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Evaluation of Seat Comfort of Office Armchairs: an Impact of Articulated Seat Support and Gas Spring

Procjena udobnosti sjedala uredskih stolaca: utjecaj gibljivog postolja sjedala i zračne opruge

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ABSTRACT • *This paper describes the application of an alternative seating system. The aim of this alternative approach was to determine the comfort of office armchairs equipped with new construction solutions ensuring articulated support of the seat as well as articulated mounting of the gas spring. An office armchair with a different seat support and gas spring was selected. Operational loads were applied to the seat surface. The following parameters were measured and calculated in the course of the performed experiments: contact area, average contact pressure and coefficient of seat pressure distribution (SPD). A new discomfort coefficient D expressing seat quality was elaborated. Preliminary data suggests that the prototypes provided greater sitting comfort than did the conventional chair. It was demonstrated that the new construction solution of the gas spring support guaranteed the highest comfort of the use of the examined armchairs.*

Key words: *articulated support, discomfort coefficient, gas spring, office armchair, seat*

SAŽETAK • *U radu se opisuje primjena alternativnog sustava za sjedenje. Cilj provedenog ispitivanja bio je utvrditi udobnost uredskih stolaca opremljenih novim konstrukcijskim rješenjima koja osiguravaju gibljivost postolja sjedala i gibljivost zračne opruge. Izabran je uredski stolac s promijenjenim načinom potpore sjedala i zračne opruge. Površina sjedala izložena je uobičajenim opterećenjima. Tijekom provedbe eksperimenta mjereni su i izračunavani ovi parametri: kontaktno područje, prosječni kontaktni pritisak i koeficijent raspodjele tlaka na sjedalu (SPD). Uveden je novi koeficijent neudobnosti D kojim je izražena kvaliteta sjedala. Preliminarni podaci pokazuju da prototipovi sjedala osiguravaju veću udobnost sjedenja nego konvencionalni uredski stolac. Dokazano je da novo konstrukcijsko rješenje postolja zračne opruge jamči najviši komfor pri uporabi istraživanih stolaca.*

Ključne riječi**:** *gibljivo postolje, koeficijent neudobnosti, zračna opruga, uredski stolac, sjedalo*

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1 INTRODUCTION
1. UVOD

Office armchairs, depending on the purpose of their utilization, can be used for several minutes or several hours. Despite advanced industrial developments, many workers are still required to adapt to the machines and thus accept less than ideal working conditions. Computer dominated jobs and industrial automation have created more sedentary tasks often characterized by constrained postures, high frequency (repetitive work), monotonous work requiring good eyesight, and precision work with repetitive movements in the arms, hands, and fingers. As a result of these limitations, a variety of musculoskeletal conditions, involving the entire upper limb, neck and back, have approached the forefront of work related disorders (Fernandez *et al*., 1999). The authors concluded that in light assembly and computer work tasks, an arm support system would be recommended to minimize the effort and RPE, and to maximize comfort. A study by Zhu and Shin (2012) has shown that forearm support can help computer users lessen physical stress in typing, but only when the supports are positioned at resting elbow height. Also, evaluation of a dynamic arm support for seated and standing tasks suggested that a dynamic forearm support may improve subjective comfort and reduce static muscle loads in the upper extremity for tasks that involve horizontal movement of the arms (Odell *et al*., 2007).

The research on sitting comfort demonstrates a particularly pronounced relationship between seat pressure and comfort. De Looze *et al*. (2003) concluded that the most consistent predictor of seat comfort was related to seat pressure distribution and that this relationship was considerably more straightforward than with the research that measures muscle activity or spinal profiles. Using a specially designed seat fixture, Goossens (1998) varied pressures and found a strong correlation between the amount of pressure applied to the buttocks and discomfort. The values of maximum contact pressure and the seat contact area are most commonly employed as measures of their utilization comfort (Adler, 2007; Ebe and Griffin, 2001; Milvojevich *et al*., 2000; Tewari and Prasad, 2000; Uenishi *et al*., 2000). According to Dhingra *et al*. (2003), the distribution of contact pressure is more uniform on a soft seat than on a hard one. Ebe and Griffin (2001) confirmed that the values of contact pressure under ischium bones can be applied as the principal criterion of foam hardness and seat comfort. There is, therefore, a close correlation between the contact area and the value of contact pressure. Reswick and Rogers (1976) described the relationship between contact pressure, time of their action and the degree of soft tissue damages. Kosiak (1961, 1959) reported that microscopic pathological changes of soft tissues appeared already after one hour of pressure action of values not exceeding 8 kPa. On the other hand, no such changes were observed when the applied pressure had the value of 4.7 kPa. According to Hostensa *et al*. (2001), Landis (1930), Takahashi *et al*. (2010) pressures ranging from 2.7 to 4 kPa can close capillary blood vessels and cause discomfort during sitting. That is why the contact pressure of 4-8 kPa was employed as a criterion of comfort in many investigations dealing with designing of various seats and beds (Butcher and Thompson, 2010, 2009; Hamanami *et al*., 2004; Seigler and Ahmadian, 2003; Smardzewski, 2009; Smardzewski *et al*., 2010a, 2010b; Tewari and Prasad, 2000; Wang and Lakes, 2004; Wang *et al*., 2004). Rasmussen and Zee (2009) made an attempt at a numerical parameter optimization of an airplane armchair. Their conclusion was that, although there were some general characteristics of seats, numerous additional factors had to be taken into consideration during the modelling process before experimental results could be used in practice. Paoliello *et al*. (2008) made an analysis of armchairs loading during their daily use. Vlaović *et al.* (2008) proposed a questionnaire method for assessing seat comfort of office armchairs. Nero *et al*. (2011) described the application of an alternative seating concept for surgeons that reflects the research of Zen sitting postures, which require Zazen meditators to maintain fixed postures for long durations. The aim of this alternative approach was to provide sitters with a seat pan with sacral support that provides a more even distribution of seat pressures, induces forward pelvic rotation and improves lumbar, buttock and thigh support. The authors concluded that the sacral support of the prototype chair prevents backward pelvic rotation. Preliminary data suggests that the prototype provided greater sitting comfort and support for constrained operating postures than did the conventional chair. These findings support the selective application of concave-shaped seat pans that conform to users' buttocks and reflect Zen sitting principles. However, this solution is characterized by rigid support of seats and columns. What is lacking, however, is a wider discussion concerning the effect of the new construction of seat support on the comfort of utilization of office armchairs as well as ways of assessment of this comfort.

The principal goal of the present investigations was to determine the comfort of office armchairs with novel design solutions ensuring articulated support of the seat as well as articulated mounting of the gas spring. Another objective was to select the most advantageous construction design that would exert the strongest influence on armchair comfort.

2 METHODS AND MATERIALS
2. METODE I MATERIJALI

The armchair selected for the investigations was an office armchair with the backrest manufactured from 34 mm thick Atria® foam and 7.85 kPa hardness (PN-EN ISO 2439), whereas the seat was made from 47 mm thick and 8.9 kPa stiffness Event® foam (Fig. 1). The column of the pneumatic spring was mounted in a five-arm base using three different methods. The first of them was a stiff linkage typical for majority of office armchair constructions (Fig. 1a, 2a,d – type S).

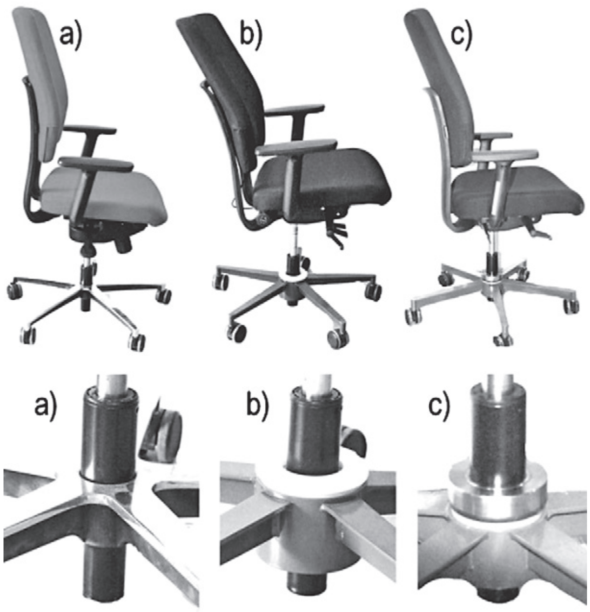

Figure 1 Examples of office armchairs: a) a seat with articulated support; gas spring with rigid support – type BS; b) a seat with rigid support, gas spring with articulated support and with possibility of regulation of the deflection angle – type AP; c) a seat with rigid support; gas spring with articulated support but without possibility of regulation of the deflection angle – type NP

Slika 1. Uzorci uredskih stolaca: a) sjedalo s gibljivim postoljem; zračna opruga s krutim postoljem – tip BS; b) sjedalo s krutim postoljem, zračna opruga s gibljivim postoljem i s mogućnošću regulacije nagibnog kuta– tip AP; c) sjedalo s krutim postoljem; zračna opruga s gibljivim postoljem, ali bez mogućnosti regulacije nagibnog kuta – tip NP

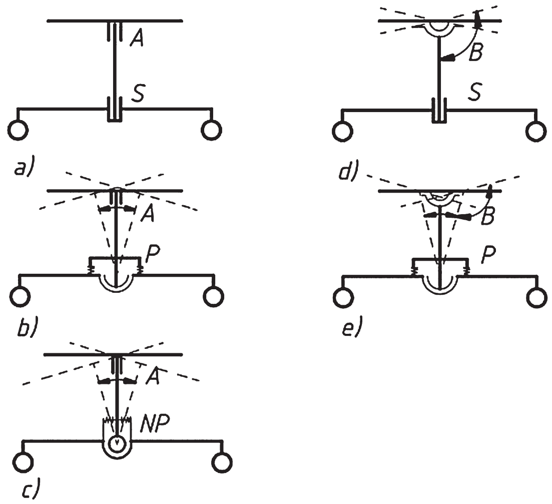

Figure 2 Methods of linkage of the seat and gas spring: a) AS – rigid support of the seat and gas spring; b) AP – rigid support of the seat and gas spring with articulated support and with possibility of regulation of the deflection angle; c) NP - rigid support of the seat and gas spring with articulated support but with no possibility of regulation of the deflection angle; d) BS – seat with articulated support and gas spring with rigid support; e) BP - seat with articulated support and gas spring with possibility of regulation of the deflection angle

Slika 2. Metode povezivanja sjedala i zračne opruge: a) AS – kruto postolje sjedala i zračne opruge; b) AP – kruto postolje sjedala i zračna opruga s gibljivim postoljem i mogućnošću regulacije nagibnog kuta; c) NP – kruto postolje sjedala i zračna opruga s gibljivim postoljem ali bez mogućnosti regulacije nagibnog kuta; d) BS – sjedalo s gibljivim postoljem i zračna opruga s krutim postoljem; e) BP – sjedalo s gibljivim postoljem i zračna opruga s mogućnošću regulacije nagibnog kuta

The second method ensured articulated support with a possibility of regulation of the deflection angle of the column from the perpendicular (Fig. 1b, 2b,e – type P), whereas the third one was also an articulated coupling but with no possibility of deflection regulation (Fig. 1c, 2c – type NP). The seat together with the backrest was fixed to the column of the pneumatic spring using two methods. The first method was a stiff connection with no possibility of seat deflection in the horizontal plane (Fig. 2, type A). The second solution consisted in the application of a VMS (Vertical Moving System) mechanism making it possible for the seat to be deflected in horizontal plane (Fig. 2, type B). In total, five different designs were investigated.

The examined armchairs were tested in accordance with the standard (PN-EN 1728:2012) (used only in relation to the load) (Fig. 3). An FSA Clinical, Vista Medical Ltd., sensor mat (sensing area 465 mm x 465 mm, poly thickness 2.5 mm, sensor size 11.1125 mm, sensor gap 3 mm, sensor arrangement 32 x 32, cover size 565 mm x 565 mm, number of sensors 1024, sensor surface 211 mm^2, standard calibration range 13.3 kPa) was placed on the seat surface. The mat was first calibrated and then connected to the computer (In-

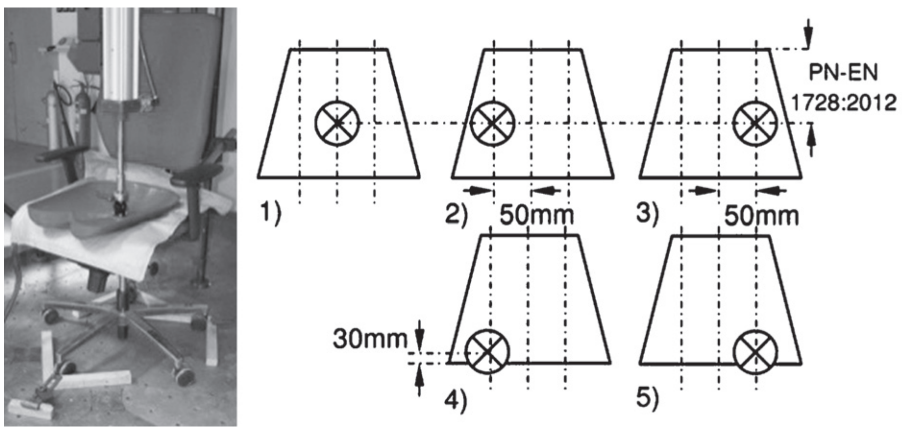

Figure 3 Method and place of loading of armchair seats. Loading types from 1 – 5

Slika 3. Način i mjesto opterećenja uredskog stolca; tipovi opterećenja 1 – 5 tel® Core™ i5 CPU, 2.53 GHz, RAM 4 GB, Windows 7®). Loads were applied only to the seat. The force of 300 N was imposed vertically downward in places indicated in Figure 3. Consecutive load schemes were designated from 1 to 5. Each loading lasted 60 seconds, during which values of the contact stresses between the indenter and the seat were measured with 10 Hz frequency and 0.01 kPa accuracy. Direct measurement results were recorded in a text file and presented graphically as distribution maps of contact pressure.

Indirect experimental results were collated in the form of diagrams comparing the following values: A (m^2) - contact area, p_m (kPa) - average contact pressure, *SPD* (%) **-** coefficient (Seat Pressure Distribution, Ahmadian *et al*., 2002).

$$SPD = \frac{\sum_{i=1}^{n} (p_i - p_m)^2}{4 \cdot n \cdot p_m^2} \cdot 100 \qquad (1)$$

where:

n – number of sensors in which contact pressure has non-zero values,

p_i – contact pressure in any mat sensor,

p_m – average contact pressure for n sensors.

Since the comfort of sitting depends directly on the contact area, values of contact pressure as well as on the above-mentioned *SPD* coefficient, a decision was also taken to define and calculate the value of the discomfort coefficient D (daN/m^4) determined on the basis of the following formula:

$$D = \frac{p_m}{SPD \cdot A} \qquad (2)$$

In the case of uniform distribution of contact pressure on the seat surface, the p_i pressure at any sensor should be equal to the average pressure p_m. In such case, the *SPD* coefficient should equal zero. Therefore, a seat characterized by low *SPD* values may indicate a more uniform support of the user's body in comparison with seats characterized by high *SPD* values. However, this does not rule out that the developing stresses will be too high for the sitting comfort. In the case of D coefficient, it should be expected that high discomfort of the user will be achieved at high p_m pressure as well as at low values of A and *SPD*. In such case, low values of the D coefficient will speak in favor of a high comfort of seat utilization.

3 RESULTS
3. REZULTATI

Figure 4 presents the distribution of seat contact pressure, when the seats are loaded in accordance with diagrams 1, 2 and 4. It is evident from this Figure that the smallest pressure occurred on seat surfaces of NP type design. At the same time, it should be observed that in the case of diagrams 2 and 4 causing deflection of the column and seat to the right, greater pressure developed on the left side of the seat. In addition, the pressure area exerted by the right thigh was larger than the area of pressure exerted by the left thigh.

Figure 5 presents differences between the contact area, *SPD* coefficient and average contact pressure of seats loaded with the force of 300 N in accordance with diagram 1 developed as a result of comparison of individual design solutions. It is evident that in the case of the NP construction, the contact area was the largest and amounted to 443 cm^2, whereas for BS and BP constructions, it was the smallest and amounted to 371 and 373 cm^2, respectively. In addition, average contact pressure on the NP seat reached the lowest value of

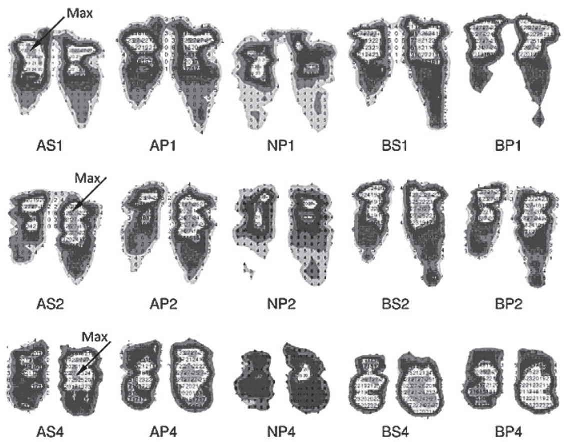

Figure 4 Distribution of contact pressure on the seat surface under loading of type 1, 2 and 4
Slika 4. Raspodjela kontaktnog pritiska na površini sjedala pod opterećenjem tipa 1, 2 i 4

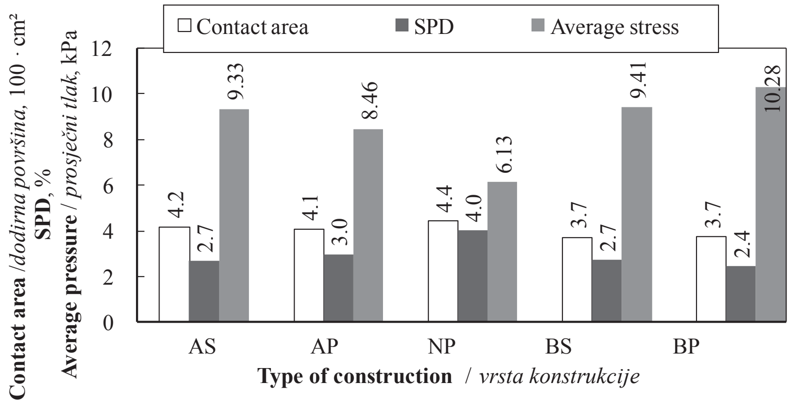

Figure 5 Characteristics of seat stiffness under type 1 loading
Slika 5. Obilježja krutosti sjedala pod opterećenjem tipa 1

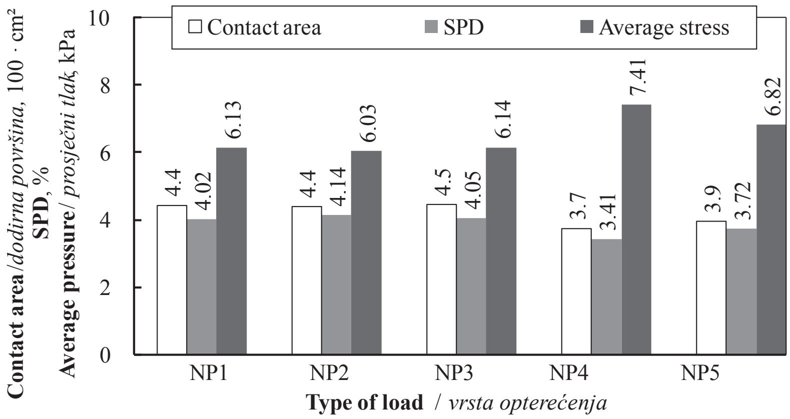

Figure 6 Stiffness characteristics of NP type seats under loads of type 1 – 5
Slika 6. Obilježja krutosti sjedala tipa NP pod opterećenjem tipa 1 – 5

6.13 kPa. These stresses for the BP type seat were the highest reaching 10.28 kPa, while for AS and BS constructions – 9.33 and 9.41 kPa. Despite favorable sizes of contact areas and average contact pressure for seats of NP design, in this case the *SPD* coefficient reached the highest value of 4.0 %, while its values for AP, AS, BS and BP constructions were determined at: 3.0, 2.7, 2.7 and 2.4 %, respectively. In this situation, this means that despite attractive values with respect to the contact area and contact pressure, the seat in the NP construction revealed the highest unevenness of pressure distribution. Therefore, Figure 6 illustrates the impact of load schemes on the quality of these seats. It is clear from Figure 6 that for load schemes 2 and 3 causing deflection of the gas spring column to the right or left, respectively, changes of the contact area, values of average contact pressure as well as of the *SPD* coefficient were small. On the other hand, for load schemes 4 and 5 causing deflection of the gas spring column forward, respectively, to the right or left, the contact area decreased, average value of contact pressure increased and the *SPD* coefficient decreased. In comparison with the load schemes 2 and 3, the value of the contact area, *SPD* coefficient and average contact pressure for the load schemes 4 and 5 changed by: -19 %, -21 %, +19 % as well as by -15 %, -9 % and +10 %.

This regularity appears to indicate that the NP construction favors comfortable sitting since it supports better the user's body during different positions adopted while working.

4 DISCUSSION
4. RASPRAVA

The above observations illustrate well the calculated values of the discomfort coefficient *D*. Figure 7 presents the influence of the seat type construction and load on the *D* coefficient values. It is quite apparent from this Figure that the NP construction ensured the lowest values of the *D* coefficient and, hence, the highest comfort for the user. For the type of load 1-3, the *D* coefficient attained values ranging from 33.1 to 34.4 daN/m^4, whereas for the type of load 4 and 5 – 58.1 and 46.4 daN/m^4, respectively. A typical, widely applied seat of AS construction is characterized by higher *D* coefficients; for example, for the type of load 1-3, the *D* coefficient reaches values from 78.6 to 83.6 daN/m^4, and for the type 4 and 5 - 150.4 and 118.3 daN/m^4, respectively. A change in the method of the gas spring column support from fixed to articulated (AP type) results in a discernible improvement of discomfort coefficient *D*. In such case, for type of load 1 and 3, the *D* coefficient reached the value of 69.3 daN/m^4, for the load type 2 *D*=88.1 daN/m^4 and for load type 4 and 5 - 162.9 and 110.5 daN/m^4, respectively. Moreover, it can also be noticed here that the articulated seat support, as in the case of BS and BP constructions, did not cause a significant comfort improvement. In the case of the BP construction for the load type 1 and 2, coefficient *D* reached the values 112.5 and 100.7 daN/m^4, for the load type 3 - *D*=95.6 daN/m^4, whereas for the type of load 4 and 5 - 178.7 and 147.5 daN/m^4, respectively.

In order to arrange the examined seats into groups characterized by similar properties, statistical analysis of clusters was performed and Figure 8 presents the results of this analysis. The analysis was performed with all types of construction, all loading types as well as four above-mentioned criteria of seat quality assessment. It is apparent from this Figure that two basic construction clusters were formed. The first cluster, characterized by large linkage distances, was formed by the following types: AS4, BP5, AP4, BP4, BS5 and BS4. Large link-

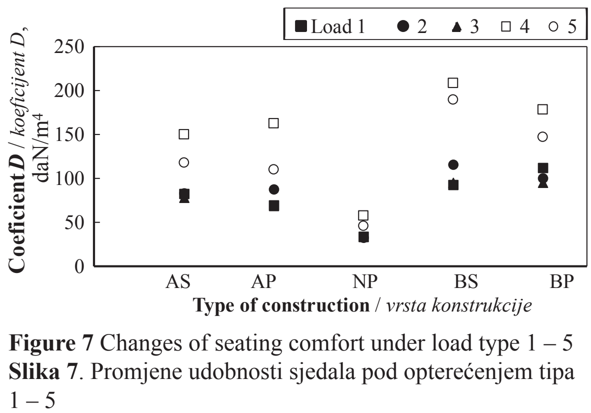

Figure 7 Changes of seating comfort under load type 1 – 5
Slika 7. Promjene udobnosti sjedala pod opterećenjem tipa 1 – 5

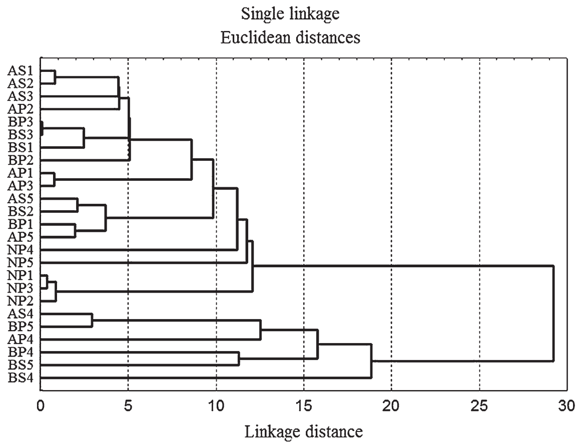

Figure 8 Collation of clusters of seats exposed to type of load 1 – 5
Slika 8. Usporedba klastera sjedala izloženih opterećenju tipa 1 – 5

age distances indicate greater differences between individual types in the cluster. The second cluster was formed by the remaining types. In this group, linkage distances were considerably smaller. On this basis, the second cluster analysis was conducted and four basic groups of similarity regarding comfort were distinguished (Fig. 9). It is evident from Figure 9 that the most important and decisive factor affecting the allocation into individual clusters was the discomfort coefficient *D*. The first cluster comprised the following construction types: AS1, AS2, AS3, BP3, AP1, AP2, AP3, BS1 and BS3; types NP1, NP2, NP3, NP4 and NP5 were allocated to cluster two; cluster three included the following types: AS5, BP1, BP2, AP5 and BS2 and the last, fourth cluster consisted of the following types AS4, BP4, BP5, AP4, BS4 and BS5. The first cluster is dominated by constructions with a fixed linkage of the seat and/or fixed linkage of the gas spring column. The second group is made exclusively of NP type construction characterized by a fixed support of the seat and articulated support of the gas spring. The third group is formed by miscellaneous types of construction but within the range of loads 1, 2 and 5. The last, fourth cluster is made of AS, BP, AP and BS with loads of type 4 and 5. On the basis of the present analysis of aggregations, it can be concluded that NP seats from the second cluster turned out to be the most uniform with respect to sitting comfort. This similarity refers to all load schemes.

5 CONCLUSIONS
5. ZAKLJUČCI

On the basis of the analysis of the obtained research results, it can be concluded that office armchairs of NP type construction, consisting of fixed seat support and articulated gas spring column, were characterized by the highest utilization comfort. Armchairs with the articulated support of the seat and a fixed support of the gas spring column exhibited a distinctly lower utilization comfort. The remaining armchair designs examined in this study can be placed between the abovementioned two solutions and can be described as having intermediate utilization comfort. *D* discomfort coefficient can be treated as an objective criterion of comfort assessment of office armchair seats. Its low values indicate high seat quality. The performed cluster analysis made it possible to select a group of the most comfortable office armchairs and to propose coefficient *D* as a decisive factor affecting the quality of seats.

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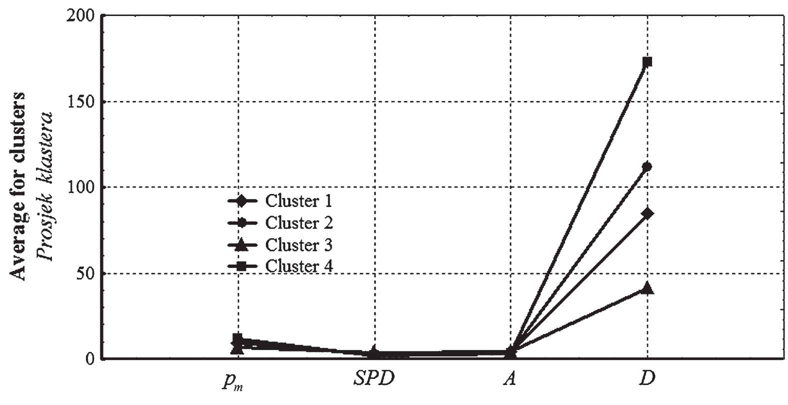

Figure 9 Impact of variables on cluster variability: p_m – average contact pressure; *SPD* – seat pressure distribution; *A* – contact surface; *D* – discomfort coefficient
Slika 9. Utjecaj varijabli na varijabilnost klastera: p_m – prosječni kontaktni pritisak; *SPD* – koeficijent raspodjele tlaka u sjedalu; *A* – kontaktna površina; *D* – koeficijent neudobnosti

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