements. Furthermore, sensor mat for measurements should be easily fixed on any type of surface to avoid slips or bends of the mat. Moreover, adding more sensors covering all seat surface would let to represent leg position in details. For sophisticated ergonomic study, the outcomes of the measurements should be reviewed and interpreted by physiotherapist.

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