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Comparison of Ergonomic Design Approaches for Office Chairs by Accommodation Level

Celal GÜNGÖR

İzmir Katip Çelebi University, Forest Industrial Engineering, İzmir, TÜRKİYE
Corresponding Author: celalgungor53@hotmail.com

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Abstract

Aim of study: It is very important to design office furniture based on the anthropometry of employees because it affects their comfort, performance, and in serious cases, their health. Adjustable chairs are typically designed for a certain percentile of the user population. However, this design approach may not provide an accommodation level as intended because a chair has more than one design dimension. The objective of this study is to compare the percentile-based design approach and subject-based design approach by accommodation level.

Material and methods: A sample of 4.082 males from the 2012 ANSUR II database was used to compare two design approaches by accommodation level. An adjustable office chair was designed to investigate whether or not the final accommodation level differed from the desired accommodation level. Using four anthropometric measurements, the lower and upper limits for four chair dimensions are calculated to cover 95% of users.

Main results: The anthropometric measurements of a total of 728 subjects (17.83%) did not match for at least one chair dimension, resulting in the adjustable chair accommodating 82.17% of users, rather than 95% as intended. Two additional chair dimensions (backrest height and width) reduced the accommodation level to 77.36%.

Highlights: Considering that eleven different chair dimensions are considered in a typical chair design, it is reasonable to assume that the accommodation level will be even lower.

Keywords: Anthropometry, Physical Ergonomics, Office Chair.

Ofis Sandalyeleri için Ergonomik Tasarım Yaklaşımlarının Uygunluk Seviyelerine Göre Karşılaştırılması

Öz

Çalışmanın amacı: Ofis mobilyalarının çalışanların antropometrisine dayalı olarak tasarlanması, konforlarını, performanslarını ve ciddi durumlarda sağlıklarını etkilediği için çok önemlidir. Ayarlanabilen sandalyeler, tipik olarak kullanıcı popülasyonunun belirli bir yüzdesi için tasarlanır. Ancak bu tasarım yaklaşımı, bir sandalyenin birden fazla tasarım boyutuna sahip olması nedeniyle amaçlandığı gibi bir uygunluk seviyesi sağlamayabilir. Bu çalışmanın amacı, yüzdelik-temelli tasarım yaklaşımı ile kişi-temelli tasarım yaklaşımını uygunluk seviyelerine göre karşılaştırmaktır.

Materyal ve yöntem: 2012 ANSUR II veri tabanından 4.082 erkekten oluşan bir örneklem, iki tasarım yaklaşımını uygunluk seviyesine göre karşılaştırmak için kullanılmıştır. Nihai uygunluk seviyesinin istenen uygunluk seviyesinden farklı olup olmadığını araştırmak için ayarlanabilir bir ofis koltuğu tasarlanmıştır. Dört antropometrik ölçü kullanılarak, dört sandalye boyutu için alt ve üst sınırlar, kullanıcıların %95'ini kapsayacak şekilde hesaplanmıştır.

Temel sonuçlar: Toplam 728 deneğin antropometrik ölçüleri (%17.83), en az bir sandalye boyutu için eşleşmemiştir ve ayarlanabilir sandalyenin, amaçlandığı gibi %95 yerine kullanıcıların %82.17'sine uygun olduğu tespit edilmiştir. İki ilave sandalye boyutu (sırtlık yüksekliği ve genişliği) ise uygunluk seviyesini %77.36'ya düşürmüştür.

Araştırma vurguları: Tipik bir sandalye tasarımında on bir farklı sandalye boyutunun dikkate alındığı düşünüldüğünde, uygunluk seviyesinin daha da düşük olacağını varsaymak gerekir.

Anahtar Kelimeler: Antropometri, Fiziksel Ergonomi, Ofis Sandalyesi.

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Introduction

Technological advances in manufacturing and services have led to an increase in office work and the amount of time employees spend with office furniture. Many office activities involve sitting for long periods of time. When office furniture fits poorly to the anthropometry of employees, it significantly affects their health (Dalager et al., 2019; Grimes & Legg, 2004; Ivelic et al., 2002; Nelson & Silverstein, 1998; Robertson et al., 2009; Robertson & Michael O'Neill, 1999; Roossien et al., 2017; Saes et al., 2015; Triglav et al., 2019; Winkel & Jorgensen,1986) performance (I. Castellucci et al., 2016; Ivelic et al., 2002; Robertson & Michael O'Neill, 1999), and comfort (Harrison et al., 1999; Zemp et al., 2015). Therefore, it is very important to design office furniture of whose physical dimensions fit the anthropometric characteristics of the employees.

The dimensions of the chair (Figure 1) should be designed based on the anthropometry of the user. For example, the seat height should be based on the popliteal height of the user (Chaffin et al., 1999; Kroemer et al., 2001). Similarly, the seat depth, seat width, backrest height, backrest width, and armrest height should be determined based on the buttock-to-popliteal length, seated hip breadth, shoulder height, bideltoid breadth, and elbow rest height, respectively. Table 1 shows the most common dimensions for chairs and the corresponding standard anthropometric measurements.

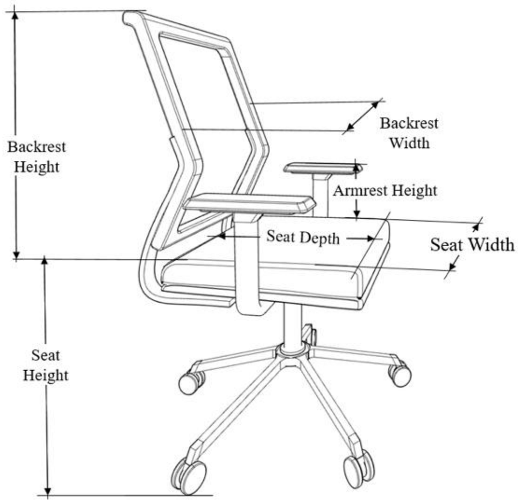

Figure 1. Chair dimensions

Table 1. Dimensions of chairs and related anthropometric measurements

Chair dimension	Anthropometric measurement
Seat height	Popliteal height
Seat depth	Buttock-to-popliteal length
Seat width	Hip breadth (seated)
Armrest height	Elbow rest height
Backrest height	Acromial (Shoulder) height (seated)
Backrest width	Bideltoid breadth

In offices, adjustable chairs are preferred over fixed (not-adjustable) chairs as they accommodate more people. Anthropometric measurements of users are required to design these office chairs. An adjustable chair is typically designed to fit 95% of the users. For example, the seat height of an adjustable chair is calculated based on the distribution of users' popliteal height data. If the lowest chair seat height from the floor is designed for the 2.5th percentile of users and the highest chair seat height from the floor is designed for the 97.5th percentile of users, then the chair accommodates 95% of users. However, this statement would be true if there was only one design dimension (parameter). There is more than one design dimension in chair design, such as buttock-to-popliteal length, hip breadth, and elbow rest height (Figure 2). The 95% of the user population may not necessarily fall within the 95% of all anthropometric measurements. For example, an obese person may have an average (the 50th percentile) sitting height but his/her hip breadth may be within the 99th percentile. If a chair is designed based on the anthropometric measurements of 95% of the user population, that person will be within 95% of the sitting height but outside the 95% of the hip breadth. This suggests that the "percentile-based design approach" provides a different level of accommodation than the "subject-based design approach." It should be noted that the term "subject-based design approach" is used to define a "personalized" product. It is basically a hypothetical product that fits all users.

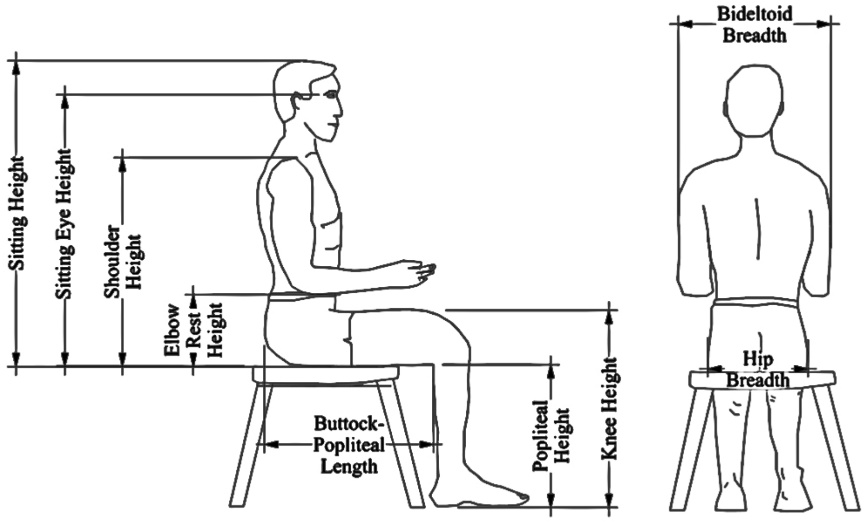

Figure 2. Anthropometric measurements for chair design

It is important to know the accommodation level of a product, which helps to target the customer. An adjustable chair is usually expected to have a 95% accommodation level. However, a chair may not accommodate 95% of customers even if it has a 95% accommodation level for each dimension. The present study aims to investigate whether the size of a chair designed based on anthropometric percentiles is suitable or not for each person and whether the final accommodation level differs from the desired accommodation level. In other words, this study compares two ergonomic design approaches (percentile-based design approach and subject-based design approach) by accommodation level.

Materials and Methods

Anthropometric Measurements

In addition to height and weight, there are eleven anthropometric measurements that are often used in the design of chairs. They are sitting height, sitting eye height, sitting acromial/shoulder height, elbow rest height, buttock-to-popliteal length, popliteal height, sitting knee height, thigh clearance, sitting hip breadth, forearm-forearm (elbow-to-elbow) breadth, and bideltoid breadth (Figure 2). In the present study, four of them were selected because they are the measurements that constrict the seating space mostly: popliteal height, sitting hip breadth, buttock-popliteal length, and elbow rest height.

Anthropometric Data and Study Sample

The 2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II) database (Gordon et al., 2014) is used in the present study as the study sample. It was selected because it has been one of the most comprehensive publicly available datasets on body size and shape, containing 134 body measures (93 directly measured and 41 derived measures, and 15 demographic/administrative variables) for 6.068 adult U.S. military personnel (4.082 males and 1.986 females). The anthropometric dataset of male subjects was used to demonstrate differences between design approaches in this study. Only one gender was selected to minimize the gender effect on body dimensions. As suggested in the Memorandum for Record on the subject of the 2012 US Army Anthropometric Working Databases, male and female databases should be treated and analyzed separately because combining the databases would result in a sample that is not representative of a real population and could easily lead to incorrect conclusions. Males were selected for this study because they have a larger sample size compared to females. The mean age of the male subjects was 32.2 (SD 8.8) years and ranged from 17 to 58 years. The average height and weight were 177.9 (SD 7.5) cm and 85.3 (SD 13.6) kg, respectively.

Adjustable Chair

When designing adjustable chair, the lower and upper limits of chair size dimensions are calculated to cover 95% of users. Thus, the accommodation level is expected to be 95%. The lower and upper limits for seat height and armrest height are designed for the 2.5th and 97.5th percentile of users. The seat width is designed for the 95th percentile and the seat depth for the 5th percentile. It should be noted that there are different suggestions for furniture dimensions in the literature. For example, it is suggested that the seat height should be between 88% and 95% of the popliteal height (Parcells et al., 1999). Ismaila et al. (2015) suggested using 75th percentile of popliteal height; Kothiyal and Tettey (Kothiyal & Tettey, 2001) suggested using 5th percentile of popliteal height of females and additional 4.5 cm; Taifa and Desai (Taifa & Desai, 2017) used 5th percentile (female) to 95th percentile (male) of popliteal height and additional 2.5 cm for shoe allowance. Many researchers suggest designing the height of seat based on Equation 1. The left side of the equation represents the lower limit and the right side represents the upper limit of the seat height. In the equation, PH is popliteal heigh and SC is shoe clearance. Unfortunately, researchers do not agree on the value of shoe clearance. Different values such as 2 cm (Agha, 2010; Baharampour et al., 2013; Dianat et al., 2013; Gouvali & Boudolos, 2006; Qutubuddin et al., 2013; Yanto et al., 2017), 2.5 cm (I. Castellucci et al., 2010; Kalurkar & Salunke, n.d.; van Niekerk et al., 2013), 3 cm (Afzan et al., 2012; H. I. Castellucci et al., 2010; Hoque et al., 2014; Noshin et al., 2018; Parvez et al., 2018), 4 cm (Lee et al., 2020), and 4.5 cm (Pheasant, 1984) are recommended in the literature.

$$(PH + SC) \times \cos 30° \leq \text{Seating Height} \leq (PH + SC) \times \cos 5° \quad (1)$$

Similarly, some researchers (Molenbroek et al., 2003) have suggested that the seat height should be such that a user’s lower leg forms an angle of no more than 30° to the vertical axis. However, it should be clarified that the purpose of the present study is not to find the optimal chair dimensions, but to observe whether there are differences in the level of accommodation achieved by the two different design approaches. The first design approach suggests using percentiles and the alternative design approach suggests using each subject’s anthropometrics measurements. It hypothesizes that there is a difference between the percentile-based design (it does not matter which percentile is used) and the subject-based design.

Results

The mean values and standard deviation for four anthropometric measurements (popliteal height, sitting hip breadth, buttock-to-popliteal length, and elbow rest height) used in chair design were calculated. The statistics for the anthropometric measurements of all male subjects can be found in Table 2. The calculated values for the dimensions of the chair, as well as the number and percentages of subjects who do not accommodate, are also shown in Table 2.

Table 2. Statistics for anthropometric measurement of 4.082 males, for adjustable chair dimensions, and not-accommodate users

Antropometric Measurements	Mean (cm)	Lower and upper limits of chair dimensions	Lower Limit (cm)	N of Not-Acc.	% of Not-Acc.	Upper Limit (cm)	N of Not-Acc.	% of Not-Acc.	N of Total Not-Acc.	% of Total Not-Acc.
Popliteal height	42.98	< 2.5th percentile & 97.5th percentile <	38.12	86	2.11	47.85	115	2.82	201	4.93
Buttock-popliteal length	50.29	< 5th percentile	45.78	182	4.46	---	---	---	182	4.46
Hip breadth	37.93	95th percentile <	---	---	---	42.90	236	5.78	236	5.78
Elbow rest height	24.50	< 2.5th percentile & 97.5th percentile <	18.89	125	3.06	30.12	84	2.06	209	5.12

The mean popliteal height was 42.98 (2.48) cm. A total of 86 subjects (2.11%) of all subjects had a popliteal height of 38.12 cm or less and a total of 115 subjects (2.82%) of all subjects had a popliteal height of 47.85 cm or more. Of the 4.082 subjects, a total of 201 subjects had smaller or larger popliteal height. In other words: If an adjustable chair intended for 95% of users is designed based on the 2.5th percentile and the 97.5th percentile for seat height, it will not accommodate the 4.93% of the user population as intended.

The average buttock-to-popliteal length was calculated to be 50.29 (2.74) cm. Assuming that the seat depth of a chair accommodates 95% of users, it should be greater than the 5th percentile buttock-to-popliteal length which is 45.78 cm. There was a total of 182 subjects whose buttock-to-popliteal length was less than this value, which gives a proportion of 4.46% of the not-accommodate users.

The average hip breadth for all subjects was 37.93 (3.02) cm. When chair width is designed based on the 95th percentile of subjects, 5% of all subjects cannot sit comfortably in the chair. For the subjects in the study, the hip breadth for the 95th percentile was 42.90 cm, and 236 subjects had a hip breadth greater than this value. This means that the chair does not accommodate 5.78% of the user population.

The average elbow rest height was 24.50 (2.87) cm for the study sample. If the armrest height of a chair is designed for the 2.5th percentile and the 97.5th percentile, it will accommodate 95% of the user population. The lower and upper bounds for armrest height in our design were calculated to be 18.89 cm and 30.12 cm, respectively. For 125 subjects the elbow rest height was less than 18.89 cm and for 84 subjects it was greater than 30.12 cm, resulting in a total of 209 not-accommodate subjects (5.12% of all subjects).

An ergonomically designed chair is expected to accommodate %95 of users. Even if the dimensions of a chair are calculated based on anthropometric data, it may not accommodate the user population as intended. In the present study, only four chair dimensions were calculated based on the anthropometric data of the subjects. Out of 4.082 subjects, the adjustable chair accommodates 3.354 subjects in terms of the four anthropometric measurements. 631 subjects had a fitting problem with one chair dimension, 94 subjects had fitting problems with two dimensions, and 3 subjects had fitting problems with three dimensions. This means that the anthropometric measurements of a total of 728 subjects (17.83%) did not match at least one chair dimension. The result suggest that the adjustable chair accommodates 82.17% of users, not 95% as intended.

Discussion and Conclusion

In this study, the four main chair dimensions were evaluated. Considering that eleven different chair dimensions are considered in a typical chair design, it is reasonable to assume that the accommodation level will be even less than 82.17%. For example, the backrest dimensions (height and width) of the chair were not considered in this study. However, backrest dimensions should be based on anthropometric measurements of seated acromial (shoulder) height and bideltoid breadth. If both chair dimensions were designed for the 95th percentile, the minimum backrest dimensions would be 65.35 cm in height and 56.39 cm in width. Of 4.082 subjects, 237 subjects (5.81%) would have larger bideltoid breadth and 198 subjects (4.85%) would have larger acromial height than the design limits. 924 subjects in total (22.64%) would have a problem with fitting at least one chair dimension. Thus, the accommodation level decreases with additional design constraints.

It should also be noted that the study population in the present study is very homogeneous in terms of body measurements. The subjects are male, young and members of the military. They are also mostly physically fit. However, an office chair is designed for civilian subjects with different body dimensions, age, gender, occupations and health conditions. It can be assumed that the accommodation level of the chair for the general population is much lower than for military personnel.

Finally, the focus of the present study is on sizes; however, the literature recommends considering the shapes of the subjects (Branton, 1984; Nijholt et al., 2016; Wang et al., 2018), their seating posture (lordosis and kyphosis lumbar seated position) (Pynt et al., 2001), the type of chair (dynamic and static chairs) (van Dieën et al., 2001), and the proportions of the chair (Kelly, 2005) to accommodate a maximum number of users. In addition to the anthropometry of the user, these design considerations affect the percentage of accommodation level.

An office chair can be designed based on the percentile-based design approach. All the dimensions of the chair can be calculated based on the relevant anthropometric measurements for the percentile of the target user. In the present study, an anthropometric office chair was designed based on an available open-source anthropometric dataset (ANSUR II). Each dimension of the chair was designed for the 95th percentile value of the relevant body dimensions. However, the accommodation level of the chair with six chair dimensions would decrease from 82.17% to 77.36% compared to the accommodation level of the chair with four chair dimensions.

It should be noted that the chair itself was evaluated in this study. However, it should be designed as part of a workstation with a table and other furniture. Thigh clearance, for example, was not considered as a limiting chair dimension in the present study. However, it has a very high important role in the design of a workstation. It determines the minimum distance between the seat pan and the table. It should be known that the degree of fit of the office chair was not 95% as intended. The number of subjects whose anthropometric dimensions, at least one dimension, did not match the chair's dimensions was 782 out of 4.082 subjects. Thus, the subject-based design approach resulted in a degree of fit of 82.17%, not 95%. With a different subject population and additional chair dimensions, the degree of fit could be much lower. If each user's anthropometric measurements are known, designers should examine the subject-based accommodation level to determine the actual percentage of accommodation.

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: C.G.; Investigation: C.G.; Material and Methodology: C.G.; Supervision: C.G.; Visualization: C.G.; Writing-Original Draft: C.G.; Writing-review & Editing: C.G.; Other: Author has read and agreed to the published version of manuscript.

Conflict of Interest

The author has no conflicts of interest to declare.

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