Ergonomic Design of Chairs for Sedentary Populations: An IPA–DEMATEL Approach to Design Validation

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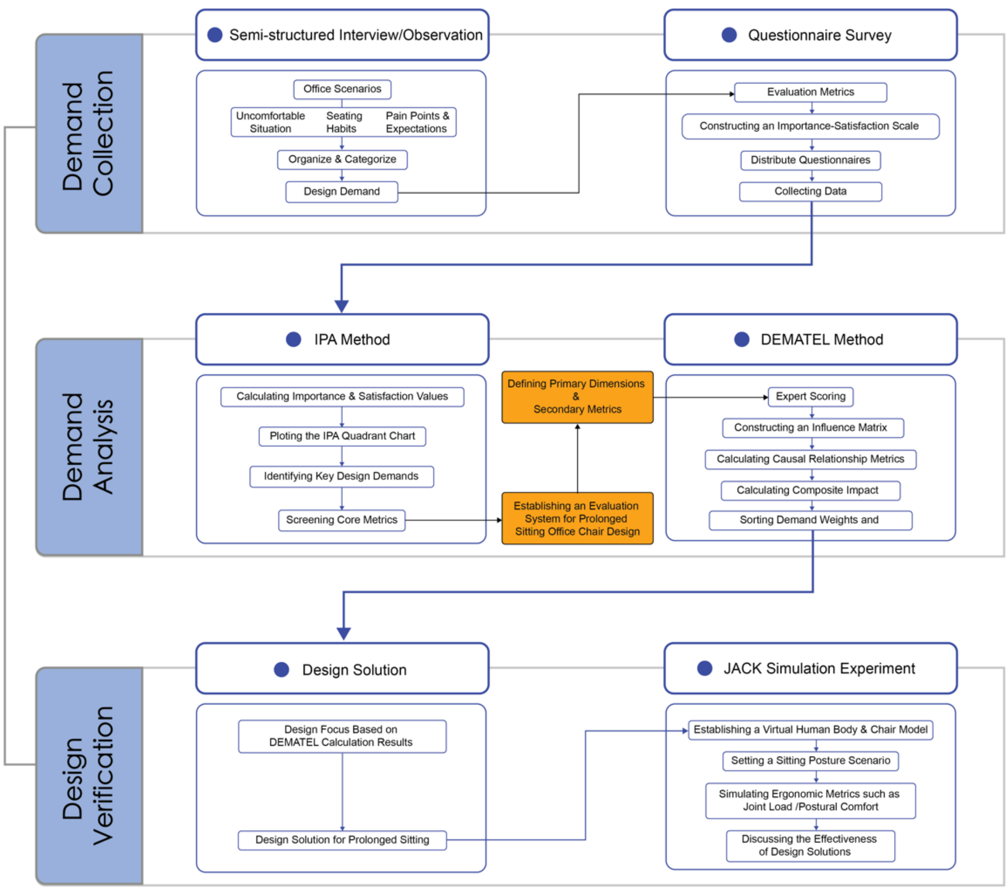
GRAPHICAL ABSTRACT



Ergonomic Design of Chairs for Sedentary Populations: An IPA–DEMATEL Approach to Design Validation

Yongtao Zheng ,[a] and Ziyi Dai , [b,]*

As modern work intensifies and working hours become stretched, the development of office chairs that support extended sitting periods and alleviate musculoskeletal fatigue presents a significant challenge. In response, this study aimed to optimize ergonomic support to meet the demands of a sedentary office environment. Initially, a combination of semi-structured interviews and field studies were conducted to collect data on symptoms of discomfort, posture patterns, pain points, and anticipated functionalities during extended sitting. The qualitative information was converted into metrics for evaluation. Following this, quantitative scores were obtained using an IPA scale, and the DEMATEL technique was utilized to examine causal relationships and the magnitude of influence between indicators, facilitating the computation of comprehensive impact weights. Based on these evaluations, a design scheme was formulated and validated *via* virtual simulation in JACK software. Results indicate the importance of prioritizing ergonomic adaptability, material properties, safety, ease of adjustment, and structural stability in the design of sedentary office chairs. Significantly, the key elements for enhancing comfort during prolonged sitting were identified as the active adaptation of lumbar support and the maintenance of posture stability.

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Keywords: Sedentary behavior; Office chairs; Importance-Performance Analysis (IPA); Decision-Making Trial and Evaluation Laboratory (DEMATEL)

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INTRODUCTION

In the information age, the transformation of office work patterns has made sedentary behavior a global norm for office workers, accounting for 81.8% of total working time (Arippa *et al*. 2023). Prolonged sitting can lead to adverse health outcomes, including cardiovascular issues such as elevated blood pressure, as well as musculoskeletal disorders like lumbar disc herniation, and cervical strain (Palluppetta *et al*. 2025). Office chairs are essential elements in workplace environments and serve dual functions: providing biomechanical support to enhance postural comfort and mitigating health risks associated with sedentary behavior (Fundoiano-Hershcovitz *et al*. 2022). However, existing chair designs predominantly adopt reactive strategies to address sedentary challenges. These typically involve either by reducing sitting duration through persuasive interventions or by optimizing seated postures biomechanically optimizing postures by conforming users to fixed chair configurations. For example, Damen *et al*. (2020) developed the Ivy interactive office chair, which uses data physicalization to visualize sitting duration *via* an interactive interface, thereby encouraging behavioral changes. Similarly, Kim *et al*. (2023) conducted biomechanical comparisons of six lower-limb sitting postures to identify the advantages and limitations of each configuration. This method was used to inform ergonomic chair design and posture optimization strategies. However, these approaches fail to sufficiently address the growing demand for sustained focus in high-intensity work environments. As prolonged concentration has become the norm in contemporary workplaces, proactive chair designs that are tailored to extended office hours are necessary to effectively balance the need for productivity and occupational health (Davidson *et al*. 2025). Therefore, this study proposes an active interaction framework for office chair design that balances prolonged work requirements with the mitigation of musculo-skeletal risks. This approach not only reduces sedentary health risks but also creates new market opportunities through functionally innovative seating solutions.

Building on these advancements, recent studies have explored proactive interaction strategies in office chair design, aiming to reconcile the demands of a sedentary lifestyle with health preservation. For example, dynamic office chairs with adjustable backrests enable significant lateral flexion of the lumbar region while maintaining the stability of the upper body, thereby reducing discomfort caused by prolonged sitting (Kuster *et al*. 2018). Other approaches include height-adjustable chairs that dynamically modify sitting posture to prevent maladaptive positions, sustain muscular functions, and alleviate musculoskeletal discomfort (Naumova *et al*. 2022). Furthermore, Cardenas *et al*. (2024) introduced a design featuring a vertically segmented seat pan that allows foot-tapping movements while sitting, which enhances gastrocnemius muscle oxygen saturation and delivers positive physiological effects. While these studies provide valuable insights into balancing sedentary requirements with health risks, systematic methodologies for translating office workers' needs into specific design elements remain underdeveloped, and there is a lack of rigorous scientific evaluation mechanisms for design validation. To address this research gap, this study proposes a proactive interaction framework for office chair design that is tailored to the sedentary population (SP). Specifically, this study aims to: (1) Systematically translate SP requirements and pain points from sedentary office scenarios into quantifiable design indicators through field investigations; (2) apply Importance-Performance Analysis (IPA) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to prioritize SP needs and establish causal relationships among design factors; and (3) develop a chair prototype that harmonizes the demands of extended sitting with the reduction of musculo-skeletal risk, validate its ergonomics through JACK simulations, and propose a design pathway for sedentary office environments.

The use of proactive interaction chairs has demonstrated significant advantages in balancing prolonged office demands with musculo-skeletal risk mitigation. To address this, the present research establishes a design framework that integrates these proactive strategies. First, semi-structured interviews and field observations are conducted to collect SP-related discomfort symptoms, posture habits, usage pain points, and functional expectations during prolonged sitting. These qualitative data are then systematically categorized into design requirements. Subsequently, a dual-dimensional IPA scale is developed to quantitatively assess user requirements. By integrating the IPA and DEMATEL methods, this study establishes a weighted evaluation indicator system to prioritize design factors through computational ranking. Finally, the top-ranked, high-impact requirements are selected as design focal points to develop structural and functional chair prototypes. Ergonomic validation is performed through JACK simulations, enabling iterative adjustments to optimize the design. This methodology ultimately yields a chair design framework that simultaneously satisfies extended sitting demands and reduces sedentary health risks.

Following the introduction, this article is structured into four core sections in order to systematically present the research framework and findings: (1) Literature Review, which examines the typology of health risks associated with sedentary behavior and their interrelationships, while summarizing the evolutionary trajectory of chair design research targeting sedentary behavior; (2) Research Methodology that clarifies the procedural framework for constructing the evaluation indicator system and computational models, emphasizing the integration of IPA and DEMATEL methods to prioritize design requirements; (3) Empirical Analysis and Design Practice, which details the implementation of simulation experiments using JACK software, outlines the design validation processes, and discusses iterative optimization outcomes for the chair prototype; and (4) Discussion and Conclusion that synthesizes key findings, explores theoretical and practical implications, and identifies methodological limitations alongside future research directions to advance the field of proactive office chair design.

LITERATURE REVIEW

Impacts of Sedentary Posture and Office Chair Design Research

In contemporary work environments, sedentary behavior has become increasingly prevalent. Prolonged static sitting postures correlate strongly with the rising incidence of diverse health issues. Existing medical and ergonomic research indicates that maintaining constrained static postures imposes multidimensional adverse effects on the human body. Biomechanically, prolonged sitting alters the natural physiological curvature of the spine. Fazel *et al*. (2021) noted that the seated human body typically assumes a flexed posture, increasing lumbar flexion. Similarly, Ekechukwu *et al*. (2021) found that sustained flexion increases spinal loading, and that cumulative tissue damage results from that static mechanical stress of sitting. According to Amiri and Zemkova (2023), static lumbar loading during sedentary behavior induces fatigue in deep trunk muscles, impairs spinal mobility, and triggers pain. To address the health risks associated with sedentary behavior, office chair design has emerged as a critical intervention strategy.

Regarding mechanical dynamic interventions, Frey *et al*. (2021) investigated the effects of dynamic chair designs on biomechanical characteristics, subjective pain perception, and seat displacement amplitude, confirming that dynamic seat pan configurations effectively mitigate multiple adverse effects of sedentary behavior. Furthermore, Noguchi *et al*. (2023) designed a novel proactive office chair based on a kinematic analysis of lumbosacral motion, discomfort perception, and task efficiency. This design employs dual auditory and tactile cues to guide users in transitioning between sitting and standing postures with minimal desk adjustments. In the realm of digital interactive interventions, Rakauskas *et al*. (2025) integrated pressure sensors, vibration motors, LED strips, and communication modules to monitor sitting duration and posture in real time, delivering multimodal (tactile, visual, auditory) reminders. Additionally, Martínez-Estrada *et al*. (2023) embedded movable textile sensors into office chairs to enable real-time posture monitoring and the identification of harmful postures that lead to musculoskeletal injuries or bodily discomfort.

In this context, proactive office chairs demonstrate significant potential to balance extended work demands with health risk mitigation. However, existing studies often exhibit a "technology-over-experience" bias. Most designs lack systematic exploration of the the SP's genuine subjective needs, resulting in suboptimal trade-offs among comfort, health preservation, and work efficiency. Therefore, this study systematically collects SP's requirements during prolonged sitting, including physical discomfort, posture habits, usage pain points, and functional expectations, and constructs an importance and satisfaction scale to obtain quantitative scoring data. These insights are subsequently integrated into chair design to advance research on office seating that balances prolonged sitting demands with health risk reduction.

Wooden Materials and Design Decision-Making

As a natural and sustainable material, wood plays a significant role in product design by evoking warmth, tranquility, and natural comfort (Tunahan *et al*. 2025). It is widely applied across diverse domains such as jewelry design (Fan and Wang 2026), Chinese-style furniture design (Wang *et al*. 2025), public seating design (Chang *et al*. 2025), and packaging design (Zhang and Jiang 2026). Design decision-making, a pivotal phase in the design process, focuses on requirement elicitation, metric quantification, and solution optimization throughout the design lifecycle. For instance, Qu *et al*. (2025) analyzed air purifier requirements using an integrated model of FKANO and DEMATEL to clarify core user demands. Ren *et al*. (2025) transformed fuzzy user requirements into explicit design criteria by converting needs into subjective and objective weights *via* AHP and coefficient of variation methods. Zhang and Jiang (2026) calculated the composite weights of evaluation indicators through expert evaluations using a combined FAHP-CRITIC approach. Chang *et al*. (2025) applied the DEMATEL method to clarify causal relationships among design criteria and employed TOPSIS method for solution evaluation and optimization. Furthermore, Zhang *et al*. (2025) systematically extracted core user requirements and classified demand attributes using the FKANO model and DEMATEL method, identifying factors driven by priority.

However, wood remains rarely incorporated into office chair design. This omission overlooks material properties as a critical experiential medium and perpetuates the bias of prioritizing technology over experience in seating research. Simultaneously, systematic methodologies for clarifying SP's requirements and establishing design criteria in office chair development remain underexplored. Therefore, this study initiates design process based on user needs and experiential perspectives. It employs standardized methods to capture and quantify user requirements and expert judgments, thereby establishing a scientific foundation for design decision-making and advancing research on the design of office chairs for prolonged sitting.

METHODOLOGY

Proposed Framework

This study focuses on optimizing office chair design for sedentary office environments, aiming to identify the genuine subjective needs of the SP and to develop seating solutions that effectively balance comfort, health preservation, and work efficiency. By integrating semistructured interviews, the IPA, DEMATEL, and JACK simulation, this research systematically translates SP requirements into quantifiable design elements and validated solutions. The overall technical workflow, illustrated in Fig. 1, comprises six sequential phases:

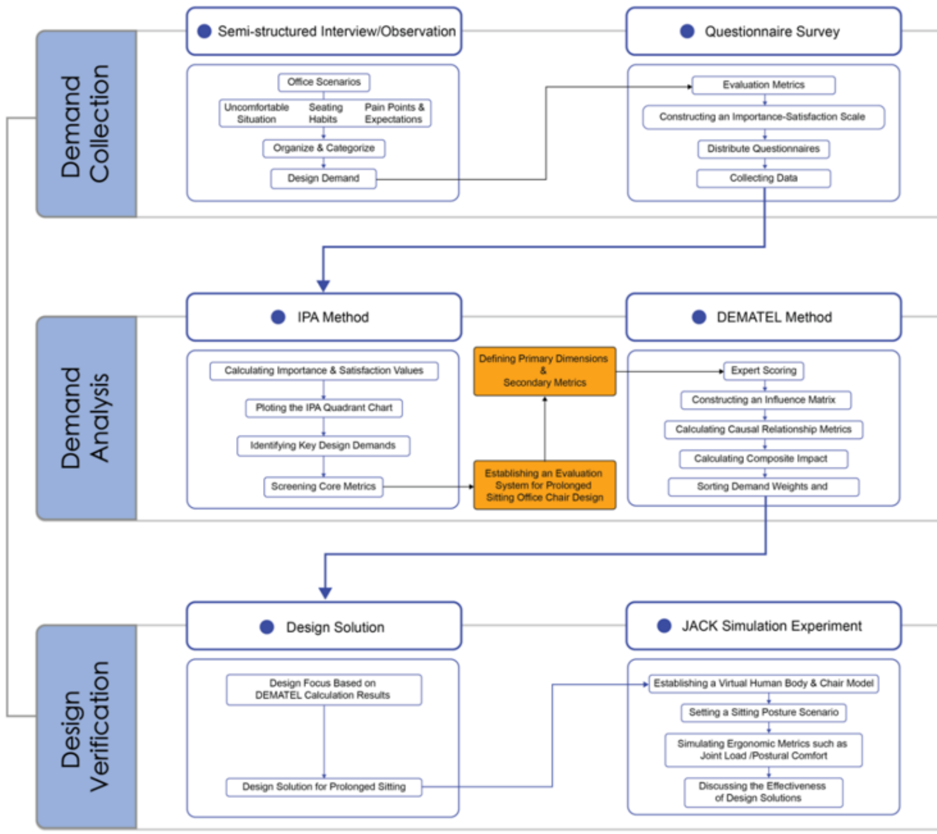

Fig. 1. Research Framework

Step 1: Semistructured interviews and field observations were conducted to collect physical discomfort reported by the SP, posture habits, usage issues, and functional expectations during current chair use. Preliminary design requirements were systematically categorized and refined.

Step 2: Preliminary requirements were transformed into evaluation indicators. A two dimensional importance and satisfaction scale was designed, and a questionnaire survey was administered to target users to obtain quantitative scoring data for each indicator.

Step 3: Average importance and satisfaction scores were calculated for each requirement. An IPA four quadrant plot was generated to identify critical design priorities, such as items with high importance and low satisfaction. Core indicators were selected to establish a chair evaluation system tailored to the prolonged sitting scenarios of the SP, defining primary dimensions and secondary indicators.

Step 4: Experts rated the interrelationships among indicators to construct a direct influence matrix. The DEMATEL method was applied to analyze causal relationships and influence magnitudes, compute comprehensive influence values, and determine final weights and rankings of design requirements.

Step 5: The highest ranked and highly impactful requirements served as the core design focus for developing structural and functional chair prototypes. The design underwent iterative optimization guided by the evaluation indicator system.

Step 6: Virtual human and chair models were constructed in JACK software. Typical office tasks and posture scenarios were simulated to analyze ergonomic metrics including joint loading and postural comfort, thereby validating and refining the chair design.

IPA Method

Martilla and James (1977) first proposed the IPA method to evaluate the importance and performance of attributes. Through a visual analytical framework, IPA clearly maps the relative positioning of each attribute's importance and satisfaction levels, enabling decision-makers to identify priority improvement areas and strategic development directions. It is widely recognized as an effective approach for pinpointing critical influencing factors. With evolving applications, IPA has expanded beyond service management improvement (Tseng 2020) into product design research. For instance, Yao *et al*. (2022) collected subjective user evaluations of target products, employing satisfaction and importance as core evaluation metrics. Accordingly, this study applies IPA to analyze SP's evaluations of office chairs, aiming to precisely identify authentic user needs. The implementation procedures are as follows:

(1) Construct an importance–satisfaction analysis table: Based on semi-structured interviews and field observations, SP-reported physical discomfort, posture habits, usage pain points, and functional expectations during current chair use are systematically collected, categorized, and refined into preliminary design requirement items.

(2) Define evaluation indicators and develop a 7-point Likert-scale questionnaire: The scale ranges from 1 to 7, with scores corresponding to: very unimportant/very dissatisfied (1), unimportant/dissatisfied (2), somewhat unimportant/somewhat dissatisfied (3), neutral (4), somewhat important/somewhat satisfied (5), important/satisfied (6), and very important/very satisfied (7). Importance scores (I_{ij}) and satisfaction scores (P_{ij}) are collected, and mean importance and satisfaction values for each indicator are computed.

$$\bar{I} = \frac{\sum_{i=1}^{n} I_{ij}}{n} \tag{1}$$

$$\bar{P} = \frac{\sum_{i=1}^{n} P_{ij}}{n} \tag{2}$$

(3) IPA Quadrant Partitioning: The overall mean importance across all indicators serves as the vertical threshold line, and the overall mean satisfaction serves as the horizontal threshold line, expressed as:

$$\bar{I}_{\text{total}} = \frac{\sum_{j=1}^{m} \bar{I}_j}{m} \tag{3}$$

$$\bar{P}_{\text{total}} = \frac{\sum_{j=1}^{m} \bar{P}_j}{m} \tag{4}$$

In these expressions, I_j denotes the mean importance score of the jth indicator, P_j denotes the mean satisfaction score of the j^{th} indicator, and m represents the total number of evaluation indicators.

(4) Plotting the IPA Quadrant Diagram: Within this study's IPA framework, "I" represents the importance metric and "P" represents the satisfaction metric. Using $\bar{I}_{\text{total}}$ and $\bar{P}_{\text{total}}$ as central dividing lines, a two-dimensional IPA quadrant diagram is plotted. Each indicator is positioned at coordinates (P_j, I_j) to delineate quadrants (see Fig. 2). The vertical axis reflects the importance level of product attributes; the horizontal axis reflects the

satisfaction level. Both dimensions are dichotomized into high/low levels, forming four quadrants:

Fig. 2. IPA Quadrant

DEMATEL Method

Building upon the IPA-derived importance–satisfaction indicators and the established hierarchical structure (first-level dimensions and second-level indicators), this study further incorporates the DEMATEL method to analyze causal relationships and influence magnitudes among design criteria, compute comprehensive influence values, and determine weighted rankings of design requirements. DEMATEL is a matrix-based structural modeling technique designed to elucidate interrelationships among evaluation criteria (Tzeng *et al*. 2007). By calculating the prominence (total influence) and relation (net influence) of each indicator, the method systematically quantifies logical associations and direct influence pathways, thereby enabling scientifically grounded weight allocation for the indicator set. Given the multidimensional nature of SP office requirements—encompassing chair comfort, health preservation, and work efficiency—this study applies DEMATEL to the evaluation of prolonged sitting office chairs, establishing a systematic framework for evidence-based design decision-making. The DEMATEL proceeds as follows:

(1) Pairwise influence assessment: Experts evaluate the degree of influence each requirement exerts on every other requirement using a standardized scale (*e.g.*, 0 = no influence, 1 = low influence, 2 = medium influence, 3 = high influence, 4 = very high influence). The direct influence matrix A is subsequently constructed based on aggregated expert judgments:

$$A = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & 0 & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix} = \left(A_{\text{ij}}\right)_{n\times n} \tag{5}$$

(2) Matrix normalization: The direct influence matrix A is normalized to generate matrix X through element-wise division by the maximum row sum of A, ensuring all influence values fall within [0,1]:

$$X = A\Big/\max_{1\le i\le n}\sum_{j=1}^{n} A_{ij} = \left(x_{ij}\right)_{n\times n} \tag{6}$$

(3) Total influence matrix calculation: The total influence matrix T is derived by use of Eq. 7, capturing both direct and indirect effects:

$$T = X(I - X)^{-1} \tag{7}$$

(4) Causal metric derivation: Based on the matrix T, the influence degree D_i and passivity degree C_i are calculated as follows:

Influence degree:

$$D_i = \sum_{j=1}^{n} T_{ij} (1 \leq i \leq n, 1 \leq j \leq n) \tag{8}$$

Passivity degree:

$$C_i = \sum_{j=1}^{n} T_{ji} (1 \leq i \leq n, 1 \leq j \leq n) \tag{9}$$

By analyzing D_i+C_i (centrality) and D_i-C_i (net influence), an Influence Network Relationship Map (INRM) was constructed (see Fig. 3), and demand factors were categorized. This method provides a structured analytical approach for uncovering potential causal chains, enhancing the systematic, scientific, and practical adaptability of office chairs that balance comfort, health, and work efficiency.

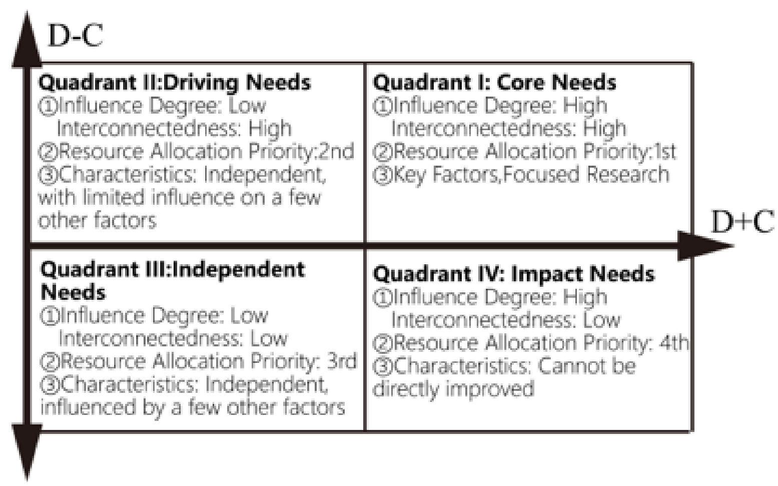

Fig. 3. INRM-Based classification of demand categories (Zhang *et al.* 2025)

RESULTS

Design Requirements Gathering

This study focused on the perceptions of office workers regarding core attributes, perceived importance, and performance expectations for office chairs through interviews and observations. A total of 24 office workers were interviewed, comprising 13 males and 11 females (aged 25 to 42 years.). Participants spent 3 to 4 hours in the morning and 3 to 5 h in the afternoon daily at their desks and had over one year of experience using office chairs. Occupations included administrative staff, designers, and academic researchers. Semistructured interviews required participants to describe physical discomfort, posture habits, usage problems, and functional expectations during chair use, supplemented by observational notes on user needs. Detailed interview questions are provided in Appendix A.

After organizing and refining the interview content, this study identified 20 design requirements for office chairs (Table 1). These requirements encompass SP's demands for comfort, health benefits, and work efficiency during prolonged sitting, while also reflecting their concerns regarding material safety and environmental sustainability.

Table 1. User Demands for Prolonged Sitting

No.	Design Demand	No.	Design Demand
C1	Effective Lumbar Support	C11	Lumbar Relaxation Ease
C2	Stability and Mobile Balance	C12	Cushion Pressure Distribution
C3	Maintain Lumbar Support	C13	Seated Stability
C4	Support-Breathability Balance	C14	Workspace Compatibility
C5	Desk-Compatible Height Range	C15	Breathable Seat Surface Material
C6	Structural Deformation Resistance	C16	Surface Wear Resistance
C7	Backrest Tilt Adaptive Adjustment	C17	Office Environment Adaptability
C8	Eco-friendly Contact Materials	C18	Adjustment Component Label Clarity
C9	Adjustability of Armrests	C19	Neck Support Adaptability
C10	Mechanism Operation Smoothness	C20	Sedentary Alert

User Needs Identification

In this study, a seven-point scale was employed to quantify both the importance and satisfaction levels of SP regarding office chair requirements, enabling the identification of critical design needs requiring priority optimization such as scenarios characterized by high importance and low satisfaction. Based on this methodology, the research pinpointed unmet needs deemed important by SP. A total of 120 valid questionnaires were collected, consisting of 76 male respondents (aged 25 to 42 years) and 44 female respondents (aged 25 to 39 years). Occupations included 50 administrative staff, 30 designers, and 40 researchers. All Interviewees spent 6 to 9 hours daily at their desks and had over one year of experience using office chairs. Purposeful sampling was employed to ensure sample diversity and relevance. The survey employed a blended online and offline approach with detailed instructions to ensure data consistency. The analysis results of the IPA model analysis results are detailed in Fig. 4, while the mean importance and satisfaction scores for each attribute are presented in Table 2. The first quadrant represents high importance and high satisfaction, indicating core strengths that the product must maintain, includes C2, C6, C7, C13, and C19. The second quadrant corresponds to high importance but low satisfaction, highlighting areas requiring urgent improvement, specifically C1, C3, C4, C5, C8, C9, C11, C12, and C15. The third quadrant represents low importance and low satisfaction, indicating requirements of low priority requirements, including C14, C18, and C20. The fourth quadrant corresponds to low importance and high satisfaction, suggesting potential overinvestment, which includes C10, C16, and C17.

To further identify key requirements with high influence as design priorities, a seating design solution balancing comfort, health, and work efficiency was developed. This study employs affinity diagramming to systematically organize and synthesize the priority levels of Quadrants 1 and 2 derived from analysis of the IPA model. This establishes a rational indicator system, providing a theoretical foundation for subsequent weight calculations. Through organized group discussion workshops, multiple rounds of consolidation and deliberation, four primary dimensions were ultimately identified. These were further refined into 13 secondary indicators (Fig. 5).

Table 2. Prioritization of Demands for Prolonged Sitting

Demand	*I* (Average Importance)	*P* (Average Satisfaction)	Priority
C1	5.825	4.150	Prioritize Improvement
C2	5.917	5.300	Maintain the Advantage
C3	5.700	4.083	Prioritize Improvement
C4	5.650	4.233	Prioritize Improvement
C5	5.583	4.317	Prioritize Improvement
C6	5.433	5.050	Maintain the Advantage
C7	5.400	5.117	Maintain the Advantage
C8	5.350	4.433	Prioritize Improvement
C9	5.317	4.500	Prioritize Improvement
C10	5.067	5.233	Overcommitment
C11	5.633	4.600	Prioritize Improvement
C12	5.550	4.583	Prioritize Improvement
C13	5.483	4.933	Maintain the Advantage
C14	5.017	4.355	Low Priority
C15	5.383	4.625	Prioritize Improvement
C16	4.983	5.150	Overcommitment
C17	4.867	5.083	Overcommitment
C18	4.750	4.283	Low Priority
C19	5.533	5.250	Maintain the Advantage
C20	4.633	4.117	Low Priority

Fig. 4. IPA Quadrant

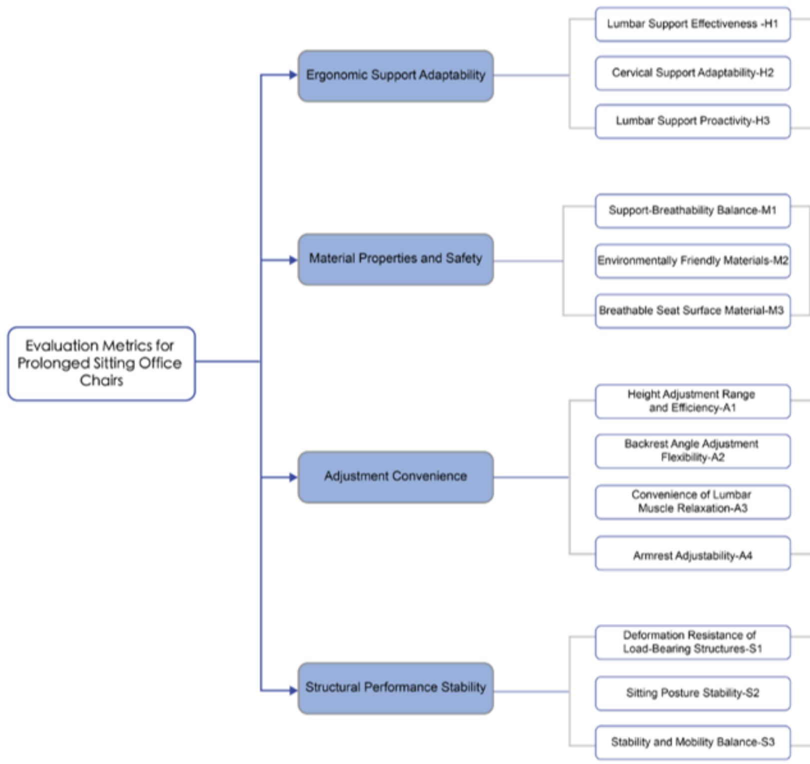

Fig. 5. Evaluation index system diagram for office chairs designed for prolonged sitting

Analysis of Key Design Factors and Impacts for Prolonged Sitting

The aim of this study was to design office chairs that strike a balance among comfort, health, and work efficiency. After identifying four primary dimensions and thirteen secondary indicators, the DEMATEL method was used to visualize the relationships among these indicators using an influence diagram. This approach calculated the weights and causal relationships for each indicator within the primary dimensions.

Based on a questionnaire completed by 10 experts in office chair design regarding the direct influence levels among factors, this study calculated the standardised direct influence matrix (Table 3).

Table 3. Direct Impact Matrix of Office Chair Standards for Prolonged Sitting

	H1	H2	H3	M1	M2	M3	A1	A2	A3	A4	S1	S2	S3
H1	0.092	0.174	0.114	0.078	0.078	0.080	0.131	0.135	0.102	0.081	0.099	0.202	0.206
H2	0.108	0.079	0.103	0.072	0.072	0.074	0.120	0.099	0.093	0.074	0.091	0.186	0.190
H3	0.205	0.206	0.114	0.094	0.094	0.097	0.156	0.164	0.180	0.126	0.122	0.270	0.274
M1	0.262	0.236	0.247	0.079	0.108	0.110	0.206	0.216	0.204	0.142	0.140	0.308	0.285
M2	0.240	0.241	0.234	0.116	0.088	0.198	0.184	0.192	0.182	0.146	0.227	0.313	0.318
M3	0.138	0.136	0.211	0.138	0.138	0.061	0.115	0.121	0.116	0.091	0.106	0.169	0.168
A1	0.178	0.178	0.144	0.092	0.092	0.095	0.096	0.187	0.176	0.096	0.173	0.263	0.267
A2	0.211	0.187	0.174	0.082	0.082	0.084	0.140	0.089	0.110	0.087	0.103	0.192	0.167
A3	0.207	0.208	0.222	0.093	0.093	0.095	0.129	0.187	0.097	0.099	0.144	0.242	0.245
A4	0.177	0.148	0.141	0.091	0.091	0.093	0.177	0.188	0.177	0.066	0.146	0.262	0.239
S1	0.200	0.202	0.190	0.091	0.091	0.093	0.151	0.158	0.149	0.096	0.087	0.236	0.240
S2	0.097	0.097	0.093	0.065	0.065	0.067	0.084	0.088	0.083	0.068	0.081	0.088	0.172
S3	0.098	0.097	0.093	0.064	0.064	0.066	0.083	0.088	0.083	0.067	0.106	0.117	0.089

Based on the data from the direct influence matrix derived from the specifications, the values of centrality (D_i+C_i) and causality (D_i−C_i) for each indicator were calculated (Table 4). The centrality value reflects the importance level of the corresponding indicator, while the causality value indicates the direct influence of that indicator on others. However, if this value is negative and has a large absolute value, it indicates that the indicator is significantly influenced by other indicators. The weight ranking of each indicator is as follows: H3 > S2 > S3 > A3 > A1 > H1 > M1 > A2 > S1 > H2 > A4 > M3. By integrating centrality, causality, and weight, an influence relationship diagram for each indicator is plotted (Fig. 6), further visualizing the complex causal associations. Specific analysis results are summarized as shown in Table 4.

Table 4. Degree of Causal Influence for Prolonged Sitting Indicators

Indicator	Influence *D*	Affectedness *C*	Centrality *D+C*	Causality *D-C*	Weight
H1	1.571	2.212	3.784	-0.641	0.0788
H2	1.359	2.187	3.546	-0.828	0.0739
H3	2.100	2.078	4.179	0.022	0.0870
M1	2.543	1.155	3.699	1.388	0.0770
M2	2.678	1.155	3.833	1.523	0.0798
M3	1.707	1.213	2.921	0.494	0.0608
A1	2.035	1.770	3.806	0.265	0.0793
A2	1.709	1.912	3.621	-0.202	0.0754
A3	2.060	1.751	3.811	0.309	0.0794
A4	1.996	1.240	3.235	0.756	0.0674
S1	1.983	1.625	3.607	0.358	0.0751
S2	1.150	2.848	3.997	-1.698	0.0833
S3	1.114	2.859	3.973	-1.745	0.0827

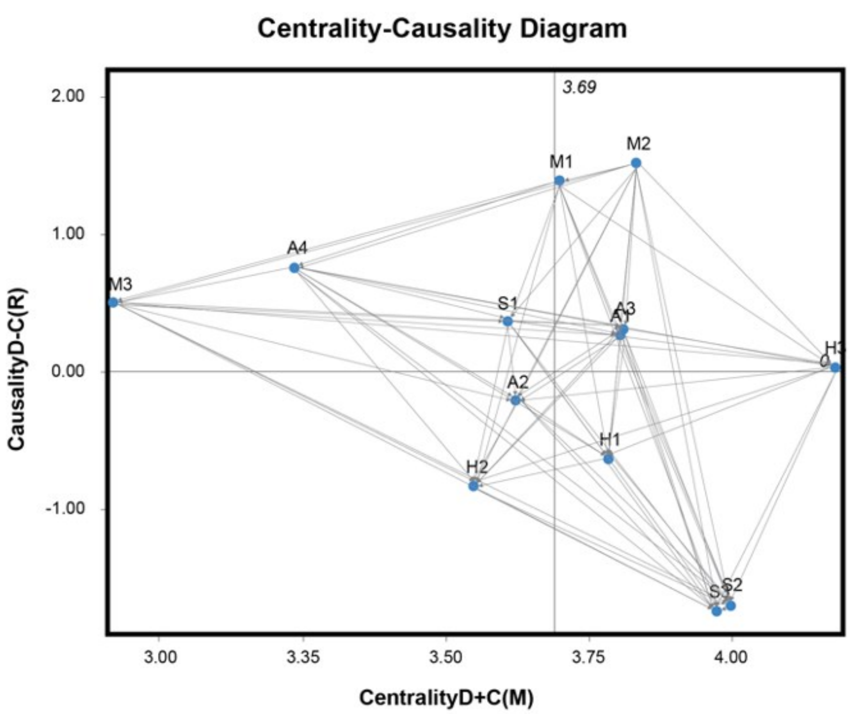

Fig. 6. Influence network relation map (INRM) of design indicators for prolonged sitting

Design Optimization of Office Chairs for Prolonged Sitting

The core objective of this study is to uncover the authentic subjective needs of SP and design an active office chair that integrates comfort, health benefits, and work efficiency. Based on the weighted user needs derived through the IPA and DEMATEL methods, this study proposes the following design solution (Fig. 7).

In this design, a dual-section partitioned the backrest structure is featured: the upper section supports the shoulders, while the lower section supports the lumbar region. The lumbar support incorporates an inflatable cushion (Fig. 8). After detecting 20 min of upright sitting *via* embedded pressure sensors, the system automatically activates an inflatable massage function to relieve the back muscles of the user. Furthermore, additional embedded pressure sensors assess the fit between the lumbar support section and the waist of the user. Through the extension and retraction of rear mechanical push rods (Fig. 9), the lumbar support achieves active adaptation, maintaining effective support even as the sitting posture of the user changes. The backrest support rod employs a curved laminated wood panel crafted through bending processes. Leveraging micro-deformation and rebound properties of wood, it enables efficient and flexible fine adjustments of the backrest. For the seat cushion design, to achieve sitting stability, the seat surface is curved to position the hips slightly higher than the thighs while allowing the user to conform to the lumbar support curve. A hollow wooden support frame combined with mesh fabric provides uniform hip support, breathability, and stability. In the armrest design, a layered structure enables the forward and backward movement of the armrests, better adapting to hand support. The base of the office chair employs a stainless steel five-point design for overall stability, complemented by casters for smooth mobility.

Fig. 7. Design of office chairs for sedentary work

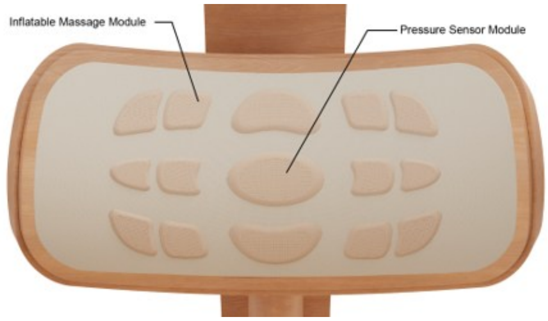

Fig. 8. Active massage cushion design

Fig. 9. Design of actively adjustable lumbar support

JACK Simulation Experiments

A crucial aspect of ergonomic simulation testing involves simulating the compression forces exerted on the lumbar spine during office chair usage. To verify the ergonomic performance of the optimized office chair design, this study carries out simulation experiments adopting the JACK human ergonomics simulation software. The P50 male digital human model with a height of 168.70 cm and a weight of 68.00 kg was selected as the test subject to simulate and analyze the sitting posture of typical office users. Utilizing the lower back analysis tool within the JACK software package (Fig. 10), this study analyzed the pressure applied to the lower lumbar vertebrae, specifically L4 and L5. As illustrated in Fig. 10, the compression force on the L4/L5 vertebrae measures 359 N. This value falls significantly below the 3,400 N action limit established by the National Institute for Occupational Safety and Health (NIOSH). Consequently, the proposed design effectively distributes pressure across the lumbar spine, ensuring user safety, and comfort during office tasks while fulfilling ergonomic requirements.

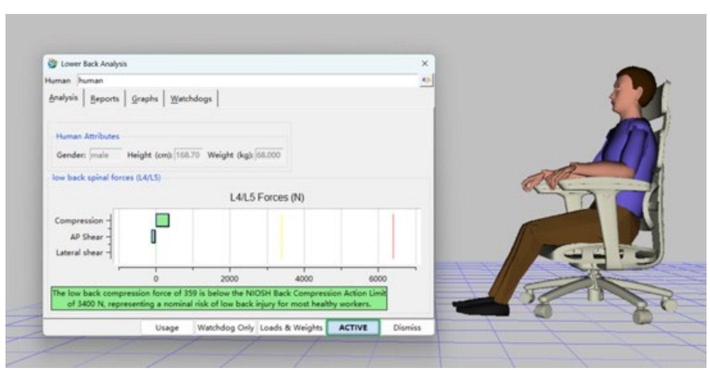

Fig. 10. Dynamic analysis of lumbar spine loading

The coziness assessment for the SP utilizes the Comfort Evaluation tool to analyze the seated posture of the target demographic, generating scores that range from 0 to 80. A lower score indicates greater comfort. As shown in Figure 11, the comfort scores for the various body regions were as follows: The buttocks achieved a score of 33.4, reflecting the optimal contouring of the seat surface and effective pressure distribution. The overall composite comfort score registered at 38.1, and the fatigue score was 35.3. These results indicate that the adopted sitting posture effectively mitigates the risk of muscle following prolonged sitting. Scores for the shoulders at 20.9 , the neck at 10.7, and the back at 10.6 also fall comfortably within the acceptable range. This confirms that the design of the backrest and armrests effectively maintains the natural angles of the upper body joints and reduces muscular loads. These data offer specific evaluations for different anatomical regions. All scores remain below the threshold of 60 point stipulated by general literature and fully comply with ergonomic standards.

In summary, the optimized parameters for the office chair demonstrates outstanding ergonomic performance: comfort scores for all body regions fall within reasonable ranges, and the risk of lumbar injury is significantly reduced. These results fully validate the effectiveness of this ergonomic design, offering individuals engaged in sedentary work a seating solution with robust support beside resistance to fatigue.

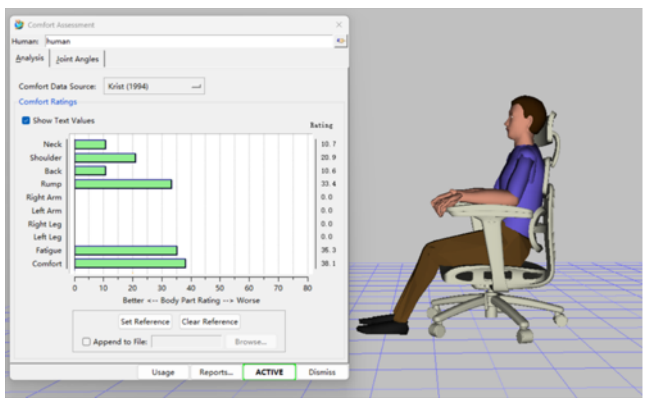

Fig. 11. Human comfort evaluation

Design Feedback and Evaluation

In order to comprehensively evaluate user acceptance of this optimized office chair design, this study invited 30 sedentary workers to conduct a comprehensive assessment. Participants included 5 female administrative staffs (aged 25 to 36 years), 15 male designers (aged 25 to 42 years), 5 female researchers(aged 30 to 42 years), and 5 male researchers(aged 30 to 40 years). All participants spent 6 to 9 hours daily at their desks The evaluation covered five core areas including support, comfort, material properties, safety, convenience, and stability. The evaluation utilized a 5 point rating scale, where a score of 1 represents extreme dissatisfaction and a score of 5 represents extreme satisfaction. Researchers statistically analysed the collected feedback data, calculated the average score for each metric and presented the results in a radar chart (Fig. 12). The results showed that the mean scores for each dimension were as follows: material properties and safety (M = 4.57), supportiveness (M = 4.23), comfort (M = 4.33), stability (M = 4.00), and convenience (M = 4.03). The overall average score across all dimensions was 4.23.

The results of the evaluation indicate that respondents were highly satisfied with the optimized design across all parameters, with all dimension scores exceeding 4 points.

This reflects the effectiveness of the ergonomic improvements, the strategic application of wooden materials, and the manufacturing processes. Furthermore, the scores for all supplementary evaluated aspects also consistently exceeded the threshold of 3.9 points. These outcomes validate the practical feasibility of the design and provide robust data to support the optimization of similar products and future market promotion.

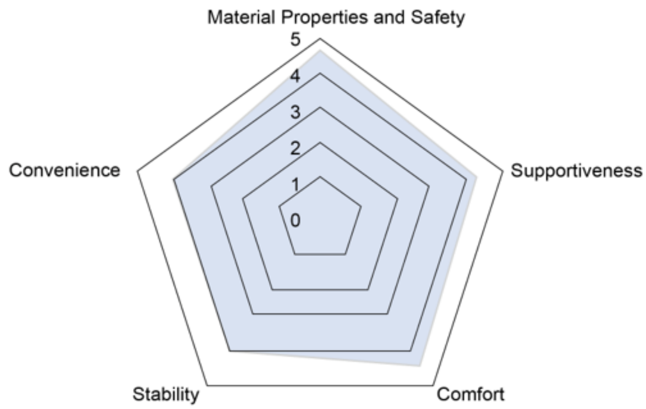

Fig. 12. User acceptance radar chart

Despite these contributions, this study presents certain limitations. Regarding the research sample, the subjects were primarily selected from urban areas in southern China and were limited to administrative staff, designers, and researchers. This results in insufficient occupational diversity and a limited sample size. Methodologically, the study relied exclusively on subjective weighting methods and did not incorporate objective weighting methods for comprehensive analysis. This approach lacks balanced integration of subjective and objective methodologies, resulting in an overreliance on the subjective judgments of experts.

Subsequent research will expand the sample size to include diverse occupational groups with prolonged work demands, thereby enhancing the generalisability of the findings. A combined objective and subjective weighting method will be used to analyse the data, providing further clarity on the core metrics essential for designing ergonomic office seating. Based on the results of this analysis, multiple design solutions will be optimised and compared with existing seating options. The effectiveness of these designs will subsequently be validated through empirical experimentation.

CONCLUSIONS

1. This study utilized a combination of the importance-performance analysis (IPA) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) methods to identify four primary criteria that require prioritization when designing active office chairs that balance comfort, health, and work efficiency.

2. The main criteria comprise ergonomic support adaptability; material properties and safety; ease of adjustment; and structural stability. Among these, active lumbar support emerged as critically important, as it ensures effective support for the lower back, even when the user changes postures.

3. Active lumbar support can furthermore be integrated with an active massage cushion to minimize workplace disruption while facilitating the convenient relaxation of lumbar muscles. Seating stability and overall balance represent additional critical design demands for prolonged sitting, as they prevent disruptions caused by chair movement and enhance productivity.

4. Furthermore, JACK simulation experiments validate that the proposed design solution provides an optimally conforming seat surface and an ideal pressure distribution. The design of the backrest and armrests effectively maintains the natural angles of the upper body joints, significantly reducing the risk of muscle fatigue associated with prolonged sitting.

Use of Generative AI

To ensure transparency, the authors state that ChatGPT (OpenAl) was used only for English translation and language polishing, while all research design, data analysis, and conclusions are the independent work of the authors.

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APPENDIX

Semi-Structured Interview Guide

Opening statement

Hello! Thank you very much for taking the time to participate in this interview on office chair design requirements. This interview aims to explore the core needs and optimization directions of office chairs in practical use, and the findings will be used for academic publication. All information will be used solely for research analysis and treated with strict confidentiality. Your personal information and responses will be anonymized and will not be disclosed to any third party.

The interview is expected to last 30 to 40 minutes and will focus on ergonomic design, functional adjustability, material selection, and scenario adaptation of office chairs.

Before we begin, please confirm:

You understand the purpose and process of this interview and are participating voluntarily.

You may decline to answer any question or terminate the interview at any time without any consequences.

Section 1: Background Information

Please briefly describe your experience with office chairs.

What performance dimensions of office chairs do you typically focus on during your work?

Section 2: Basic Ergonomic and Structural Perceptions

What characteristics should office chair lumbar support possess? How do the effectiveness and persistence of lumbar support affect your experience in different sitting postures?

How do you evaluate an office chair's static weight stability, mobility balance, and sitting posture stability? How important are these features in practical use?

How do you perceive the relationship between an office chair's support and overall breathability? How do you balance these needs in use?

Section 3: Functional Adjustability and Material Requirements

What desk height ranges should the seat height adjustment accommodate? How does this function impact your experience?

How do you assess an office chair's resistance to structural deformation under long-term load? What scenarios or performance indicators influence your judgment of its reliability?

What usage scenarios should the backrest tilt adjustment accommodate? What are your expectations for its flexibility and angle range?

Do you consider the environmental friendliness, non-toxicity, and safety of office chair contact materials as important factors? Please explain.

Which armrest adjustment functions (*e.g.*, height, angle) are most practical and frequently used? How do they affect your experience?

How important do you consider the operational smoothness of office chair mechanisms (*e.g.*, casters, height adjustment, etc.)? How do these impact your user experience?

How do you evaluate the convenience of lumbar muscle relaxation in office chairs? How does this feature affect your experience?

How do seat cushion pressure distribution and firmness influence comfort during prolonged work? What are your preferences?

How clear should the functional labels on adjustment components be? How does this affect your operational experience?

Section 4: Scenario Adaptation and User Experience Optimization

How do you evaluate an office chair's adaptability to standard workstation spaces? How does space occupancy impact your experience?

How do the skin-friendliness and breathability of seat contact materials affect your experience? Do your priorities for these features change with seasons (summer/winter)?

What service life should office chair surface wear resistance and low maintenance satisfy? How does this influence your selection or evaluation?

How important is the stylistic integration of office chairs with the overall office environment in your selection or design process? Please explain.

What height range should neck support cover to accommodate most users? How does this affect your experience?

How practical are sedentary alerts and sitting posture reminders on office chairs? Which type of reminder do you prefer?

Section 5: Additional Comments

Beyond the topics covered, do you have any other observations, requirements, or suggestions regarding office chair design?