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BODY PRESSURE DISTRIBUTION MAPS USED FOR SITTING COMFORT VISUALIZATION

UDK 331.101.1: 681.17
RECEIVED: 2016-10-28
ACCEPTED: 2017-03-01

SUMMARY: The increasing time period people spend in sitting position presents several risks of suffering musculoskeletal disorders. The main objective of this research was to raise awareness for prolonged sitting students about negative consequences of the incorrect seat. In the mainframe of the research the body pressure distribution of different body shaped students in diverse postures were measured on the most frequently used chairs in university's lecture halls and laboratories. The recorded pressure maps were analysed from sitting comfort aspects thereafter and suggestions for correct sitting postures formulated finally. Research data and analysis revealed that most of the subject sit asymmetrically on chairs, the difference between left and right sides can reach 25%, the body built and sitting posture has a significant influence on the pressure distribution and peak pressures in the selected zones. Beside to a comfortable seat a special attention should be paid also to a correct posture, because many of health complains can be linked to the latter.

Kley words: *pressure distribution, body postures, sitting comfort, pressure zones, ergonomics*

INTRODUCTION

Never seen developments in the informational technology sector during the last decades points to the fact that the seating time continuously increase and deskbound workers will be stacked to their chair even for more prolonged periods. However, the concepts of ideal sitting posture have a long history in the literature, for example in 1884 Staffel (*1884*) wrote a standard for the sitting position that was quoted later by many other authors *(Fick, 1911, Strasser, 1913, Schede, 1935)*. Seats with adjustable backrests and seat bottoms with rounded front edges were developed by Drescher to reduce pressure on the under-thigh region *(Drescher, 1929)*. In a comprehensive work Akerbloom provided a review of sitting principles from the period 1853-1947 *(Akerbloom, 1948)*. The analysis of human–seat interface and understanding the effect of body weight distribution on seat comfort is beneficial for ergonomical and functional chair design. A balanced weight distribution on chair's seat, armrests and back is a key component on the usefulness of seating. According to Brienza and Kiosak compression or shear forces, or both developing during seating lead to discomfort *(Brienza et al., 1996, Kiosak, 1976)*. The importance of a high seating comfort is underlined by other studies arguing that prolonged seating represents a potential risk to spinal and paraspinal disorders *(Corlett, 1999)*. Long hours of sitting in awkward

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postures might increase the risk of developing low back pain and/or sciatica *(Fick, 1911)*. The permanent seating position's harmful and adverse effects could be reduced by a favorable seat construction, and good sitting behavior, or the regularly modified body position *(Szabo, 2011, 2011a)*. Porter and Gyi *(1998)* conducted an experiment to investigate observed optimum driving postures and positions and they developed guidelines for optimum postural comfort. The relationships among Korean drivers' body dimensions, their driving postures and preferred seat adjustments was studied by Park et al. after collecting data concerning the preferred driving postures and adopted seat adjustment levels *(Park et al., 2000)*. Hinz et al. *(2003)* investigated the characteristics of the contact areas between the seat cushion and the subject under static conditions and the effect of surface elasticity on pressure distribution *(Lis et al., 2007)*. The contribution of armrests in reducing weight on seat pan and mitigating stress on the spine was studied by Nag et al. *(2008)*.

This research intends to analyze the body pressure distribution of students with different body built using the most prevalent chairs in the university lecture halls and to determine the negative consequences of the wrong seat.

MATERIALS AND METHODS

Classrooms for students are comparable with the office environment of white collars. Both users category are sitting mostly in functional positions i.e. writing and reading at desks. Therefore the furnished environment must be developed taking into account these main functions, and optimization of several parameters is necessary. Between these parameters we find the seat dimensions and functions (seat and back angle, surfaces size, heights, cushions, forms) and the characteristics of desks as well (table top height and tilting angle).

At the University of West Hungary a student participates at three courses daily on the average, which means 3x2x45 minutes totally, in this way a student spends at least 270 minutes a day seating, almost a full day weekly. In this time period only the contact hours are included and the interval doesn't contain the participation in laboratories and homework completion. Having this long seating time the comfort of chairs is essential from many points of view. The main objectives of this research was to measure the body pressure distribution of students on different classroom chair types and analyze the pressure maps in order to evaluate the seating comfort. Beside the objective measurement technique, a less impartial questionnaire was prepared to evaluate the users' opinions about chair convenience.

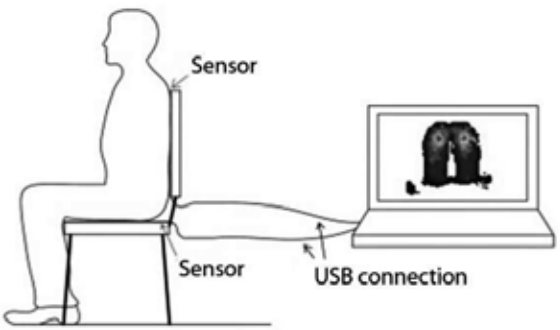


Figure 1. Measuring system
Slika 1. Mjerni sustav

The measurements were made using the Tekscan's Body Pressure Measurement System (Conformat) with pressure sensitive foils size of 488 × 427 mm (Figure 1), containing 2016 pressure points with pressure range of 0-350 mm Hg, and accuracy of + / - 3.5 mmHg. The computerized data recorder provides a real-time picture of the pressure distribution. Before using the BPMS (Body Pressure Measuring System) measuring system the pressure sensor foils were calibrated with the help of a vacuum pump. After calibration the pressure maps of different body built persons and seating positions were collected and analyzed with the software delivered with the system (BPMS Research 7.20) in the form of image (.FSX or .jpg) or short (0-200 s long) video files.

Ten persons (5 males and 5 females), four frequently used chair types were chosen and six typical body postures were defined (Table 1.)

collecting 390 pressure maps altogether. The subjects were selected based on their body type and body mass index (BMI). Table 1. contains the basic characteristics of subjects.

Table 1. Characteristics of the measured subjects

Tablica 1. Karakteristike mjerenih subjekata

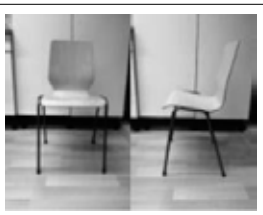
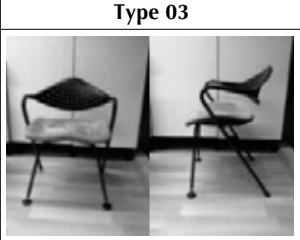
User	1	2	3	4	5	6	7	8	9	10
Sex (female/male)	f	f	f	f	f	m	m	m	m	m
Age	21	21	21	22	21	22	23	23	22	21
Body mass (kg)	57	60	51	68	43	85	62	90	116	98
Height (cm)	165	168	165	160	151	192	182	197	216	186
BMI	20.94	21.26	18.73	26.56	18.86	23.06	18.72	23.19	24.86	28.33

The high number of seating positions, the body built variation between subjects and the large number of pressure maps recorded were considered sufficient to drag reliable conclusions regarding to the chairs' comfort, dimensions correctness and to search for relationships between different factors.

The measured chairs are for generally use, classroom chairs, three types with conventional design with four legs and back, the third type upholstered and the forth with three legs and round seat used in laboratories (Table 2.).

Table 2. Chair types used for body distribution measurements

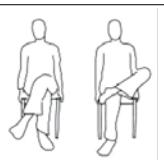
Tablica 2. Tipovi stolica korišteni za mjerenje distribucije tijela

Type 01	**Type 02**	**Type 03**	**Type 04**
			
General chair, divided solid surface. Mildly hollow seat, high and arched backrest.	General chair with undivided solid surface, without upholstery, limber backrest.	Upholstered chair with low backrest.	Three-legged chair with circular seat. Edges are rounded.

The pressure maps were recorded in four different seating positions. Because of different chair structure the positions differ in the case of round seat chair as Table 3. shows. The straight seat is characterized by a normal seating position without back support and arms resting on thighs. Sitting position 12 differs from the straight seat just in leaning back only, the lean forward position is opposite to the previous one plus the arms rest on the table top. Forth position is related to the moments when the sitter decline to one side for example hanging on the phone which results in an unbalanced pressure on the seat and chair arms. The next posture is with crossed legs with a pulled up ankle in the case of male subjects and just crossed thighs for female subjects. The so called "floppy" posture is a kind of loose position with a crump back slightly back support and arms resting on thighs. In the case of laboratory chair the previous postures differ to some extent due to the higher height of the seat and cross bars fixed between legs. In the first posture the feet lean on the cross bars the back is straight, in the second position the feet rest on the floor, the third is characterized by one foot on the floor the second on the bar, in the case of the forth the feet are on the floor but the bust is leaning forward, in the fifth posture one legs is crossed the second rest on the bar, and the last is a "floppy" posture also.

Table 3. Sitting position

Tablica 3. Način sjedenja

Chair types 01-03					
Sitting position 11	Sitting position 12	Sitting position 13	Sitting position 14	Sitting position 15	Sitting position 16
					
Straight	Lean back	Lean forward	Lean side	Crossed leg	Floppy
Chair type 04					
Sitting position 21	Sitting position 22	Sitting position 23	Sitting position 24	Sitting position 25	Sitting position 26
Straight, legs on the stand	Straight, legs on the floor	Straight, one leg on the stand, other on the floor	Lean forward, leg on the floor	Straight with crossed legs	Sitting on the edge

After measuring the body pressure distributions and recording the pressure maps four equal pressure zones were defined for comparison purposes. The four zones were the left and right buttock zone and the front contact zone between thighs and seats (Figure 2.).

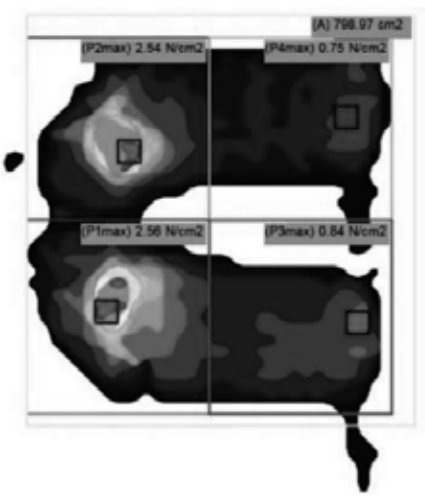


Figure 2. The selected pressure zones

Slika 2. Odabrane zone tlaka

Beside the exact pressure distribution measurements the subjective users' opinion about chair and posture comfort were recorded based on a questionnaire. The questions referred at overall chair comfort, functionality, usability, dimensions, postures and general feelings related to the chair use.

RESULTS

In this paper the results of the body pressure distribution for four subjects measured in postures 1-4 for chair types 1-3 and postures 1, 4, 6 for the laboratory chair are presented. The selection criteria in the case of subjects was the body mass index, therefore subjects with the minimum and maximum BMI indexes per gender were selected (3, 4, 7 and 10). The measured pressure distribution data were recorded in digital form for further analysis. On the pressure maps color coded patch field indicates the different pressures. The measured pressure distribution values were compared with the users' subjective opinion recorded in a questionnaire. The measured maximum contact pressures, the peak pressure values of the four zones and the total contact surface areas are presented in Table 4.

The table's values demonstrate the higher pressure of the buttock zones and the asymmetrical pressure distribution on the chairs. In the case of the upholstered chair (type 3) the contact area increased about 10% because of the cushioning and lead to a pressure magnitude decrease. Figure 3. presents the influence of sitting posture on pressure distribution. Based on the pressure maps and measured peak values, the pressure distribution changes can be observed, however the differences are not so remarkable we supposed to be. The reason is the slight increase of the contact surface which balance at some extent the pressure values.

The influence of the body mass index on pressure distribution is demonstrated on Figure 4. When subjects seat straight on chair 2, those with low BMI index have smaller contact area resulting in high pressure values in the buttock zone.

Table 4. The contact areas and maximum pressure values of the measured subjects

Tablica 4. Dodirna mjesta i najveće vrijednosti tlaka kod promatranih subjekata

Subj.	Chair type	Sitting position	Contact area	Max. pressure	Peak pressures of zones, N/cm²			
			A, cm²	Pmax N/cm²	P1max	P2max	P3max	P4max
3 (F)	Chair 1	Straight	779,4	2,56	2,56	2,54	0,84	0,75
		Leaned back	858,8	2,30	1,43	2,30	1,08	0,89
		L. forward	721,6	2,54	2,44	2,54	0,63	0,43
		L. laterally	846,5	2,66	0,65	2,66	0,87	1,13
	Chair 2	Straight	937,3	2,48	2,32	2,48	0,13	1,12
		Leaned back	987,9	2,17	2,17	2,06	0,97	1,11
		L. forward	959,0	1,70	1,26	1,70	1,14	0,91
		L. laterally	978,6	2,54	0,84	2,54	0,91	1,21
	Chair 3	Straight	1 106,6	1,22	0,84	1,22	0,84	0,92
		Leaned back	1 215,0	0,99	0,81	0,99	0,62	0,72
		L. forward	1 122,1	0,89	0,77	0,74	0,84	0,89
		L. laterally	1 175,7	1,12	0,62	1,12	0,56	0,85
	Chair 4	Straight	677,2	2,62	1,52	2,55	2,62	2,30
		L. forward	619,4	2,69	0,92	1,02	2,69	2,69
		Sit on edge	527,5	2,69	0,54	0,48	2,69	2,69
4 (F)	Chair 1	Straight	1 211,9	1,43	1,43	0,96	1,09	1,40
		Leaned back	1 203,6	1,30	1,24	1,30	0,96	1,22
		L. forward	1 094,2	1,35	1,16	0,99	0,92	1,35
		L. laterally	1 139,6	1,41	1,41	1,37	0,75	0,67
	Chair 2	Straight	1 158,2	1,35	1,35	1,20	1,20	1,27
		Leaned back	1 234,4	1,21	1,12	1,21	0,90	0,94
		L. forward	1 084,9	1,38	1,17	1,12	1,38	1,34
		L. laterally	1 235,6	1,14	1,05	1,09	0,88	1,14
	Chair 3	Straight	1 307,9	1,23	1,10	1,23	1,04	1,23
		Leaned back	1 471,0	0,95	0,78	0,95	0,84	0,76
		L. forward	1 349,2	0,99	0,97	0,92	0,99	0,86
		L. laterally	1 482,3	0,91	0,76	0,91	0,76	0,84
	Chair 4	Straight	775,2	2,22	2,09	1,91	2,22	2,12
		L. forward	770,1	2,62	2,06	1,76	2,57	2,62
		Sit on edge	700,9	2,62	2,62	1,38	2,53	1,32

7 (M)	Chair 1	Straight	995,1	2,66	1,75	2,66	1,50	1,49
		Leaned back	872,3	2,48	2,01	2,48	0,41	1,02
		L. forward	768,0	2,60	2,60	2,57	0,68	1,09
		L. laterally	759,7	2,55	0,76	2,55	0,46	1,79
	Chair 2	Straight	1 000,3	2,62	2,62	2,57	0,84	1,21
		Leaned back	996,1	1,54	1,37	1,54	0,77	1,23
		L. forward	903,2	2,42	1,58	2,42	0,86	1,19
		L. laterally	845,4	2,33	1,24	2,33	0,58	2,31
	Chair 3	Straight	1 230,5	1,43	1,43	1,36	0,58	0,54
		Leaned back	1 108,6	1,10	0,95	1,10	0,50	0,77
		L. forward	1 105,6	1,37	0,94	1,37	0,59	0,82
		L. laterally	1 046,7	1,10	0,55	1,10	0,30	0,93
	Chair 4	Straight	663,7	2,58	1,38	2,58	1,57	1,78
		L. forward	546,1	2,69	0,20	1,06	2,69	2,69
		Sit on edge	466,6	2,69	0,22	1,02	2,69	2,69
10 (M)	Chair 1	Straight	1 011,4	2,62	2,55	2,62	1,12	1,88
		Leaned back	1 031,2	2,62	2,51	2,62	0,93	1,25
		L. forward	842,3	2,34	2,01	2,00	1,78	2,34
		L. laterally	986,8	2,33	2,16	2,33	0,93	1,45
	Chair 2	Straight	1 204,6	2,33	2,28	2,33	1,55	1,88
		Leaned back	1 238,7	2,21	2,21	2,16	1,31	1,36
		L. forward	1 034,3	2,11	1,96	2,11	1,64	1,82
		L. laterally	1 132,4	2,69	1,35	2,69	1,12	2,69
	Chair 3	Straight	1 267,6	2,06	2,06	1,78	1,66	2,04
		Leaned back	1 321,3	2,33	1,91	2,33	1,25	1,09
		L. forward	1 087,0	2,18	2,18	1,53	1,84	1,55
		L. laterally	1 201,6	2,32	1,59	2,32	1,06	1,48
	Chair 4	Straight	846,5	2,69	2,30	2,69	2,69	2,69
		L. forward	648,3	2,69	1,83	2,28	2,69	2,69
		Sit on edge	390,2	2,62	0,17	0,29	2,62	2,62

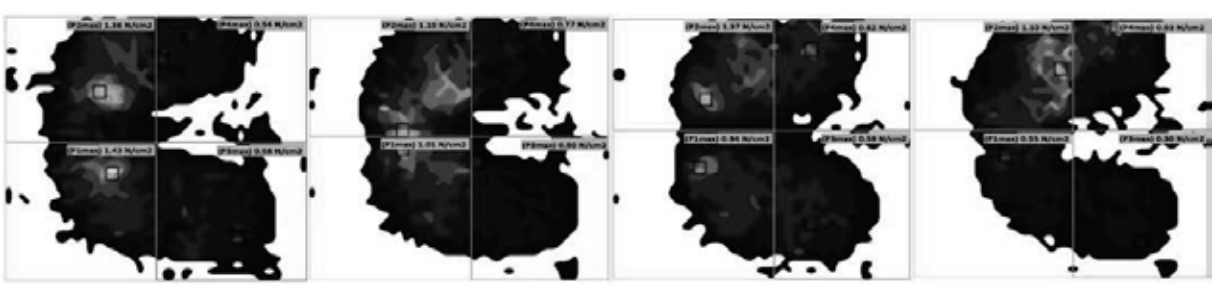


Figure 3. The influence of posture on the body pressure distribution (subject 7, chair type 3)
Slika 3. Utjecaj držanja pri sjedenju na distribuciju tlaka na tijelo (subjekt 7, tip stolice 3)

Chair types effect also the chair comfort, the upholstered chair increased the contact surface, the straight, hard seating chairs demonstrated higher pressure zones. The most uncomfortable chair is the laboratory chair having a circular seating pane with thicker edge. Based on Figure 5 the pressure map of the laboratory chair reveal high pressure zones on thighs, the loads are carried by legs instead of buttock zones (ischium) explaining the cause of discomfort. Because of the smaller seat size of chair type 4 moderate differences of the contact surfaces are observed and the peak pressures are similar indifferent of sitting positions.

Table 5. summarizes the straight sitting pressure distributions on three chair types for female subject no 4. with above average BMI index. In the first case the user evaluated the chair to be with a medium comfort, a slight compression was observed on the back and in the front of the seat. The pressure map and diagrams of the pressure zone underline the subject's subjective evaluation. In the second case the chair was considered more comfortable which can be confirmed by a more uniform pressure distribution map. This highlight the importance of the seat and back cushion. When the user seated on chair type 4 immediately remarked the discom-

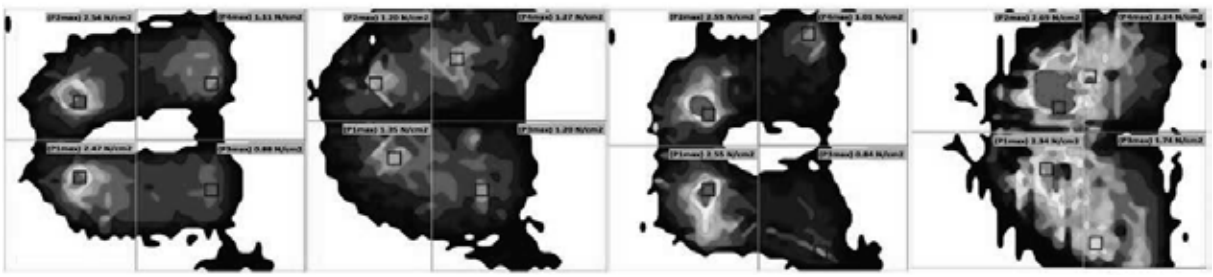


Figure 4. The influence of BMI index on the body pressure distribution (straight seat, chair type 2)
Slika 4. Utjecaj indeksa tjelesne mase na distribuciju tlaka na tijelo (uspravno sjedenje, tip stolice 2)

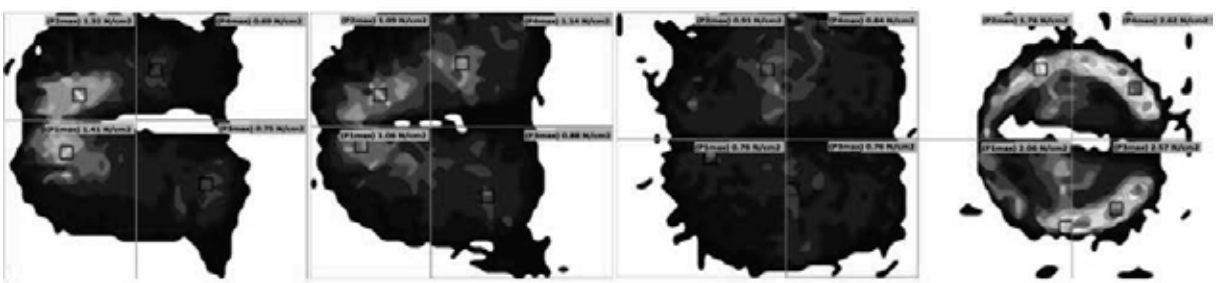


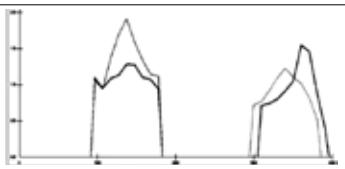
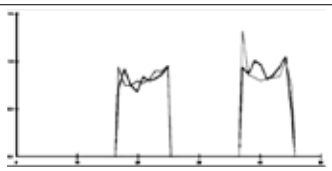
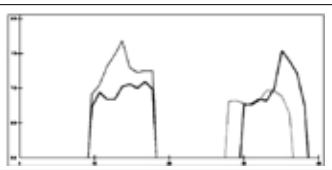
Figure 5. The influence of chair type on the body pressure distribution (subject 4, leaned forward)
Slika 5. Utjecaj tipa stolice na distribuciju tlaka na tijelo (subjekt 4, nagnut naprijed)

From these comparisons it can be deduced that in cases where the user's comfort level was marked low, high differential pressure zones are located. The agreement was valid for both chair types and sitting postures. On the pressure maps with high discomfort zones peak pressures were observed which indicate that beside compression forces shear forces are present contributing to the user's low comfort.

fort of the round and hollow seat plate. The seat was considered too small and an inconvenient compression feeling was observed on thighs. The pressure maps recorded in different postures indicate high pressure zones near the edge as a result of the seat center's hollow form. These high pressures caused significant shear stress in the lower thigh soft tissues leading to a remarkable discomfort feeling.

Table 5. Pressure distribution maps and diagrams of subject 4

Tablica 5. Prikazi i dijagrami distribucije tlaka za subjekt 4

Subject 4		Pressure parameters (N/cm^2)	Pressure distribution
a	Seat pressure map and diagram for chair type 1, sitting position 11.		
b	Seat pressure map and diagram for chair type 3, sitting position 11.		
c	Seat pressure map and diagram for chair type 4, sitting position 21.		

CONCLUSION

Based on the recorded pressure maps it can be seen that the heavier person's pressure values were significantly smaller because of the larger surface contact area with the chair and the pressure distribution is more uniform compared with the thinner individuals' same values. Almost all subjects demonstrated a greater or lesser degree of asymmetry, even in the case of straight seat, which is a direct result of a bad posture. The asymmetry can reach 15-25%. Postures affect significantly the pressure maps since higher pressure zones appears contributing to a faster fatigue of the body. The measured values were matched with the oral assessment of the subjects, in this way we had the opportunity to determine the weight distribution characteristics and pressure values that reach the comfort threshold of the subjects. For example, for the subject complaining about the bad back shape of chair type 1, we measured extremely high pressure values on back surface. In the case of chair type 3 many complained about the uncomfortable back which can be seen also from the high pressure zone around the spine. It can be deduced that sometimes the apparently high seating comfort (upholstered) could be shaded by a bad back. Those who considered chair type four with the worst comfort came to this conclusion because they exerted heavy loads on their thighs or considered too small the seat area. Research data and analysis revealed also that in addition to the comfort of the chair the environment is important too, because an improperly furnished room can reduce the performance of the audience. Taking into consideration facilities and use of a certain environment and measuring the ergonomic characteristics of the furniture we can appreciate the comfort level of them. Beside to a comfortable seat a special attention should be paid also to a correct posture, because many of health complains can be linked to the latter.

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MAPE DISTRIBUCIJE TLAKA NA TIJELO U VIZUALIZACIJI UDOBNOSTI SJEDENJA

SAŽETAK: Sve dulje vrijeme koje ljudi provode sjedeći predstavlja veći broj rizika za mišićno--koštane poremećaje. Glavni cilj istraživanja je podići svijest kod studenata o predugom sjedenju i negativnim učincima neispravnog načina sjedenja. Glavni dio istraživanja bavi se distribucijom tlaka na tijelo kod različitih tipova građe tijela i različitim načinima sjedenja mjereno na stolicama kojima su najčešće opremljene sveučilišne predavaonice i laboratoriji. Mape tlaka analizirane su s aspekta udobnosti sjedenja, a formulirane su i preporuke za pravilno držanje. Podaci pokazuju da većina subjekata sjedi asimetrično, a razlika lijeve i desne strane može biti do 25 %. Građa tijela i držanje pri sjedenju znatno utječu na distribuciju tlaka i najvišu razinu tlaka u odabranim zonama. Osim udobnih sjedala, pozornost treba obratiti na ispravno držanje pri sjedenju jer se mnoge zdravstvene tegobe mogu povezati s lošim držanjem.

Ključne riječi: *distribucija tlaka, držanje tijela, udobnost sjedenja, zone tlaka, ergonomija*

Izlaganje sa skupa
Primljeno: 28.10.2016.
Prihvaćeno: 1.3.2017.