Comfort of Public Seating: Personalized Compensation Design

Hua Wei

weihuafairy@163.com

Guangdong University of Technology , Guangzhou, China

Abstract. This study focuses on the increasing trend of spinal problems among Chinese students during their school years, especially those who spend long hours using public seating. Addressing the issue of individual needs not being met due to inadequate public seating design, personalized compensation design is proposed as a solution. By assessing potential sitting postures, constructing demand models, and designing compensatory products, individual needs are met, delaying the replacement of seating. This paper elaborates on the concept of personalized compensation design, the relationship between seating parameters and human sitting postures, and the improvement and supplementation of existing products through personalized design. Through optimization model solving and solution evaluation, the effectiveness of personalized compensation design in enhancing the comfort and adaptability of public seating is validated.

Keywords: Personalized Compensation Design; Public Seating; Matching Value

1 Introduction

With the increasing student population in schools, lumbar spine diseases have become a significant health concern among students. Prolonged improper sitting postures contribute to this issue. Current uniform classroom seating designs do not account for individual differences, leading to uneven stress on students' waists and potentially causing or worsening lumbar spine disorders.

To address these issues, this study proposes a personalized compensation design method to optimize public seating, reduce waist pressure on students, and prevent lumbar spine disorders. This method, based on ergonomics principles, analyzes the compatibility between seating design and human sitting posture parameters to create personalized demand models for compensatory product design. Unlike traditional design approaches, personalized compensation design focuses on meeting users' specific needs, enhancing product comfort and applicability, and promoting environmental sustainability by extending the lifespan of seats and reducing resource waste.

This innovative study introduces personalized design concepts to public facilities, emphasizing a user-centered approach. Through theoretical analysis, empirical research, and product development, this research offers a new perspective and method for addressing students' lumbar spine health issues, with broad application potential and benefits for various student groups.

ADDT 2024, May 24-26, Luoyang, People's Republic of China

DOI 10.4108/eai.24-5-2024.2350082

2 Related Work

Personalized compensation design, as an emerging design concept and method, has its theoretical foundation rooted in multiple disciplines. This section will review and evaluate the current research status from three aspects: the evolution of compensation design concepts, research on ergonomic seating design, and the application of personalized design. The aim is to provide theoretical support and practical insights for this study.

2.1 Evolution of Compensation Design

The term "compensation" originated in the field of biology, referring to the adaptation of organisms through changes in morphology, structure, or function to cope with environmental pressures or to compensate for functional deficiencies[1]. As research progressed, the concept of compensation gradually found its way into fields such as psychology and engineering. Bäuml and Schnelzer [2] proposed a broad definition of compensation, which involves using external aids to address deficiencies in systems or individuals to achieve desired functions and goals. This definition laid the groundwork for research in compensation design in the engineering domain.

In the realm of industrial design, compensation design emphasizes a user-centered approach, aiming to address product or environmental deficiencies through auxiliary design to meet users' atypical needs [3]. In the field of product design, compensation design aims to address deficiencies in products, systems, or environments through artificial design methods, thereby positively enhancing these shortcomings. For example, Zubair et al. [4] demonstrated the practical application of compensation design by installing tremor compensation devices on seats to alleviate hand tremors in elderly individuals.

2.2 Research on Ergonomic Seating Design

Ergonomics is one of the key disciplines guiding seating design. Numerous studies have explored the relationship between seating parameters and factors such as body parameters, sitting posture, and physiological load.In recent years, researchers have started focusing on the impact of seating design on specific populations. Woo et al. [5] proposed an adaptive backrest design method for adolescents, which effectively reduces pressure on the lower back by optimizing the backrest shape. Li et al. [6] designed an intelligent seat for the elderly that automatically adjusts seat parameters based on the user's physiological characteristics, enhancing comfort and safety. These studies offer new insights into personalized seating design.

2.3 Application of Personalized Design

Personalized design aims to meet the individualized needs of users by providing tailored products and services. In the field of public facility design, the application of personalized design is still in its early stages. Sabri et al. [7] studied the impact of human body measurement parameters on determining the comfort and safety of car seats, and found that the geometric features of seats help reduce fatigue, and the matching of seat parameters with human parameters is beneficial for meeting individual posture preferences. This study contributes to the exploration of personalized public facility design.

The relationship between seating design and human sitting posture is a crucial consideration in seating design. According to the office chair industry standard QB/T2280, design parameters for seating include seat height, width, depth, seat tilt angle, lumbar support height, and backrest angle. Wang et al. [8] proposed a method for measuring airplane seat dimensions to provide data support for personalized seat design. Additionally, research by Chaléat-Valayer et al. [9] suggests that adjustable seat height can alter hip angles to maintain lumbar lordosis and reduce lower back pain.

3 Method

This study presents a personalized compensation design method aimed at optimizing public seating design, reducing lumbar stress on users, and preventing or alleviating diseases such as lower back pain. The method primarily consists of the following steps.

3.1 Establishing a Human-Seating Parameter Matching Model

Firstly, based on three typical sitting postures of users on the seat (reclined, upright, and forward-leaning)(See Fig. 1), analyze the matching relationship between human parameters (such as lumbar height, thigh length, etc.) and seating design parameters (such as seat height, backrest angle, etc.) to establish a parameter matching model. Secondly, by calculating the matching value P, assess the degree of alignment between seating design and human needs.

In the upright posture, the lumbar vertebra L5 bears the weight of the upper body, making the lumbar vertebra L5 and sacral vertebra S1 the most vulnerable parts for intervertebral disc protrusion. By adjusting the backrest and seat surface, the force at the lumbar joint L5-S1 can be transmitted or partially dissipated, providing protection to the lumbar vertebrae and preventing or alleviating lumbar spine diseases.

Calculation Formula for Matching Value P:

$$P = \left(\frac{a1}{s}\right) \times \left(\frac{a2}{h}\right) \times \left(\frac{y2 - y1}{d2 - d1}\right) \quad (1)$$

Where, a1 is thigh length, s is seat depth, a2 is calf length, h is seat height, y1 and y2 are respectively the bottom and top heights of the backrest, and d1 and d2 are respectively the heights of the sacrum and lumbar vertebrae, as shown in Figure 2.

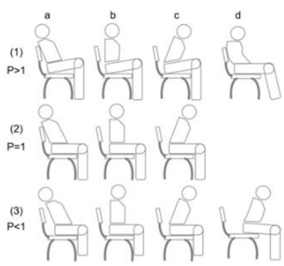

Fig. 1. Different Sitting Posture Forms and Body Compensation Measures Under Various Matching Values

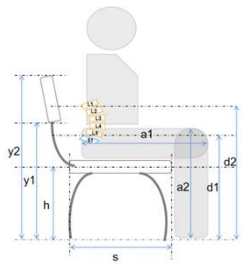

Fig. 2. Matching Value Parameter Diagram

Based on the magnitude of the matching value P, the matching situations can be categorized into three types:

(1)P = 1 indicates a perfect match between seating design and body parameters, allowing users to easily adjust between different sitting postures.

(2)P > 1 indicates that the seat size is relatively larger than the body, potentially leading to discomfort.

(3)P < 1 indicates that the seat size is relatively smaller than the body, which may also cause discomfort.

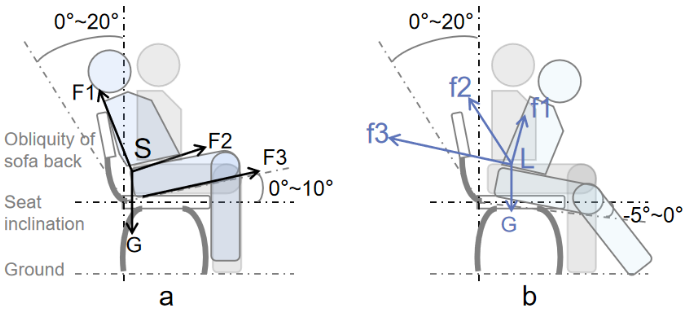

Fig. 3. Simple Diagram of Forces during Reclining and Forward-leaning Postures

3.2 Constructing a Seated Posture Mechanical Balance Model

Analyzing the Lumbar Force Situation of Users in Three Typical Sitting Postures and Constructing a Seated Posture Mechanical Balance Model. Taking the reclined sitting posture as an example, assuming the user's back is closely against the backrest, the center of force on the spine is S, subjected to the upper body gravity G, the support force F2 perpendicular to the backrest, the support force F1 perpendicular to the seat surface, and the frictional force F3 along the direction away from the backrest on the seat surface, as shown in Fig.3. According to Newton's first law, the mechanical equilibrium equation is:

$$G = cos\alpha \times F1 + sin\beta \times F2 + sin\alpha \times F3 \quad (2)$$

$$sin\alpha \times F1 = cos\beta \times F2 + cos\alpha \times F3 \quad (3)$$

Where α is the seat tilt angle, and β is the backrest tilt angle. Similarly, mechanical equilibrium equations can be established for the upright and forward-leaning sitting postures. By combining individual physiological parameters (such as weight, lumbar spine elastic modulus, etc.), the magnitude of lumbar force under different sitting postures can be calculated.

In Figure 3(a), as the backrest tilt angle and seat tilt angle increase, the support force F1 on the seat gradually decreases, while the backrest support force F2 and seat frictional force F3 increase. This indicates that in the reclined posture, the main support against gravity comes from the backrest support force F2. The contact point between the backrest and the person is on the back, and the support force that needs to be provided by the lumbar spine joint L5-S1 due to factors such as transmission loss must be greater than the value of F2 that ultimately acts to maintain mechanical balance. When the backrest tilt angle increases to 15°~20°, the force on lumbar joints L2-L5 increases to a steady state, while the force on lumbar joint L5-S1 is minimized and reaches a steady state. Therefore, most people choose a backrest tilt angle of 20°, but those with lumbar spine diseases often choose a backrest tilt angle of 10°.This is because individuals with lumbar spine diseases need to exert force with their lumbar spine when transitioning from a seated position, and the protrusion of the lumbar spine causes obstacles to exerting force. Therefore, in the reclined position, the lumbar joint L5-S1 needs support and protection to reduce pressure on this part of the spine, thereby alleviating stress and preventing injuries and diseases.

In the forward-leaning posture as shown in Figure 3(b), the center of force on the spine is at point L. At this point, the person is away from the backrest and experiences upward support force f2 along the lower leg, perpendicular support force f1 on the seat surface, and seat frictional force f3. When adjusting posture, the lower limbs change along with the thighs and seat surface, and the lower legs must provide forward support. Assuming the rotation angle of the lower leg is γ, according to Newton's first law, the body is in force balance, which can be represented by the demand model.

$$G = sin|\alpha| \times f3 + cos|\alpha| \times f1 + cos\gamma \times f2 \quad (4)$$

$$cos|\alpha| \times f3 + sin\gamma \times f2 = sin|\alpha| \times f1 \quad (5)$$

$$Cos\gamma = 1 - sin|\alpha| \quad (6)$$

Equation (6) is calculated based on the distance of leg movement and geometric relationships. When the seat tilt angle decreases, there is a tendency for the body to slide downward. The frictional force f3 increases, the leg support force f2 increases, and the perpendicular support force f1 on the seat surface gradually decreases. This posture mainly relies on leg strength to maintain body stability. The force on the lumbar joint L5-S1 is greater than that on the lumbar joint L2-L5. When the seat tilt angle is not equal to 0°, this posture transfers force to the legs, suitable for standing or semi-sitting labor positions, but not conducive to student learning. Therefore, the seat tilt angle of campus public seating is typically set at 0° to 10°. When the seat tilt angle is 0°, G=f1, and f2 and f3 disappear. At this point, the lumbar spine experiences the highest force because of the forward lean of the body, with the force transmitted to the lumbar joint L5-S1 being greater than f1. The process of analyzing the loading on the lumbar spine, as shown in Table 1, which represents the lumbar spine equilibrium demand model, allows for the calculation of the parameters, seat pan angle α and backrest angle β.

3.3 Optimize seat design parameters

Based on the calculation results of the matching value P, assess the degree of match between the seat design and user requirements. For cases where P≠1, optimize the seat design by adjusting key design parameters such as the seat tilt angle α and backrest tilt angle β to better suit individual needs and reduce lumbar force. The optimization objective is to minimize the lumbar force Fn while satisfying the constraints of the mechanical equilibrium equation. This can be measured using sensors or calculated using Hooke's law [10]. Hooke's law can be expressed as follows:

$$\frac{F_n}{S} = E\left(\frac{\Delta d}{d2 - d1}\right) \quad (7)$$

Where Fn is the lumbar force, E is the lumbar elastic modulus, which can be taken as 0.779 [11], S is the lumbar force area, d is the original length of the lumbar spine, and △d is the deformation of the lumbar spine. By solving the optimization model, obtain the optimal design parameters α' and β' for the seat, and compare them with the original design parameters α and β to formulate an optimized seat design solution.

Table 1. Lumbar balance demand model

The equilibrium relation of force		Seat inclination α	Obliquity of sofa back β	Leg rotation angle γ	Requirement Description: Normal lumbar spine	Requirement Description: Lumbar disc herniation
Hypsokinesis	G=cosα*F1+sinβ*F2+sinα*F3（1）	0~10°	0~20°	——	Force transmission, force dispersion and force support	β smaller than normal lumbar spine
	Sinα*F1=cosβ*F2+cosα*F3（2）	0~10°	0~20°	——		
Forward Lean	G=sin|α|*f3+cos|α|*f1+cosγ*f2（3）	-5~0°	——	0~[arccos(1-sin|α|)]°	Force transmission, force dispersion and force support	Prevention of spinal hyperprotrusion
	Cos|α|*f3+sinγ*f2=sin|α|*f1（4）	-5~0°	——	0~[arccos(1-sin|α|)]°		

3.4 Personalized compensation design process and solution

Based on the different matching values, select the appropriate demand model for personalized compensation design. This includes adjusting the backrest tilt angle and seat tilt angle of the seat to accommodate the body size and sitting posture needs of different users. Through experiments and calculations, we can determine the ideal seat parameters (α' and β') and compare them with the existing seat parameters to form a compensation design strategy. As shown in Fig. 4, the first step is to obtain the existing seat parameters and human parameters, calculate the matching value, determine the sitting posture, select the appropriate demand model for the sitting posture, and evaluate it. The values of F2 and f1 need to be measured by sensors or calculated using Hooke's law formula (7). When the lumbar stress is minimized, according to formulas (2) to (5), determine α' and β', compare them with the existing seat parameters α and β, and find a compensation solution.

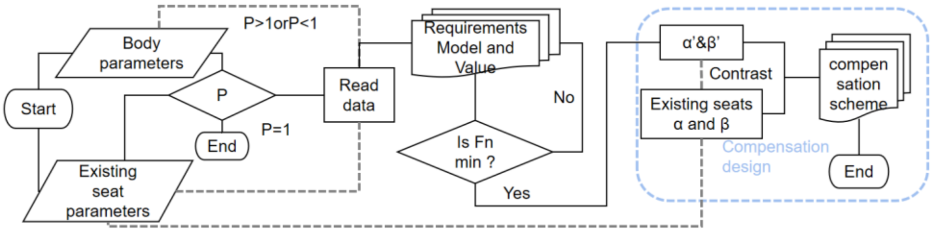

Fig. 4. Compensation design optimization process

Taking the case of the seating in the stair classrooms at the Innovation Harbor Campus of Xi'an Jiaotong University. As shown in Fig.5, ultimately, based on the design direction obtained after solving, we developed an adjustable inflatable seat cushion as a compensation design product. This cushion can supplement the backrest tilt angle and seat tilt angle by adjusting the air pressure to meet the lumbar and leg needs of different users. This design not only enhances the comfort and functionality of the seat but also reduces localized pressure on the lumbar spine and buttocks by increasing the force area, thereby improving blood circulation.

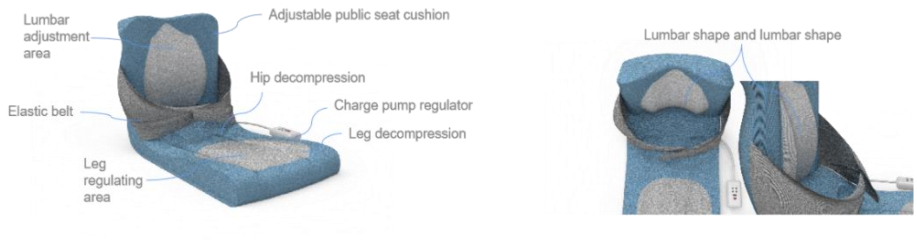

Fig. 5. Public seating compensation design product

3.5 Scheme Evaluation

To validate the effectiveness of the design solution, we conducted offline surveys and collected feedback from 30 college students. Through analysis of variance, we confirmed the feasibility and user satisfaction of the solution, thereby verifying the practicality and effectiveness of the personalized compensation design approach. The questionnaire underwent analysis of variance, resulting in $P=0.38>0.05$, indicating no significant differences in ratings, further demonstrating the consistent evaluation of the feasibility of the solution by the surveyed students. The results show that ratings for lumbar force and adjustability are above 80, indicating that the solution aligns with the initial design intent, while ratings for buttock and leg force as well as portability meet the students' expectations for the future use of the compensation design product.

4 Discussion

In this study, we addressed the lumbar issues in public seating, particularly in campus stair classrooms, by introducing personalized compensation design. Our analysis of human parameters in various sitting postures revealed that a perfectly matched seat design ($P=1$) significantly reduced lumbar pressure, especially when reclined. However, a forward-leaning posture was less favorable for extended use. Traditional seat designs were found inadequate for diverse user needs, leading us to propose an adjustable design that personalizes backrest and seat angles to fit individual body sizes and postures.

Despite the higher initial investment, personalized compensation design offers substantial long-term advantages. It extends seat longevity, reduces replacement frequency, and enhances comfort, thereby preventing health issues related to poor posture. Additionally, by promoting better sitting posture, this design can cut down on medical costs associated with lumbar problems and boost work and study efficiency. Ultimately, it enhances life quality and economic benefits.

5 Conclusion

This study successfully introduced and validated a personalized compensation design method for public seating, effectively bridging the gap between public seating design and individual user needs. Through practical testing and user feedback, our developed adjustable inflatable seat cushion demonstrated good adaptability and comfort, particularly receiving high praise for lumbar and leg support, as well as adjustability. Furthermore, personalized compensation design not only enhances the comfort and functionality of seats but also contributes to extending the lifespan of existing products and reducing resource wastage. In comparison to traditional modular design, personalized compensation design focuses more on meeting individual atypical needs rather than simply pursuing functional iterations.

In conclusion, we advocate for students and designers to pay attention to the importance of sitting posture and seat design. Through rational design and use, we can prevent lumbar issues and enhance learning and work efficiency. We hope this research can provide new ideas and methods for future product design.

References

[1] Pigliucci, M.“Phenotypic plasticity: beyond nature and nurture,” Johns Hopkins University Press, (2001)

[2] Bäuml, B., Schnelzer, M. “Compensation in human-robot collaboration - Adaptation to individual user characteristics,” In 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). pp. 4737-4744. IEEE (2018)

[3] Tang, T. “Wideband IQ Imbalance Compensation Design and Implementation Based on Blind Equalization Technology,” Electronics Technology Application, 49(2), 72-75 (2023)

[4] Zubair, M., Suthar, B., & Jung, S. “Design and Analysis of Flexure Mechanisms for Human Hand Tremor Compensation,” IEEE Access, 10, 36006-36017 (2022).

[5] Woo, E. H., White, P., Lai, C. W. “Ergonomics standards and guidelines for computer workstation design and the impact on users' health–a review,” Ergonomics. 59(3), (2016)

[6] Li, W., Xu, G., Xing, J., Lyu, T., Huang, Z. “An intelligent chair for elderly based on ergonomics,” In Journal of Physics: Conference Series. 1486(7), 072001. IOP Publishing (2020)

[7] Sabri, N., Khamis, N. K., Tahir, M. F. M., et al. “Impact of Anthropometric Parameters on Pressure Variables for Determining Comfort and Safety of Automotive Seat: A Systematic Review,” Iranian Journal of Public Health, 51(2), (2022)

[8] Wang, J., Zhi, J.-Y., Zhang, X.-W., et al. “A method of aircraft seat dimension design for long-term use by passengers with different body types,” Safety and Health at Work, (2023)

[9] Chaléat-Valayer, E., Samuel, C., Verdun, S., et al. “Impact of an ergonomic seat on the stand-to-sit strategy in healthy subjects: Spinal and lower limbs kinematics,” Applied Ergonomics. 80, 67–74 (2019)

[10] Thompson, J.O. “Hooke's Law. Science,”64(1656), 298–299 (1926)

[11] Wang, J., Li, Y. C., Wang, F., et al. “Relationship between Trabecular Bone Mineral Density and Elastic Modulus of Human Body,” Medical Biomechanics, no. 05, vol. 29, pp. 465-470 (2014).