

Footrest Design in Achieving an Ergonomic Sitting Posture

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ABSTRACT

Ergonomic problems, particularly postural disorders resulting from prolonged sitting, are prevalent among workers involved in administrative tasks, computer operations, and public communication activities. Extended sitting durations can cause physical fatigue, impaired blood circulation, and discomfort in the lower back and legs, which may eventually lead to decreased work efficiency and musculoskeletal complaints. This study aims to develop an ergonomic footrest equipped with adjustable features based on users' anthropometric dimensions to improve comfort and prevent postural strain. Data were collected from 60 office workers, including measurements of sitting height, lower leg length, foot width, and other dimensions related to foot positioning while seated, using standard anthropometric instruments such as an anthropometer, measuring tape, and caliper. Data adequacy and uniformity tests were performed to ensure reliability and consistency, and percentile analysis was applied as a basis for design parameters. The final design resulted in a footrest height of 51.85 cm derived from sitting popliteal height, accommodating 95% of users for optimal posture; a width of 30 cm based on sitting popliteal width; and a length of 50.99 cm based on foot length, ensuring full foot support. The proposed ergonomic footrest design is expected to minimize the risk of postural disorders, enhance user comfort, and support overall workplace health and productivity.

INTRODUCTION

The current development of industry is characterized by the increasing use of complex equipment and machinery to support production activities. In industrial work environments, the proper use of equipment is essential to enhance productivity and efficiency (Lagu et al., 2024). Every tool and machine is designed to facilitate human tasks that may be difficult to perform manually. However, such equipment must be compatible and aligned with human capabilities as the primary users. A mismatch between equipment and human physical conditions can lead to various problems, ranging from discomfort and reduced productivity to serious health risks such as musculoskeletal injuries and postural disorders (Mutmainah & Puteri, 2019).

According to global data released by the International Labour Organization (ILO), occupational accidents (OA) and occupational diseases (OD) worldwide reach 430 million cases annually, comprising 270 million OA cases (62.8%) and 160 million OD cases (37.2%). These

cases result in approximately 2.78 million worker deaths each year. Around 40% of the total OA and OD cases are experienced by young workers. The economic impact is estimated to cost up to 3.94%–4% of a country's Gross Domestic Product (GDP). In the United States, medical costs associated with OA and OD are estimated at USD 67 billion, while indirect costs approach USD 183 billion. Therefore, industrial equipment must be properly designed to provide comfort and safety for workers. The main purpose of such adjustments is to reduce the physical burden experienced by workers during tool use and to improve overall performance. Without proper adaptation, workers may experience prolonged physical and mental fatigue, which ultimately affects their productivity and well-being (Firmansyah & Mashabai, 2020). For this reason, the development of equipment and workplace design that prioritizes human comfort has become one of the main priorities in modern industry. This is where ergonomics plays a crucial role, as it aims to optimize the interaction between humans, tools, and the work environment, resulting in safer and more efficient work conditions (Ulhaq et al., 2024).

Ergonomics is a discipline that studies how tools, tasks, and work environments can be adapted to human characteristics in order to enhance effectiveness, efficiency, and worker well-being (Ahmad & Maesa, 2021). In ergonomic applications, factors such as equipment design, working posture, and rest breaks are considered to prevent physical strain and fatigue (Putri & Susilowati). Through ergonomic approaches, workers are expected to work more comfortably, reduce injury risks, and achieve optimal productivity. One of the key branches of ergonomics is anthropometry, which focuses on the measurement of human body dimensions as a reference for equipment design. Anthropometry is fundamental in ergonomics, as it ensures that tools, machines, and workplaces are designed according to human size and physical capacity (Saputro & Suryati, 2023).

Anthropometry is the study of human body dimensions, including length, width, and circumference of specific body parts relevant to equipment and workspace design (Noviardi et al., 2023). Anthropometric data are used to identify variations in human body sizes so that equipment can be adjusted to accommodate a wide range of users. For example, desk height, chair size, and tool handles should be adapted to the range of worker body sizes to ensure accessibility and avoid muscle strain. In ergonomics, anthropometric measurement is crucial because every tool used in work must accommodate differences in body dimensions. Without accurate anthropometric data, equipment design may be suboptimal and increase workers' physical workload (Marianti & Arista, 2021).

In the workplace, non-ergonomic body positions are one of the main causes of occupational diseases. One body posture that is often overlooked but has significant health impacts is foot positioning. Improper foot positions during work—such as hanging without support, bending for long periods, or lacking stable contact—can cause health problems ranging from muscle fatigue to impaired blood circulation. This condition is common among workers who sit for prolonged periods, such as office employees, machine operators, or those using fixed workstations. The accumulation of poor foot posture can lead to health problems such as varicose veins, edema, and muscle pain. The issue is worsened when the work environment does not provide adequate foot support facilities, such as footrests. Without proper foot support, body weight distribution becomes unbalanced, particularly affecting the lower back and legs. Consequently, workers are at higher risk of postural disorders and increased muscle tension in the legs and pelvis. Moreover, unsupported or dangling feet may restrict blood circulation, causing stiffness and excessive fatigue. In the long term, this not only affects work comfort but also decreases overall worker productivity (Bahri & Mulyadi, 2021).

In addition to posture-related problems, cold working environments can also affect foot comfort (Pramono et al., 2022). In certain conditions, especially in air-conditioned workplaces or low-temperature environments, workers' feet often become cold and stiff, which negatively impacts concentration and comfort. This may result in local foot hypothermia, ultimately reducing work efficiency. In such cases, ergonomic footrests with heating features provide an effective solution to improve comfort and protect workers' health (Abbasi et al., 2024).

Based on these problems, it is important to design a footrest that not only provides ergonomic foot support but also includes heating features. A heated footrest can help reduce muscle tension in the legs, maintain blood circulation, and improve comfort, particularly in low-temperature workplaces. This design supports workers' physical health while also enhancing their overall work experience. Thus, a heated ergonomic footrest has great potential as an innovative solution to prevent foot-related occupational health issues while adding value to workplace ergonomics. The collected data will serve as a reference to understand the diverse needs of workers and as the basis for designing equipment and workplaces that prioritize safety and comfort. This study also aims to provide practical insights for students regarding the importance of anthropometric data in ergonomic design, enabling them to implement ergonomics principles in industry to create more human-centered and productive workplaces (Ananda et al., 2021).

RESEARCH METHODS

The ergonomic footrest design was developed to address postural issues and discomfort resulting from prolonged sitting among office workers. This study utilized anthropometric data collected from 60 office employees using standard instruments such as an anthropometer, measuring tape, and caliper. The collected data were tested for adequacy and uniformity before percentile analysis was conducted. The 95th percentile was selected as the design basis to ensure that the footrest accommodates up to 95% of users, including those with larger body dimensions.

The calculations yielded the main dimensional parameters of the footrest as follows:

- Footrest height: 51.85 cm, derived from the *Seated Popliteal Height (SPH)*.
- Footrest width: 30 cm, based on the *Seated Popliteal Breadth (SPB)*.
- Footrest length: 50.99 cm, derived from the *Foot Length (FL)*.

The final product was modeled using CAD software as an ergonomic footrest equipped with an adjustable height system through hydraulic mechanisms and an integrated heating feature. The heating function is intended to enhance thermal comfort and improve blood circulation, particularly in cold work environments. The selected construction material is Aluminum 6061, chosen for its lightweight properties, high strength, and good thermal conductivity. This design is expected to minimize postural disorders, enhance comfort, and support workers' health and productivity. The research flowchart is presented in Figure 1.

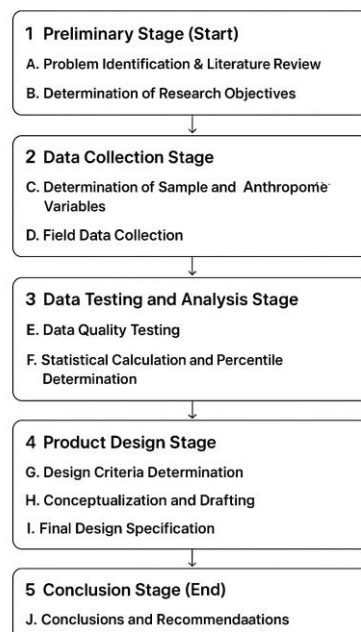


Figure 1. Research Flowchart

The initial stage of the design process involved developing the product concept, which aimed to identify user needs and formulate solutions to postural discomfort caused by prolonged sitting. The product developed was an ergonomic footrest equipped with a foot-warming feature, designed to improve comfort and reduce the risk of poor blood circulation and lower back pain. The conceptualization process considered ergonomic principles, functionality, and user health, ensuring that the product would not only be technically effective but also support workers' well-being during extended sitting activities.

The next stage involved collecting and analyzing anthropometric data from 60 respondents to obtain relevant body dimensions such as sitting height, lower leg length, and foot width. Measurements were conducted using standard anthropometric instruments, including an anthropometer, measuring tape, and caliper, to ensure accuracy and reliability. The collected data were then tested for adequacy and uniformity to confirm their validity and representativeness. Once the data were deemed acceptable, the 95th percentile was calculated as the design reference to determine the optimal dimensions of the footrest. This approach ensures that the resulting design accommodates the majority of users and provides maximum comfort during use.

The final stage encompassed the product design and fabrication process based on the anthropometric analysis results. The design was developed using computer-aided design (CAD) software, taking into account the dimensions, optimal inclination angle, and integration of the heating feature. The manufacturing process utilized high-quality materials such as wood, plastic, or lightweight metal and included quality control procedures to guarantee safety and functionality. The final product, an ergonomic footrest that is precise, functional, and comfortable, is expected to promote proper posture, enhance user comfort, and improve health and productivity in the workplace.

RESULTS AND DISCUSSION

The research findings reveal a series of results that underpin the design of an ergonomic footrest based on anthropometric data. Beginning with the formulation of the product concept and continuing through the statistical analysis of body measurements, the entire process produced relevant information for designing footrest dimensions that align with the physical characteristics of the majority of users. These findings serve as an essential foundation for developing a design that is not only functional but also promotes comfort and postural health during prolonged sitting. From this process, key body dimensions were identified as references for the footrest design, including sitting popliteal height, leg length, and standing hip width. The processed data were subsequently applied to determine the final product dimensions using the 95th percentile, thereby accommodating the needs of most users.

Anthropometric Data

The product concept is designed to meet the needs of workers engaged in prolonged sitting activities. The objective of the product is to create an ergonomic footrest that can support the feet, improve blood circulation, and reduce muscle tension in the lower body. With this solution, it is expected that workers in various workplaces can perform their tasks more comfortably and avoid long-term health problems resulting from non-ergonomic sitting postures.

This stage begins with data collection from 60 respondents drawn from academic and office environments. The selection of respondents is intended to represent the population of workers or individuals who spend extended periods of time sitting. Measurements were taken on 36 body dimensions, covering the upper body (such as arm length, shoulder breadth, and shoulder height), the lower body (such as leg length, knee height, and foot length), as well as sitting dimensions (such as popliteal height and hip breadth).



Figure 2. Data Collection

Data collection was carried out using an anthropometric chair, a specialized device designed to facilitate precise measurement of body dimensions in a seated posture. This instrument enables accurate measurements that serve as references for determining the main design dimensions of the footrest, including footrest height (based on sitting popliteal height), footrest length (based on leg length), and footrest width (based on hip breadth in a standing position).

Table 1. Footrest Percentile Data

Dimension	Product Component	95 th Percentile
Seated Popliteal Height	Footrest Height	51.85 cm
Seated Popliteal Breadth	Footrest Length	50.99 cm
Foot Length	Footrest Width	30 cm

Table 1 illustrates the footrest dimensions designed based on the 95th percentile of three relevant body measurements: Seated Popliteal Height (SPH), Seated Popliteal Breadth (SPB), and Foot Length (FL). The 95th percentile was applied to ensure that the footrest accommodates 95% of users, meaning the dimensions are sufficiently large to provide comfort for the majority of individuals, particularly those at the upper end of the body size distribution. A footrest height of 51.85 cm, derived from SPH, ensures that 95% of users can sit with their legs comfortably positioned without excessive flexion. The footrest width of 30 cm, based on SPB, provides sufficient space for users to rest their feet freely and comfortably. Meanwhile, the footrest length of 50.99 cm, derived from FL, is designed to adequately support the feet, thereby offering the necessary stability to maintain proper posture. Overall, these dimensions prioritize comfort and usability for the majority of users, reducing the risk of discomfort and potential musculoskeletal issues associated with poor sitting posture.

Product Design



Figure 3. Product Design

The product was developed based on fundamental ergonomic principles, namely the adaptation of tools, systems, or work environments to the characteristics, needs, and limitations of humans as users. Ergonomics itself is divided into several branches, one of which is physical ergonomics, which encompasses studies on working posture, body biomechanics, and the design of assistive devices to reduce muscle strain and musculoskeletal disorders. In this context, the footrest is designed as an ergonomic solution to assist workers engaged in prolonged sitting activities, preventing postural discomfort, circulatory issues, and static pressure on the legs.

According to the theory of human-centered or user-centered design, this approach requires that every product intended for human use be grounded in a comprehensive understanding of human body dimensions, work habits, and potential risks. This study aims not only to design a footrest as a passive product but also to develop it as an ergonomic device genuinely tailored to users, by incorporating relevant body dimensions such as Seated Popliteal Height (SPH), Foot Length (FL), and Standing Hip Breadth (SHB).

Data collection was conducted systematically, following standard anthropometric measurement protocols as described by Pheasant (1998) in *Bodyspace*, to minimize human error and ensure data validity. The collected data were then tested using two fundamental anthropometric statistical procedures: adequacy testing and uniformity testing. The adequacy test was conducted to ensure that the sample size sufficiently represented the target population, while the uniformity test verified that the data exhibited a consistent distribution pattern without deviation, thus fulfilling the principle of data homogeneity (Asarela & Sari, 2023).

Validated data were processed using normal distribution to calculate percentile values, with the 95th percentile applied in this study. The choice of the 95th percentile is strongly justified theoretically, as in the principle of inclusive design, a higher percentile value ensures broader user comfort for smaller individuals (Pattiasina et al., 2021). Accordingly, the footrest dimensions were determined not only to reflect average body sizes but also to accommodate the majority of workers, including those with larger body sizes. The resulting dimensions informed the footrest's height, width, and length, with an adjustable height system enabling adaptation to users' varying popliteal heights (Muti et al., 2022).

The design concept also incorporates an additional heating feature to enhance thermal comfort and mitigate circulatory problems caused by prolonged sitting, consistent with environmental ergonomics principles of thermal comfort (Fitra et al., 2020). Compared with previous studies such as Wang et al. (2022), who analyzed the effects of footrest use on working posture through biomechanical experiments, this study adopts a more comprehensive approach. Wang's research focused on quantitative laboratory methods to measure plantar pressure and

ankle angles during static footrest use, but did not extend to product design based on anthropometric data. In contrast, the present study not only identifies the general benefits of footrests but actively integrates anthropometric data into the design and development process. Similarly, although Abbasi et al. (2024) applied anthropometric statistics in workstation design, their study focused on standing workstations, whereas this study develops a tangible product—an adjustable footrest—directly designed from anthropometric values. Ananda et al. (2021), meanwhile, concentrated on the technical simulation of load strength and distribution on motorcycle footrests using SolidWorks software. While relevant to product design, their approach was highly technical and did not address human comfort as the core design parameter. This study distinguishes itself by grounding its methodology in ergonomics, accounting for human variability and long-term working comfort.

The primary strength of this research lies in its integrated application of ergonomic theory and anthropometric data within a unified research framework. It represents the entire process of ergonomic product development, beginning with user needs identification, anthropometric data collection, statistical processing using percentiles, and culminating in actual design that considers comfort, safety, and user diversity. The research outcomes extend beyond functional product design, offering adaptability to postural variations and user variability, while serving as a model for applied ergonomics in future assistive device development, particularly for sedentary workers. Its contribution lies not only in the resulting product but also in the methodology and ergonomic framework concretely implemented in a data-driven, human-centered design (Lami et al., 2023).

The footrest designed in this study provides high levels of comfort and functionality with various adjustable features. A key feature is the ability to raise and lower the footrest through a hydraulic system. When the user presses the hydraulic pedal, the fluid within the system activates a smaller hydraulic component beneath the cushion, elevating the padded surface. This allows users to adjust the footrest height smoothly and conveniently, thereby supporting a more ergonomic leg posture.

In addition to the height adjustment and cushioned surface, the footrest incorporates an integrated heating system. When connected to a power source, electrical energy flows through a Printed Circuit Board (PCB), which regulates the current and converts it into thermal energy. The heat is transferred to a metal heating plate embedded within the footrest cushion, which is coated with a thermally conductive material to distribute warmth evenly across the surface. The gentle and consistent heat provides a relaxing effect, enhancing comfort during prolonged sitting, especially in cold environments. Light heating has been shown to reduce muscle tension, improve blood circulation, and alleviate fatigue (Faradillah et al., 2021).

This combination of adjustable height, cushioning, and integrated heating not only enhances user comfort but also exemplifies the integration of ergonomic, anthropometric, and environmental principles in a practical product design (Lami et al., 2023).

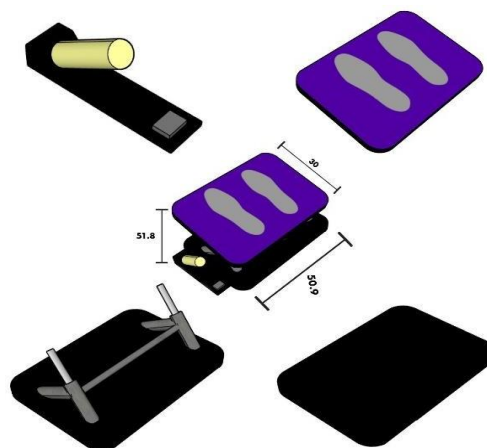


Figure 4. Product Component Design

In terms of dimensions, the footrest has an ideal size to support user comfort. With a length of 50.99 cm, a width of 30 cm, and a height of 51.85 cm, it is designed to accommodate the average foot size of users. These dimensions are also practical for use with various types of chairs or workstations, both at home and in office environments. With carefully considered proportions, the design not only prioritizes foot comfort but also contributes significantly to improving overall posture. An optimal foot position helps maintain the spine in a neutral alignment and reduces pressure on the lower back, thereby minimizing the risk of back pain and fatigue associated with non-ergonomic sitting postures.



Figure 5. Overall Product Design Layout

Product Materials

Aluminum 6061 is a widely used aluminum alloy in various structural and engineering applications due to its favorable combination of light weight, strength, and good thermal conductivity. Based on data from material editors, the thermal, mechanical, and strength properties of this material can be analyzed in detail. Its thermal conductivity is recorded at 2.234×10^{-3} btu/(in·s·°F) or 0.002234 btu/(in·s·°F), indicating that Aluminum 6061 conducts heat reasonably well compared to most insulating materials, although it is not as conductive as copper or other highly conductive metals. The specific heat capacity of 0.214 btu/(lb·°F) demonstrates that 0.214 British Thermal Units (BTU) are required to raise the temperature of one pound of Aluminum 6061 by 1°F. Furthermore, the thermal expansion coefficient of 1.311×10^{-5} in/°F (or 0.00001311/°F) signifies that the material expands by 0.00001311 times its original length for every 1°F increase in temperature. This indicates that Aluminum 6061 exhibits stability under thermal variations, although its thermal expansion must still be considered in engineering designs operating under fluctuating temperatures (Ananda et al., 2021).

Table 2. Material Information (Ananda et al., 2021)

Category	Parameter	Value / Description
Information	Name	Aluminum 6061
	Description	Aluminum magnesium silicon alloy
	Keywords	6061, alloy, structural, metal
	Type	Metal
	Subclass	Aluminum
	Source	Autodesk
Basic Thermal	Thermal Conductivity	2.234×10^{-3} BTU/(in·sec·°F)
	Specific Heat	0.214 BTU/(lb·°F)
	Thermal Expansion Coefficient	1.311×10^{-5} in/in·°F
Mechanical	Behavior	Isotropic
	Young's Modulus	9.993×10^6 psi
	Poisson's Ratio	0.33

	Shear Modulus	3.751×10^6 psi
	Density	0.098 lb/in ³
Strength	Yield Strength	3.989×10^4 psi
	Tensile Strength	4.496×10^4 psi
	Thermally Treated	Yes

In terms of mechanical properties, Aluminum 6061 has a Young's Modulus of 9.993×10^6 psi (9,993,000 psi), indicating that the material exhibits relatively high stiffness, meaning it does not easily bend or undergo elastic deformation under stress. The Poisson's Ratio of 0.33 shows that when the material is subjected to longitudinal tension, it contracts laterally by 33% of its axial strain. The Shear Modulus, recorded at 3.751×10^6 psi (3,751,000 psi), represents the material's resistance to shear forces, confirming that Aluminum 6061 possesses good stability in applications involving shear loading. Its density of 0.098 pounds per cubic inch reflects its lightweight nature, an important characteristic that makes Aluminum 6061 highly suitable for the automotive, aerospace, and manufacturing industries, where weight reduction is crucial without compromising strength (Ananda et al., 2021).

From the perspective of strength, the yield strength of Aluminum 6061 is reported as 3.989×10^4 psi (39,890 psi), which defines the maximum stress at which the material begins to experience permanent deformation. This means that if the applied stress remains below 39,890 psi, the material will return to its original shape after the load is removed. However, if the stress exceeds this value, plastic deformation occurs. In addition, the tensile strength of 4.496×10^4 psi (44,960 psi) represents the maximum stress the material can withstand before fracture. These values demonstrate that Aluminum 6061 possesses high strength relative to its weight, making it well-suited for sustaining significant structural loads (Ananda et al., 2021).

CONCLUSION

This research successfully established the design specifications for an ergonomic footrest intended for office workers, based on a careful analysis of anthropometric data from 60 respondents. By applying the 95th percentile (P_{95}), the optimal footrest dimensions were determined to ensure accommodation for 95% of users: the optimal height is 51.85 cm (based on Seated Popliteal Height), the width is 30.00 cm (based on Seated Popliteal Breadth), and the length is 50.99 cm (based on Foot Length).

The final design, utilizing Aluminium 6061, is functional, integrating a hydraulic height adjustment mechanism and an integrated heating feature. This data-supported solution provides a strong scientific basis for a product that can effectively correct sitting posture, minimize musculoskeletal discomfort, and support blood circulation, thereby directly contributing to improved health and work productivity. It is recommended that future research focuses on prototype testing and biomechanical evaluation to validate the ergonomic effectiveness and thermal performance of the design in real-world settings.

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