DESIGN FOR ERGONOMICS: CHAIR DESIGN FOR AGEING EMPLOYEES

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Customer needs relating to pieces of furniture touch upon ergonomics. Needs are special when elderly people are concerned. At the same time, these needs are expressed in the "language of the customer". Designers are facing the challenge of answering questions about what a piece of furniture has to do in order to bring about customer satisfaction in use and how relatively subjective customer needs could be translated into precise development target. Ergonomic suitability has a number of components each of which is determined by a given set of product properties. Therefore, ergonomic quality can be satisfied by using complex methods of analysis. Such method could be Quality Function Deployment (QFD), the adaptability of which for ergonomic design is confirmed in the study. It is found that the components of ergonomic quality can be treated as dependent variables the level of which is determined by product-related independent variables. A model for evaluating and designing ergonomic quality is demonstrated on the basis of design of experiments (DOE).

Introduction

The objective of our study is to use ergonomic design for seats in order to benefit ageing employees. In this article, we present a suggestion of satisfying ergonomics by using tools of mathematical statistics. We propose a three-stage approach.

The first stage is clarifying the objectives, i.e. defining what benefit or usefulness in this case would mean. In the literature one can find methods mainly based on questionnaires (Hayes 1999). We can establish that maintaining working performance and preserving health of the older workforce are the two points around which we can deploy the objectives to be met through ergonomic design Performance at older ages requires dealing with decreased muscular power, accelerated fatigue, drop of sensori-motor capabilities. Preserving health necessitates effective relaxation, safety, and avoidance of exertion with the use of the piece of furniture (Klein 2004). These requirements have to be interpreted as properties of seats conceived by the user and/or suggested by medical experts.

Having defined the expected properties of the seat, in the second stage the same should be converted into technical specifications. In the third stage the target values of the technical parameters, i.e. the best combination of their level should be found. For these two latter

stages, in this paper we present the tentative utilisation of two methods. The first one is based on the technique of Quality Function Deployment (QFD) while the second one is using Design of Experiments (DOE). The objective is to develop a model by which the ergonomic appropriateness becomes possible to assess and to design into the product.

Methods

Application of the QFD method for improving ergonomic quality

A product is the carrier of functions corresponding to a set of needs (expectations). The designer tries to cope with those needs through the choice of a multitude of technical (design) parameters characterizing the product. An essential step in the design based on customer needs is the interpretation of the needs by using product-related technical terms. QFD is a suitable method to do this. In a QFD study, customer needs (WHATS) are converted into technical parameters (HOWS); the relative importance of the latter is then determined by setting up an interaction matrix. The final result of the procedure is target levels established for the technical parameters through which customer expectations can be optimally satisfied (Roozenburg 1995). Adaptation of the method for ergonomic design will be next illustrated through a case study relating the design of a chair for ergonomic aspects, destined for use by aged employees. User needs, as shown in Table 1, were surveyed by the authors.

Table 1. List of user needs

WHATS (What users are asking for)	Customer Importance Values
stability	
load-bearing capacity	
easy to stand up	
comfortable sustained sitting	
no risk of injury	
impedes unhealthy position	
easy to move without exertion	
pleasant to the touch	
easy to clean surfaces	
provides relaxing posture	
releases trunk	
releases legs	
durable	
fits the table	

From the list above it appears that user needs are aiming at tangible, technical parameters to a minimum extent only. Instead, they relate the actual use and the relationship with the immediate environment of the product. The same needs will also be used later in the designed experiments as output variables.

As part of the QFD procedure, the individual customer needs have to be weighted. In this study we used the method of paired comparison and checked the results of assessment for consistency. Weights are based on decisions on preference between two criteria when each criterion is pared with each other one.

Columns of the "HOWS" make the next "room" of the House of Quality, the graphical presentation of the procedure. Here are listed the technical details and parameters with the objective of satisfying customer needs as shown in Table 2 below. The technical parameters listed above characterise a chair from the ergonomics point of view. The individual parameters can be assigned actual values or ranges, or perception levels positioned in interval scales e.g. hardness of upholstery such as soft, semi-soft, semi-hard etc.

Table 2: Listing of the technical parameters involved in the study

	HOWS
How to deliver WHATS (Measurable Quantities)	structural stiffness
	strength of structural joints
	resistance to abrasion of the surfaces
	width of seat
	depth of seat
	height of seat
	slope of seat
	distance of arm-rests
	height of arm-rest
	inclination angle of back
	width of arm-rests
	height of back
	length of arm-rests
	curvature of back
	radius of file on frame members
	thickness of upholstering
	hardness of upholstering
	weight of the chair
	surface quality
	air permeability of the cover fabric
	thermal conductivity of upholstery
	vapour resistance of the cover fabric
	resistance of surfaces to chemicals
	sole

The next step is to fill in the interaction matrix. The scale we chose is as follows: 9 = strong positive correlation; 3 = medium correlation; 1 = weak correlation.

Values in the cells of the interaction matrix multiplied by the weights of the criteria in each row are summed up over each column to get indication on the importance of the individual technical parameters. The higher the relative importance the more expedient is to shift the parameter's value towards its optimum level. Studying the values of the technical parameters of a few competitive products, one can conclude the target values through which the planned satisfaction level becomes attainable. While weighting of customer needs as well as establishment of the relative importance of the technical parameters are easy to do in an algorithmic way, deciding on target values requires judgements by the analyst and remains more subjective within the QFD procedure. An alternative to these judgements could be DOE.

Designing ergonomic quality into the product

Product features conceived by the users depend on several variables and/or attributes of the product; they can be treated as design parameters. From our point of view the components of the ergonomic quality are considered as dependent variables each of which is influenced by a group of quantitative and categorical independent variables. Therefore they can be studied by the methodology of design of experiments (DOE). In the foregoing we will demonstrate how the relationship between design parameters and customer satisfaction can be studied by designed experiments. Design of experiments means to select the settings of the variables where we conduct the individual runs of experiments. The aim is to find a mathematical model of the relationship between the dependent and independent variables.

The experimental runs have been defined as samples selected from a pool of chairs immediately available for test or obtained by purposeful modifications of suitable pieces. Samples were tested by evaluators who gave their assessment of features of ergonomic quality. The application of the method is illustrated here by treating two customer need items, comfortable sustained sitting and release of the trunk. The effects of five design parameters have been studied in relation with the two customer need items. We defined two setting levels for the design parameters or factors involved, as shown in Table 3.

Table 3: factors and levels

Factor	Level 1.	Level 2.
F1 - width of seat mm	370-425	426-480
F2 - depth of seat mm	360-409	410-460
F3- width of back mm	330-429	430-530
F4 - height of back mm	335-467	468-600
F5 - inclination of back °	90-97	98-105

For the number of factors studied we chose design L8 (Barker 1990) conceived for seven factors. For five factors we expediently used the setup as shown in random order below:

Table 4: Design matrix for the experiments in the chair study

Run	F1	F2	F3	F4	F5
8	1	1	1	2	2
7	1	1	1	1	1
2	2	2	1	2	2
3	2	2	1	1	1
6	1	2	2	2	1
5	1	2	2	1	2
4	2	1	2	1	2
1	2	1	2	2	1

The chairs were physically tested by four evaluators for the criteria of comfortable sustained sitting and release of the trunk. The evaluators expressed their level of satisfaction in an interval scale 0 to 5.

Results and discussion

Findings from the application of the QFD method
The paired comparison of the 14 customer needs was performed by three evaluators. Using the aggregated preference values arrived at by paired comparison, and assigning strength of correlation values in the QFD interaction matrix, the importance rating of the chair's technical parameters was generated. The results are shown in Figure 1.

Customer needs	Weights	structural stiffness	strength of structural joints	resistance to abrasion of the surfaces	width of seat	depth of seat	height of seat	slope of seat	distance of arm-rests	height of arm-rest	inclination angle of back	width of arm-rests	height of back	length of arm-rests	curvature of back	radius of file on frame members	thickness of upholstering	hardness of upholstering	weight of the chair	surface quality	air permeability of the cover fabric	thermal conductivity of upholstery	vapour resistance of the cover fabric	resistance of surfaces to chemicals	sole
stability	0,51	3	3		1	1	1		3	1	3								3						3
load-bearing capacity	0,54	9	9																3						3
easy to stand up	0,70	1			1	9	9	9	3	3	1			3			3	3							1
comfortable sustained sitting	0,68				9	9	9	9	9	9	9	9	9	9	9	9	9	9			9	9	9		
no risk of injury	0,80	3	9													9				3					
impedes unhealthy position	0,56				3	9	9	9	9	9	9	3	9	3	9	3	3	3		3					
easy to move without exertion	0,77	1			3	3	3			1			1	1					9						9
pleasant to the touch	0,23			1												3	1	1		9					
easy to clean surfaces	0,15			9																				9	
provides relaxing posture	0,58	1			9	9	9	9				9	9	9			3	3			3	3			
releases trunk	0,54						3																		
releases legs	0,58				3	3		3	3	3	3				3										
durable	0,37	9	9	9																				3	
fits the table	0,47						9						3				1	1							
Absolute importance of the paramerters		14,1	17	4,9	18	27	31	24	17	16	15	13	19	16	13	15,6	12	12	10	6,1	7,86	7,9	6,1	2,5	11
Importance ranking		12	6	20	5	2	1	3	7	8	11	13	4	9	14	10	15	15	17	20	18	18	19	21	16

Figure 1: Detail of House of Quality for chair design – importance of the technical parameters

On the basis of the QFD analysis conducted, it can be asserted that height, width, depth and slope of the seat all have outstanding importance (rated higher than 18.00 on an interval scale extending from 0 to 27.29). Therefore, these parameters, which are directly related to ergonomic quality, deserve special attention in the design.

Application of DOE
The chairs corresponding to the individual runs were given scores of the level of satisfaction from the evaluators with respect to comfort of sustained sitting and release of the trunk respectively. The method of analysis used is regression analysis, for the validity of which the assumptions of normal distribution of the residuals and constant variance was verified.

In Table 5 the results of the parameter estimation and significance tests are shown. The variables VAR1 through VAR5 correspond to factors F1 through F5, VAR6 being the dependent variable .The column "Var6 Param." contains the regression model coefficients fitted to the results of observations. With these coefficients the mathematical model is:

$$y = 3.9296 + 0.2734 \cdot x_1 + 0.1328 \cdot x_2 + 0.2266 \cdot x_3 + 0.0116 \cdot x_4 + 0.0703 \cdot x_5 \qquad \text{eq. 1}$$

where x_1 and x_2 etc are coded values of factor settings
y is score given to the level of the dependent variable

Table 5: Model parameters and their tests of significance relating to "comfort of sustained sitting"

Effect	Parameter Estimates (Comfort of Sustained sitting)					
	Level	Column	Var6 Par.	Var6 SE	Var6 t	Var6 p
Intercept		1	*3.929688*	*0.099978*	*39.30536*	
"Var1"	1	2	*-0.273437*	*0.099978*	*-2.73497*	*0.011085*
"Var2"	1	3	0.132812	0.099978	1.32841	0.195585
"Var3"	1	4	*-0.226563*	*0.099978*	*-2.26611*	*0.032000*
"Var4"	1	5	-0.101563	0.099978	-1.01584	0.319064
"Var5"	1	6	-0.070313	0.099978	-0.70328	0.488134

The effects of factors 4 and 5 are negligible (the level where they become significant is much higher than 5%) therefore they can be left out of the model. Factors 1 and 3 are decisively influential; the effect of factor 2 is worth taking into account and keeping in the model.

A similar analysis of the factor effects relating the release of the trunk as a dependent variable results in the mathematical model below:

$$y = 3.5313 + 0.2813 \cdot x_1 + 0.1875 \cdot x_2 + 0.3125 \cdot x_3 + 0.0938 \cdot x_4 + 0.1875 \cdot x_5 \qquad \text{eq. 2}$$

where, according to the significance tests, factors 1 and 3 are decisively influential; besides, the effect of factors 2 and 5 are worth taking into consideration. The mathematical models resulting from the designed experiments are useful for predicting the ergonomic suitability of a chair for a given user expectation, and may also be used to find the optimum setting of the design parameters. See more about the subject in Taguchi 2000.

Conclusions

Ergonomic suitability has a number of components each of which is determined by a given set of product properties. Components of the ergonomic quality are delineated by customer needs in an indirect way and can be satisfied by using complex methods of analysis. Such a method could be the QFD, the adaptability of which for ergonomic design can be confirmed as a result of the study presented. It further follows from the findings of study that the components of ergonomic quality can be treated as dependent variables the level of which is determined by quantitative and categorical product-related independent variables. A model for evaluating and designing ergonomic quality is possible to be based on the method of design of experiments (DOE).

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