



Validation of a new index for seat comfort assessment based on objective and subjective measurements

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Abstract

Purpose:

This work aims at validating a new statistical index (Weighted Pressure Comfort Loss, WPCL) for seat comfort assessment. The validation is carried out by deepening the relationship between subjective comfort evaluations and objective measures of seat comfort and comparing, from an engineering standpoint, the new index with the pressure peak which is currently one of the most used indexes for seat comfort assessment.

Method:

In the experimental phase, 22 experimenters evaluated four office chairs, by using different evaluation scales and methods (rating, ranking, comfort degree). The subjective comfort perceptions were collected through questionnaires. At the same time, several objective parameters related to seat comfort were measured by using a capacitive mat. In order to select the objective comfort measures which are significantly associated to the perceived comfort, a logistic regression model was adopted.

Result:

The logistic regression model selected the peak pressure as a significant predictor of perceived comfort whereas, the hypothesis of absence of correlation between the perceived comfort and the WPCL index cannot be rejected. However, from an engineering standpoint, the final seat rating evidences substantial coherence of peak pressure and WPCL index, showing not redundant results useful to design team for seat comfort improvement. Since results were strongly influenced by experimental conditions and anthropometric variability of the experimenters, further investigations should be carried out. On the basis of the first experiments, a refinement of the index and new test conditions could be investigated.

1 Introduction

Specialized literature does not provide a universally recognized definition of comfort, nevertheless in recent years, the assumption that comfort and discomfort are two distinct entities [1] is winning broad respect. In their studies, Zhang and Helander [2] show that sitting discomfort is related to the biomechanical factors associated to the interaction with the seat over time, whereas comfort reflects a perception of instantaneous well-being perceived by the user. Zhang [3] pointed out that poor biomechanics may turn comfort into discomfort even though good biomechanics is not a necessary and sufficient condition for comfort. In other words, good biomechanics can avoid discomfort and thus it can be assumed as a prerequisite for comfort. Being complex concepts, comfort and discomfort are difficult to measure and interpret [4]. A great deal of research has been done to face the problem of sitting comfort/discomfort assessment and several subjective and objective methods have been developed [5]-[9]. Typically comfort assessment is realized on the basis of subjective evaluations or postural analysis. Subjective evaluations are collected by surveying potential seat users who are asked to express their feelings of comfort/discomfort with the seat and/or compare, in terms of perceived comfort/discomfort, different seats belonging to the same class [10][11].

Postural analysis is realized by measuring one or more objective parameters, such as [12]:

- the pattern of muscle activation measured through electromyography (EMG) [13].
- the stress acting on the spine measured through pressure transducer and radio waves [13]
- the postural angles [14] obtained using contact or non contact (like photogrammetric) techniques in real experiments or using virtual manikins in virtual experiments [15]
- the body-seat interface pressure measured through capacitive mats.

Anyway, subjective and objective methods are not alternative since they complement each others.

The exclusive use of subjective evaluations can be misleading for several reasons:

- when attention focuses on particular elements of the seat, the response variability is reduced, but the interaction with other neglected features can be a noise factor [13]
- users could not be able to synthesize a subjective perception in a numeric or semantic evaluation causing a partial loss of information [11].
- the perceived differences of ergonomic features are often small and the results from comparisons of different seat concepts are rarely significant;
- the human body is very adaptive and not sensitive to distinguish variations in seats;

- subjective evaluations are costly and time-consuming [16];
- subjective evaluations are rarely applicable early in the design process [4].

On the other hand, the exclusive use of objective measures for comfort assessment, highlights the following criticisms:

- normally, the information provided by objective criteria are complement but not substitute of subjective evaluations related to user's perception of comfort;
- the construction of quantitative measures for comfort assessment cannot disregard from noises often overlooked, such as anthropometric variability.

In this perspective, a great deal of research has been performed to find objective measures for predicting seat comfort perception [17]. Research has shown that one of the main factors that affect seat comfort is seat-interface pressure distribution [18]. Moreover, pressure distribution is the objective measure with the clearest correlation with the subjective evaluation methods[4][8]. Human-seat interface pressures have a spread field of application, indeed they have been measured to improve the comfort of office chairs [19], car seats [12], motorcycles saddles [20] and others vehicles seats [21], as well as to pursue product innovation in Kansei Ergonomics [22]. In particular, in office chair design pressure maps have been used to qualitatively verify the effectiveness on seat comfort of product features like, e.g., cushion shape and materials [23]-[25] through correlation studies with the subjective user perceptions. Nevertheless the widespread use of pressure maps, just few authors [26][27] have proposed synthetic indexes for the related multidimensional data, collected by performing real or virtual experiments involving a selected sample of potential users. Furthermore, little effort has been made to highlight the usefulness of these pressure measures for specific purposes defined by designers (e.g. Design for a Target and Design for All).

In order to provide a tool that can be easily used by designers Lanzotti et al. [26][27] proposed the *Weighted Pressure Comfort Loss (WPCL)* a postural comfort index based on comfort loss due to uneven seat-interface pressure distribution. In this paper the *WPCL* index is statistically validated by assessing how its results correlate with comfort perception expressed in short-term experimental sessions. The experiments were planned by using robust design approach, taking into account the noise related to the anthropometric variability of the experimenters.

2 Identification of the goals of seat comfort assessment

The results presented in this paper are part of a wider and long-standing research activity carried on at the Department of Aerospace Engineering of University of Naples Federico II and aimed at developing simple and repeatable procedures useful to design teams for the development of more comfortable seats. To this aim, the first research step is the definition of simple quantitative seat comfort measures. These measures can be expressed into synthetic indexes that objectively meets two fundamental requirements:

- the index must be representative of user perceptions and it must be a valid surrogate of information obtained through questionnaires, until now extensively used in this field of study;

- the index must be an usable and interpretable indicator that supports the designer in his design choices.

Further, the second research step is to apply a robust design approach to validate these indexes and to identify and choose optimal levels for seat features (like materials and shapes) that improve contact between the human body and the part of a chair on which one's weight rests directly (the seat). The focus of this paper is on the validation of a new comfort index. The proposed validation procedure consists of four phases:

- Experimental setup design
- Definition of the objective and subjective measurement methods
- Comfort index definition and validation
- Experimental results elaboration

In the first phase, the experimental setup was defined in terms of control factors and noise factors by using robust design approach.

In the second phase, the experimenters, during short-term static sessions, evaluated the comfort of some office chairs expressing their judgments on three different scales (rating, ranking, comfort degree). Simultaneously, a capacitive mat allowed to capture the pressure distribution on seat interface. In this way, for each experimenter, subjective and objective measurements were collected.

In the third phase, the best objective predictors for perceived comfort were selected and validated by adopting the ordinal logistic regression (OLR). This statistical technique was applied in order to investigate the nature of relationships between the objective measurements, obtained from pressure maps and perceived comfort (subjective measurements). So the validation of *WPCL* index starts with the correlation analysis between objective and subjective measurements.

In the fourth phase, the validation follows an engineering approach based on the comparison of design choices strictly linked to the adoption of objective indexes. Even if the experimental set up is simple and just linked to one design factor, experimental results were analyzed and interpreted in order to verify if and how indexes can condition and help to improve seat design.

2.1 Previous study

In previous works [26][27], the authors proposed the index *WPCL* based on the human-seat interface pressures measured over a bidimensional pressure map obtained by discretizing the whole contact surface between the human body and the seat in a finite number, (N), of equal-area cells. When the user j is seated, n_j (with $n_j \leq N$) cells are *activated* by the effective contact between the human body and the seat. The pressure value reported in correspondence of any activated cell is always positive. The formulation of the *WPCL* index is coherent with the assumption, supported by literature, that the uniformity of pressure distribution increases the level of perceived comfort [8][25]. Coherently with these assumption, for each user, a target value x_{0j} was defined as the mean pressure over the whole contact area (eq. 1).

$$x_{0j} = \frac{PS_j}{n_j} = \frac{\sum_{i=1}^{n_j} x_{ij}}{n_j} \quad (1)$$

where:

- PS_j indicate the overall pressure impressed by the j -th user on the seat ,

- n_j is the number of activated cells in the pressure map for the j -th user,
- x_{ij} is the pressure value measured by the i -th cell when the j -th user is seated.

For each user and for each cell of the map it is possible to identify a pressure comfort loss based on a "Nominal is the Best" (NB) loss function, standardized with respect to the nominal pressure. Starting from the (1), for the j -th user the Pressure Comfort Loss Index over the activated cells of the contact surface is defined as:

$$PCL_{ij}(x_{ij}) = k_{ij} \left(\frac{x_{ij} - x_{0j}}{x_{0j}} \right)^2 \quad (2)$$

where k_{ij} is a coefficient that for each cell measures the loss corresponding to the maximum accepted deviation from the target.

Starting from eq. 2, assuming the hypotheses that the loss coefficient k_{ij} is the same for all the cells and the loss is additive, for the user j , the Pressure Comfort Loss index over the activated cells of the contact surface is:

$$PCL_j(\bar{x}) = k_j \sum_{i=1}^{n_j} \left(\frac{x_{ij} - x_{0j}}{x_{0j}} \right)^2 \quad (3)$$

being \bar{x} the vector on the n_j pressure variables x_{ij} . Additional information on k_j calculation are reported in the Appendix (eq. A1). The final formulation of the index takes into account the need to design for a specific target population through the introduction of a parameter θ related to the composition of the sample in terms of sex (eq. 4):

$$WPCL(\theta) = \theta WPCL_f + (1 - \theta) WPCL_m \quad (4)$$

with:

- $WPCL_f$ comfort loss function for the female population obtained by appropriately summing all the PCL_j of female population.
- $WPCL_m$ comfort loss function for the male population obtained by appropriately summing all the PCL_j over the male population.

2.2 Laboratory and devices

The experiments were performed at the Department of Aerospace Engineering (DIAS) of the University of Naples Federico II. A room, suitably cleared of furnishings, was chosen as scenario for the experiments. In order to collect data on pressure distribution impressed by participants on the seats the Novel Pliance mat by Novel was used fig.1. The mat is made of flexible material, characterized by 16x16 sensors uniformly distributed on its surface. The sensors send the sampled electric signals to the pliance box for converting them into digital data. Then, a dedicated software processes the data and displays them on the screen as a pressure map (fig.1). The map is a scheme of the mat; it is a matrix of 256 cells (24,5 mm x 24,5 mm) respectively corresponding to the 16x16 sensors. Each cell is characterized by a number (pressure value in kPa) and a colour (pressure range).

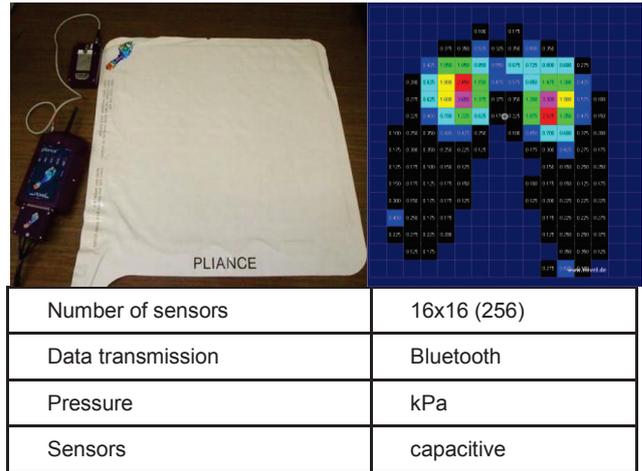


Fig. 1 Equipment and related output.

Thanks to its flexible structure the mat is a minimally invasive instrument, which does not interfere with user perception of seat comfort. Several examples of application involving these devices in comfort assessment are reported in [12][32].

3 Experimental setup design

The experiments were carefully planned to reduce noise in the evaluation of the comfort of sitting [26]. In particular, five office chairs were tested, assessing the effect of the design parameter softness on perceived comfort. Tested chairs, have a five-point base, a backrest and armrests and they differ from each other for shape and materials. The chairs are named with fantasy names (tab. 1) so as to avoid any conditioning of the brand name or the model name on the evaluation.

Denomination	Chairs
OC	Oslo Chair
MC	Madrid Chair
CC	Chicago Chair
TC	Tourin Chair

Tab. 1 Tested chairs.

3.1 Definition of the control factor

The characteristic softness (S) was considered as a qualitative ordinal variable with four levels (from 0 to 3), in order of decreasing rigidity of the seat. In particular, each seat was representative of this control factor's level (tab. 2)

Control Factor				
Softness (S)	0	1	2	3
Chair	OC	MC	CC	TC

Tab. 2 Control Factors.

3.2 Definition of the noise factor

The noise factor taken into account was the anthropometric variability of experimenters (weight) stratified by sex. The random variable (r.v.) weight of the Italian female population and the r.v. weight of the Italian male population are both normally distributed, with parameters [27] reported in tab.3.

Variable	pdf	μ (kg)	σ (kg)
Female	Normal	58	9,48

weight			
Male Weight	Normal	75	10,05

Tab. 3 Parameters of the Normal r.v. weight (kg) for Italian females and males.

The r.v. weight of the whole Italian population can be modeled as a mixture of two normal distributions, whose probability density function (pdf) is [28]:

$$f(\theta) = \theta \cdot f_f + (1 - \theta) \cdot f_m \tag{5}$$

where:

- θ is the mix coefficient representative of the proportion of females in the target population;
- f_f is the pdf of the r.v. weight of females;
- f_m is the pdf of the r.v. weight of males;

3.3 Experimenters

The experimental phase involved 22 experimenters, including 8 females (F) and 14 males (M). Anthropometric data collected from the experimenters included stature and weight. Statistics regarding these variables are reported in tab. 3.

Sex	N		Mean	St. Dev	Min	Max
F	8	stature	164,3	7,5	153,0	178,0
		weight	67,2	13,3	52,8	96,1
M	14	stature	181,6	8,3	170,0	198,0
		weight	79,4	9,3	64,4	93,0

Tab. 4 Anthropometric characteristics of experimenters.

The experimental sample is representative of the reference populations reported in tab. 3. Indeed, the sub-sample consisting of only women, covers the range from 29th to 99th percentile of the female weight distribution ($\mu=58$; $\sigma=9,48$), while the sub-sample of the men covers the range from the 14th to the 96th percentile of the male weight distribution ($\mu=75$; $\sigma=10,05$). Further details on experimenters, tested chairs and experimental setup are in [26].

3.4 Experimental protocol

More specifically, experimenters tested the seats in four short-term static experimental sessions. During the test, they were asked to read a text on VDT. According to [29], who demonstrates the invariance of global comfort rating over time, the duration of each experimental session was 5 minutes. In order to avoid the noise due to the sequence of the tested seats, the order of the test was randomized for each experimenter. Furthermore, all experimenters were blindfolded before and after each experimental session, to avoid that visual impact with the chair could affect their comfort perceptions [10].

4 Definition of the objective and subjective measurement methods

During the experimental session, for each experimenter, two types of data were recorded for each chair: objective data, obtained from pressure maps and subjective data, collected by questionnaires (tab 5). Once design factor, noise factor and responses are defined, the classical cross array showed in tab. 6 was used to plan the experiments.

4.1 Objective measures

With reference to objective data, obtained from pressure maps, many parameters were recorded: the maximum pressure (peak pressure) and the minimum pressure for each map, the sum of pressure values over all activated cells (overall pressure) and the mean of pressure values over all activated cells (mean pressure). Moreover, the total area (map area) and the weight on the mat (download weight), were measured. Finally, known the pressures of individual cells, it was possible to calculate the index PCL for each user and for each seat, using the equation 3.

Type	Label	Source
Objective	Peak pressure [N/cm ²]	Pressure maps
	Min pressure [N/cm ²]	Pressure maps
	Overall pressure [N/cm ²]	Pressure maps
	Mean pressure [N/cm ²]	Pressure maps
	Maps area [cm ²]	Pressure maps
	Download weight [N]	Pressure maps
	PCL	Calculated from pressure data
Subjective	Comfort rating	Questionnaire
	Comfort ranking	Questionnaire
	Comfort degree	Questionnaire

Tab. 5 Typology and sources of recorded data.

		Noise factor Weight					
		Female			Male		
TES	S	E ₁	E _i	E ₈	E ₁	E _j	E ₁₄
I	0		
II	1		
III	2		
IV	3		

Tab. 6 Cross array.

4.2 Subjective measures

After the test, each user expressed his/her subjective perception of comfort using three evaluation scales (rating, ranking, comfort degree) and the data were collected by questionnaires. For the rating evaluation the Borg CR10 scale [30],[31] modified by Kyung et al [32] was used. Rating scores ranged from 0 (no comfort) to 10 (extreme comfort). Every experimenter gave also a ranking of the chairs based on the perceived seat comfort. Finally, the third scale measured the user agreement with the statement "the seat is comfortable" using a four-point semantic scale : "I do not agree at all" (NA), "I scarcely agree" (SA), "I fairly agree" (FA), "I absolutely agree"(AA).

5 Comfort indexes definition and validation

The last step of the presented validation framework was the identification of good objective predictors for perceived comfort. From a statistical standpoint the nature of

dependencies between perceived seat comfort and seat pressure variables, collected in the experimental phase, was analysed through a logistic regression model. More specifically, in order to identify a robust response function to use in the regression model, an association analysis was performed on the three evaluation scales. Then an ordinal logistic regression was performed to detect the significant dependencies, if any, of perceived comfort from anthropometric variables (*i.e.* sex, weight, stature) and pressure variables (full model). Finally, starting from parameters that were significant in the full model, a new ordinal logistic regression model was re-fitted to deepen the nature of dependencies previously identified.

5.1 Choice of a robust evaluation scale for perceived comfort

Few studies in literature have dealt with the validation of subjective scales for comfort assessment, although this aspect strongly affects the achieved results. In order to verify the consistency of the subjective data collected, the three evaluation scales adopted to collect the perceived comfort judgment were analyzed to verify their level of association. All three adopted scales are ordinal and polytomous. According to [34] the Goodman and Kruskal's index was applied to all possible combinations of binary association:

$$\gamma = \frac{(S - D)}{(S + D)} \tag{6}$$

where:

- S is the total number of pairs of responses on different evaluation scales which verify the condition $i > j'$ and $j > i'$ or both $i < i'$ and $j < j'$
- D is the total number of pairs of responses on different evaluation scales which verify the condition $i > j'$ and $j < i'$ or both $i < i'$ and $j > j'$

Results obtained, summarized in tab. 7, show a substantial consistency of the three scale. The minimum value calculated (between ranking and rating, equal to 0,653) reveals, however, a medium-high level of association between the scales. It is evident that the responses given on the scale "comfort degree" were highly associated with the other ones. So the comfort degree was selected as a good proxy of perceived comfort and set as response function in the adopted logistic regression model.

	Comfort degree	Rating	Ranking
Comfort degree	1,000	0,984	0,860
Rating	0,984	1,000	0,653
Ranking	0,860	0,653	1,000

Tab. 7 Results for the association analysis on the evaluation scales.

5.2 Logistic Regression model

According to both experimental data and results achieved in previous phases of the validation procedure, the full model of logistic regression was built. This model included all variables that were assumed explicative for the response function "comfort degree". Comfort degree was an ordinal response function with four ordered levels: "I do not agree at all" (NA), "I scarcely agree" (SA) "I fairly agree" (FA) "I absolutely agree" (AA). The list and classification of variables in the full model is reported in tab. 8: Quantitative variables are described in par. 4.2. Qualitative variables of the model were:

- Sex, that is a dichotomous variable (0=female, 1=male)
- Softness is a polytomous variable with four modalities (0, 1, 2, 3).

Type	Name
Quantitative	Peak pressure [N/cm ²]
	Mean pressure [N/cm ²]
	Maps area [cm ²]
	Download weight [N]
	PCL
	Rate stature/weight of users
Qualitative	Sex
	Softness

Tab. 8 Full-model variables.

The baseline logit model [35] was used to identify significant relationships between the response comfort degree and the explicative variables in tab. 5. The generalized linear predictor equation was:

$$\hat{g}(x)_k = \beta_{0k} + x'_i \beta_k \tag{7}$$

where:

- $\hat{g}(x)_k$ is the generalized linear predictor with K=4 (index of the logits);
- x'_i are all model variables reported in table 5;
- β_k are the parameters of the model.

The significance of all parameters β_k was tested by using a stepwise backward elimination algorithm, that verified the null hypothesis that the model parameters are equal to 0. The results showed that the null hypothesis should be rejected with the conclusion that at least two parameters were significant in the model (PCL, peak pressure). Based on these results, the model could be re-fit. Then the ordinal logistic regression model (OLR) was applied [35][36] by using the comfort degree as a response function and peak and PCL as model variables. Based on the proportional odds approach, the model compares, for each ordinal level of the response function, the probability of an equal or smaller response function $Y \leq k$, with the probability of a larger response $Y > k$. The model output is reported in tab. 9. The results indicate that peak pressure significantly affects perceived comfort.

Pred	Coeff	SE Coeff	z-val	p-val	OR	95 %CI Lower	95 % CI Upper
Const	-6,49	1,29	-5,02	0,00			
Const	-3,83	0,79	-4,85	0,00			
Const	-0,05	0,66	-0,07	0,94			
Peak	2,93	0,79	3,71	0,00	18,79	3,99	88,46
PCL	-0,02	0,01	-1,68	0,09	0,98	0,95	1,00

Tab. 9 Ordinal logistic regression table.

The positive coefficient of 2,93 for peak is the estimated change in the logit of the cumulative comfort degree probability when a set of levels is compared with the others covariates, whereas PCL held constant. Because the p-value for estimated coefficient is close to 0, there is evidence to conclude that peak has a significant effect upon comfort degree. The odds ratio value is greater than one (18,79), this indicates that high peak pressures values tend to be associated with low values of comfort degree. The p-value indicates that there is no evidence to conclude that the PCL affects the comfort degree. The value of the

odds ratio is approximately equal to 1, this indicates the independence between PCL and comfort degree.

6 Experimental results elaboration

The last step of the proposed framework was aimed at the validation of the index from an engineering point of view. Mean values of peak and WPCL for the four chairs were compared to verify the consistency of information provided by these indexes. Furthermore, the analysis of the pressure maps related to the worst values of peak and WPCL, allowed the identification of chair characteristics which were critical to improve seat comfort. Given the value of k (see Appendix), it is possible to calculate the index WPCL from PCL for a mixed population. For the analyzed sample, it was $\theta = 0.36$ and $(1-\theta) = 0.64$ (36% females and 64% males). The results, assuming WPCL as a response function, are shown in tab. 10, for female, mixed and male population.

		Response		
		F	Mix	M
TEST	S	WPCL _f	WPCL	WPCL _m
I	0	0,74	0,987	1,125
II	1	0,699	0,949	1,09
III	2	0,395	0,609	0,729
IV	3	0,213	0,342	0,415

Tab. 10 Results from using WPCL as a response function.

Level 3, corresponding to the highest level of cushion softness, was the best one in terms of WPCL, whereas levels 0 and 1 got the worst results, with comparable values of WPCL (fig.2).

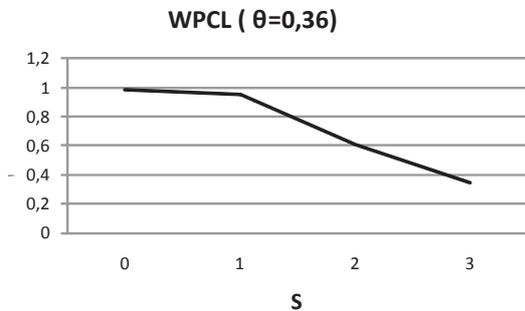


Fig. 2 Mean effects assuming WPCL as response function for a mixed population.

Level 3 seems to be also the most robust one against changes in the composition of the reference sample (fig.3). A minor change in the slope of mean effects diagram, in fact, indicates a minor change in WPCL index over different composition of the sample. The mean effects diagrams for the other levels highlight slightly higher slopes. However, whatever is the softness level, the index WPCL is greater for males than females, since it is influenced by the distribution of body weight.

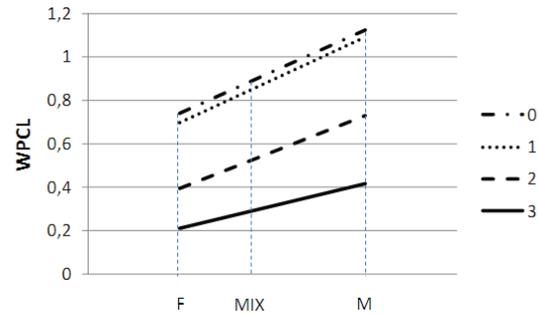


Fig. 3 WPCL Index for different sample compositions.

		Response		
		F	Mix	M
TEST	S	peak _f	peak	peak _m
I	0	1,425	2,284	2,767
II	1	1,488	1,936	2,189
III	2	0,908	1,112	1,227
IV	3	0,688	0,946	1,092

Tab. 11 Results from using peak pressure as a response function.

The same analysis was carried out, assuming the peak pressure as a response function. As shown in fig. 4, the lowest values of peak pressure were recorded for level 3. Level 2 got comparable performance, whereas level 0 and 1 once again resulted to be the worst ones.

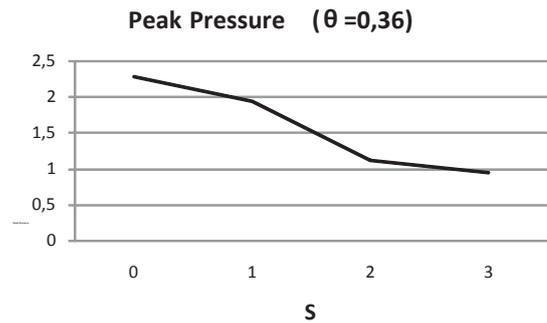


Fig. 4 Mean effects assuming peak pressure as response function for a mixed population.

The diagrams of pressure peaks for different sample compositions (Fig. 5) confirmed that level 3 is the best one, since it presents the lowest peak pressure values for any mix of the population. However, it is evident that, in this case, level 2 is more robust against the anthropometric variability induced by sex, as evidenced by the lower slope of the mean effects diagram; once again, levels 0 and 1 got the worst performance. Assuming that the sample were composed exclusively of women ($\theta = 0$), level 0 would be better than level 1. However, level 0 seems to be less robust against anthropometric variability induced by the composition of the sample, as the highest slope of its main effects diagram highlights.

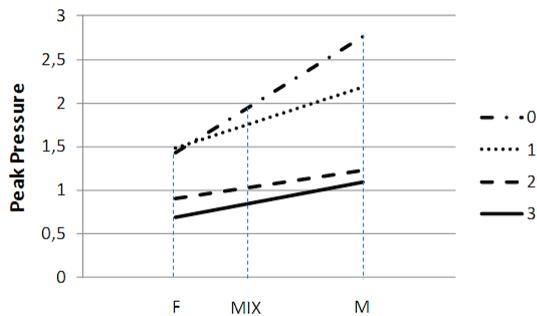


Fig. 5 Peak pressure for different sample compositions.

The ranking of chairs shows substantial coherence of the results provided by peak pressure and PCL.

With regard to level 3 (i.e. seat TC), the minimum values of these indexes are related, for each sub-sample, to the same pressure map and thus identify the same experimenter (fig.6).

This coherency in results does not mean that peak pressure and PCL provide the same information.

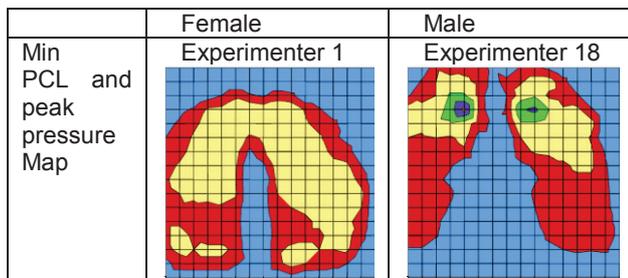


Fig. 6 Pressure maps related to minimum values of PCL and peak pressure for the seat TC.

For instance, fig. 7 show the pressure maps related to the maximum values of peak pressure and PCL for level 0 (i.e. seat OC), which resulted to be the worst one in terms of perceived comfort.

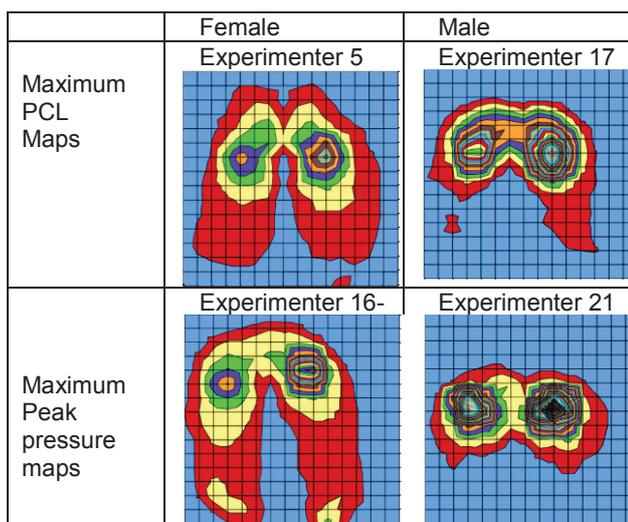


Fig. 7 Pressure maps related to maximum values of PCL and peak pressure for the seat OC.

The joint analysis of these indexes allows to obtain important information for the improvement of the seat.

Based on selected maps it is possible to highlight main issues in improving the design of tested chairs. By

integrating the information provided on sensitive areas by maximum peak pressure and PCL, it is possible to improve the seat in terms of comfort loss. More specifically, it is important to identify and analyze the most stressed areas, in order to reduce load on bony prominences of the pelvis, taking into account anatomical differences related to the sex of the experimenter [37]. As shown in fig. 6, in fact, the pelvis of women are developed more in width, while in men the sacral and iliac bone is thicker and heavier, generating localized peaks of greater magnitude. The analysis of pressure maps stratified by sex help to take into account variability and redesign the seat's shape and materials. To mitigate the peak loads at the ischial tuberosities, for different anthropometric percentiles, an insertion of material could be expected (e.g., polyurethane foam of assigned density) to reduce significantly the discomfort caused by body compression on the seat.

7 Conclusions

The purpose of this work was the validation of an index for seat comfort assessment, which could be a valuable support in the design phase. More specifically, the WPCL index proposed in a previous work, was compared with both objective and subjective parameters obtained in experimental tests planned to compare office chairs.

From the statistical standpoint, relationships between perceived comfort and objective parameters were investigated through a logistic regression model, assuming as a response function the subjective measure of users' comfort perception (comfort degree). Among others objective measures, OLR identifies peak pressure and PCL as the two parameters that are significantly associated to perceived comfort. The results revealed that comfort degree strongly depends on peak pressure, whereas there is no statistical evidence of dependence on WPCL. The assumption that the high pressure values are predictors of comfort is unsatisfactory. In fact, the peak pressure can be a useful parameter for the designer, only if integrated by information about the position of the peak itself [8].

On the other hand, the failure to identify significant correlation between WPCL index and comfort degree, must be deepened. It could be that subjective evaluation in a short-time session is more related to instantaneous stimuli like the peak pressure. This means that the opinions of users may be misleading and therefore not suitable in an analysis like the one proposed in this paper. Further investigation will concern the following critical issues:

- a refinement of the index so as to take into account variations between neighbouring cells of a pressure map instead of single values;
- An in-depth study of the most significant anthropometric variables is necessary in order to improve the robustness of the seats over different types of users (design for all).
- From an engineering standpoint, the index WPCL and the peak pressure, got consistent results with regard to softness, providing not redundant information that could help designers to improve chair design, taking into account different sensitive areas of the seat.

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Appendix: k_j definition

The calculation of k_j was made on the basis of pressure maps data, assuming that the maximum value of the ratio, expressed in formula (eq. A1) was the maximum tolerable by the user. More specific only maps which had a comfort degree score equal to 4 (completely comfortable) were selected. Identified the maximum of this ratio, the value of k_j (one for all the maps) was calculated as its reciprocal. More specifically, the resulting k_j value was equal to 0.10.

$$\frac{PCL_j(\bar{x})}{k_j} = \sum_{i=1}^{n_j} \left(\frac{x_{ij} - x_{0j}}{x_{0j}} \right)^2 \quad (A1)$$

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