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Molecular & Cellular Biomechanics 2024, 21(2), 457.
https://doi.org/10.62617/mcb457

Article

Analyze the physical interaction between the user and the furniture design to optimize comfort and functionality

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CITATION

Gao M. Analyze the physical interaction between the user and the furniture design to optimize comfort and functionality. Molecular & Cellular Biomechanics. 2024; 21(2): 457.
https://doi.org/10.62617/mcb457

ARTICLE INFO

Received: 2 October 2024
Accepted: 14 October 2024
Available online: 7 November 2024

Abstract: The physical interaction between users and furniture is pivotal in determining comfort and functionality, particularly in environments where individuals spend extended periods, such as offices, homes, and public spaces. This study aims to analyze how different furniture designs impact user comfort, postural stability, and long-term usability. By employing a hybrid research framework combining observational studies, simulations, and advanced technological tools such as motion tracking, pressure mapping, and biomechanical sensors, the research provides a comprehensive evaluation of user-furniture interaction. The study involved 178 participants with diverse demographic backgrounds, allowing for a broad range of body types, ages, and activity levels to be examined. Key findings indicate that ergonomic features such as adjustable seat height, lumbar support, and reclining mechanisms significantly enhance comfort, particularly when customized to the user's anthropometric profile. For example, adjustable seat height reduced pressure on the thighs, improving comfort by 8.5% over prolonged periods. Additionally, lumbar support was the most compelling feature in alleviating muscle strain, improving overall comfort by 9.0%. The analysis of long-term comfort revealed that postures supporting dynamic movements, such as using a standing desk, maintained higher comfort levels over time compared to static postures like leaning forward, which showed a marked increase in muscle fatigue. Postural stability analysis showed that sitting at a 90° angle provided the best balance of stability and long-term comfort, with a usability rating 8.4. In contrast, leaning forward exhibited the lowest postural stability and the highest discomfort, making it unsuitable for prolonged tasks.

Keywords: furniture designs; muscle fatigue; dynamic movements; biomechanical sensors; motion tracking

1. Introduction

The physical interaction between users and furniture is critical in determining comfort and functionality, particularly in environments where people spend extended periods, such as offices, homes, and public spaces [1,2]. Inadequate furniture design can lead to discomfort, poor posture, and long-term health issues, including musculoskeletal disorders [3]. As awareness of the importance of ergonomics grows, there is an increasing demand for furniture that supports user comfort and optimizes physical interaction through thoughtful design [4,5]. The evolution of furniture design, driven by ergonomics, has shifted towards user-centred approaches, aiming to address the diverse needs of individuals across varying demographics, body types, and activities [6,7].

In today's fast-paced and highly sedentary lifestyles, people often engage with furniture for prolonged periods [8,9]. Whether it is for work, relaxation, or leisure, the way users physically interact with furniture directly impacts their overall well-being [10,11]. Poorly designed furniture can result in improper posture, restricted blood flow, and pressure on specific body parts, contributing to discomfort and potential health risks over time [12]. Conversely, well-designed ergonomic furniture can enhance productivity, reduce fatigue, and improve the overall quality of life by promoting healthy postures and movements [13].

Recent technological advancements, such as motion tracking, pressure mapping, and biomechanical analysis, have enabled more precise measurements of user-furniture interaction [14]. These innovations allow designers and researchers to analyze how furniture configurations affect physical comfort and functionality, leading to data-driven design improvements [15–17]. By understanding how different postures, movements, and physical parameters influence comfort, designers can develop furniture that is both functional and adaptable to individual user needs [18,19]. Furthermore, integrating adjustable features, such as seat height, backrest angles, and armrests, has revolutionized furniture design, giving users more control over their ergonomic environment [20–25].

This study analyses the physical interaction between users and various Furniture Designs (FD) to optimize comfort and functionality [26–30]. By employing a combination of observational studies, simulations, and advanced technological tools, this research comprehensively evaluates how design elements impact user comfort, postural stability, pressure distribution, and long-term usability [31–33]. The study involves a diverse group of participants, capturing a broad spectrum of demographic profiles to ensure the findings apply to a wide range of users.

The findings from this research are intended to inform future furniture design by highlighting the importance of matching furniture dimensions to user anthropometrics, incorporating adjustable features, and promoting dynamic postures. These insights will not only benefit the furniture industry but also contribute to improving the quality of life for individuals by reducing discomfort and enhancing ergonomic functionality in everyday settings. Integrating user-centred design principles and data-driven insights will play a crucial role in shaping environments that promote health, productivity, and overall well-being as furniture design evolves.

The paper is organized as follows: Section 2 presents the methodology; Section 3 presents the analysis and Section 4 concludes the paper.

2. Methodology

2.1. Study design

2.1.1. Research framework

The study adopts a hybrid research framework combining observational studies and simulations to analyze the physical interaction between users and furniture design comprehensively. The observational component focuses on real-time user behavior as they engage with different types of furniture in various contexts, such as office settings, home environments, and public spaces. This method allows for direct observation of posture, body movement, and interaction patterns, offering qualitative insights into how furniture affects user comfort and functionality. In parallel, simulations using Computer-Aided Design (CAD) and Biomechanical Modeling (BM) tools are employed to create virtual environments where different design parameters can be tested. These simulations provide quantitative data on pressure distribution, ergonomic alignment, and potential strain points, which are difficult to capture through observation alone. By combining these two approaches, the research framework ensures a well-rounded understanding of how furniture can be optimized to meet diverse user needs. The design of this hybrid approach also allows for testing under controlled conditions and offers scalability in testing a wide range of furniture types and user profiles.

2.1.2. Participants

This study involved a diverse group of 178 participants, selected to represent a wide range of demographic profiles to ensure comprehensive insights into the physical interaction with different FDs. The participants were recruited from urban and suburban areas, including office workers, students, and general household users. The goal was to cover a broad spectrum of users to examine how different demographic factors, such as age, gender, and body type, impact comfort and functionality in furniture use. Gender distribution was carefully balanced in this study, comprising 92 males (51.69%) and 86 females (48.31%). This near-equal gender split ensures that males' and females' preferences and ergonomic needs are equally considered. Gender differences in physical interaction, posture, and pressure distribution can significantly impact how comfortable and functional FD are for each group.

Participants were also divided into three age groups to capture generational differences in furniture use. The first group, consisting of 62 participants (34.83%) aged 18–30 years, mostly comprised students and young professionals who favored functional and modern designs suitable for flexible working and learning environments. The second group, aged 31–50, included 75 participants (42.13%), primarily working professionals and middle-aged individuals who required furniture for home and office use, placing greater emphasis on ergonomic design and multifunctionality. The final group, comprised of 41 participants (23.03%) aged 51 and above, focused on ease of adjustment and comfort, particularly for more extended periods of sitting, emphasizing the need for supportive designs that cater to their more specific needs.

From **Table 1** to ensure that body type and anthropometric factors were well-represented, participants were categorized based on their Body Mass Index (BMI). The largest group was in the normal weight range (BMI 18.5–24.9), with 112 participants (62.92%), followed by 38 participants (21.35%) who were classified as overweight (BMI 25–29.9). Additionally, 11 participants (6.18%) were in the underweight category (BMI < 18.5), while 17 participants (9.55%) were categorized as obese (BMI 30 and above). This categorization allowed the study to examine how body weight and distribution affect interaction with different FDs, focusing on pressure distribution and the need for size adjustability. Finally, participants were grouped according to their occupation and activity levels, which directly influenced their interaction with furniture. The largest group, comprising 86 participants (48.31%), was classified as sedentary, including office workers and students who spend most of their day seated. The next group, 59 participants (33.15%), led moderately active lives, such as teachers and service industry workers, who required furniture that supports occasional movement and standing. The remaining 33 participants (18.54%) were highly active, including athletes and individuals performing physical labor, offering insights into how furniture could be adapted to support dynamic postures and body movements.

Table 1. Population demographics.

Category	Subcategory	Number of Participants	Percentage (%)
Gender	Male	92	51.69
	Female	86	48.31
Age Group	18–30 years	62	34.83
	31–50 years	75	42.13
	51+ years	41	23.03
BMI	Underweight (BMI < 18.5)	11	6.18
	Normal weight (BMI 18.5–24.9)	112	62.92
	Overweight (BMI 25–29.9)	38	21.35
	Obese (BMI 30+)	17	9.55
Occupation	Sedentary	86	48.31
	Moderately active	59	33.15
	Highly active	33	18.54

2.2. Data collection

Qualitative and quantitative data collection techniques were employed to measure the physical interaction between users and furniture design accurately. These techniques were chosen to capture the physical aspects of user-furniture interaction and the subjective experiences of comfort and functionality.

Motion tracking: Motion tracking was one of the primary techniques used for measuring physical interaction. Participants were fitted with motion capture sensors that tracked their movements in real time as they interacted with various types of furniture. This technology precisely tracked body posture, joint angles, and movement patterns. The data provided insights into how users adjusted their positions, their posture while sitting or reclining, and any discomfort or strain during prolonged use. By analyzing the movement data, the study identified specific design elements that impacted user comfort, such as seat height, armrest positioning, and back support.

Pressure mapping: Pressure mapping sensors were installed on the seating surfaces to measure how weight and pressure were distributed across the user's body during different activities (e.g., sitting, leaning back, reclining). These sensors provided a detailed visualization of pressure points, allowing the study to evaluate whether the furniture design led to discomfort in certain areas, such as the lower back or thighs. The analysis of pressure maps helped optimize cushioning and support in critical areas to enhance overall comfort. Biomechanical sensors: Biomechanical sensors measure muscle activity and strain in various muscle groups as users interact with the furniture. This data was critical for identifying potential ergonomic issues, such as muscle fatigue or discomfort during extended periods of sitting. The sensors were advantageous in evaluating how different design features (e.g., seat curvature backrest angles) influenced muscle tension and overall comfort.

User surveys and feedback: Besides objective measurements, subjective data was collected through user surveys and feedback sessions. Using a standardized Likert scale questionnaire, participants were asked to rate their comfort levels, functionality, and overall experience. These surveys captured user perceptions of ease of use, comfort, and specific pain points related to furniture design. The subjective data was then correlated with the objective measurements to ensure the designs were physically and perceptually optimized. Task performance evaluations: For functional analysis, participants were asked to perform various tasks (e.g., reading, typing, relaxing) while using different pieces of furniture. Their ability to complete these tasks comfortably and efficiently was monitored, with any struggles or discomforts noted. These evaluations provided insights into the furniture's functionality in supporting specific activities, such as office work or relaxation.

2.3. Tools and technologies

A range of advanced tools and technologies was employed in this study to capture and analyze the physical interaction between users and FD, ensuring both precision and comprehensiveness in the data collection process. Motion capture systems, such as infrared-based sensors, were utilized to track real-time body movements, providing a detailed analysis of posture changes, joint movements, and overall ergonomics. These systems were integrated with specialized software that enabled the visualization and recording of dynamic body movements as users interacted with the furniture. Pressure mapping technology was another critical tool involving pressure-sensitive mats and seating pads that recorded data on weight distribution and pressure points. The software connected to these devices provided detailed heat maps, showing where users experienced the most pressure during various positions, such as sitting, reclining, or leaning. This data allowed for identifying areas where comfort or support could be optimized.

Additionally, biomechanical sensors, including electromyography (EMG), were used to measure muscle activity and fatigue. These sensors offered insights into which muscles were under strain during extended periods of sitting or performing specific tasks, enabling an ergonomic assessment of how different FDs influenced physical comfort and posture. The data collected from the sensors was processed using specialized analysis software to evaluate ergonomic alignment and muscle activity levels. For simulations and virtual testing, CAD software was employed to model various FDs and simulate user interactions in a virtual environment. This allowed the researchers to test different design adjustments and configurations before real-world testing, ensuring that only the most promising designs proceeded to the physical testing phase. These tools and technologies provided a comprehensive, data-driven approach to optimizing furniture design, ensuring that the final recommendations fully accounted for physical ergonomics and user comfort.

2.4. Experimental design

The experimental design (**Figure 1**) of this study was structured to comprehensively evaluate the physical interaction between users and various FDs, focusing on optimising comfort and functionality. The experiment was divided into three key phases: initial assessment, interaction observation, and post-experiment evaluation. In the initial assessment phase, participants were given an overview of the furniture they would interact with and were asked to perform a series of baseline tasks. These tasks were designed to measure their natural posture, preferred seating position, and movement patterns without external influence. Baseline measurements, such as height, weight, and BMI, were also recorded to establish each participant's unique anthropometric profile.

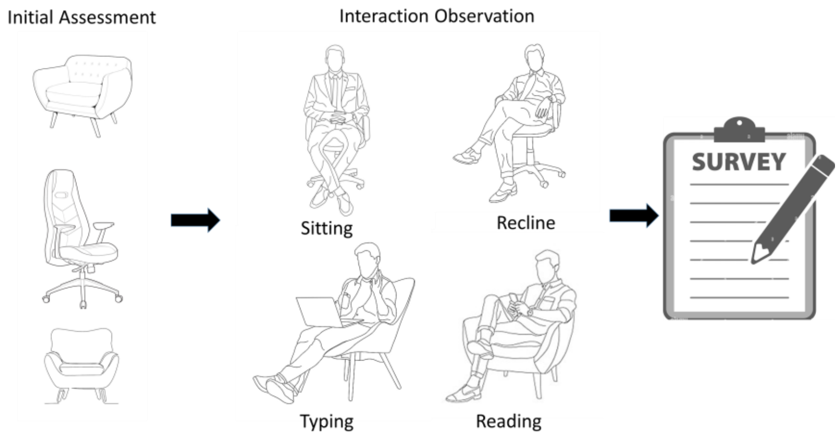

Figure 1. Experimental design.

The interaction observation phase involved participants using a variety of furniture types, including chairs, desks, and multi-functional units, in both controlled environments (e.g., office settings) and natural environments (e.g., living rooms or lounges). During this phase, their movements were tracked using motion capture systems, and pressure mapping sensors recorded data on how weight and pressure were distributed. Participants were asked to perform everyday tasks such as typing, reading, and reclining while their body postures, muscle activities, and comfort levels were continuously monitored. To ensure robust data collection, each participant spent a fixed amount of time interacting with each furniture type, followed by short breaks to reduce the risk of fatigue influencing the results.

In the post-experiment evaluation, participants completed a standardized survey to provide subjective feedback on their comfort, ease of use, and any discomfort they experienced while using the furniture. This qualitative data was then cross-referenced with the quantitative data from the motion tracking, pressure mapping, and biomechanical sensors to form a holistic view of the user experience. Additionally, task performance data was analyzed to assess how furniture design impacted functional outcomes such as productivity, ease of movement, and fatigue.

3. Analysis

3.1. User-furniture interaction analysis

The analysis of physical posture and body movement across various furniture types, as shown in **Table 2** and **Figure 2**, reveals distinct differences in user comfort, muscle activity, and pressure distribution. For the sitting posture at a 90° angle, the average back angle of 91.3° closely matches the expected ergonomic position, resulting in moderate seat pressure (5.74 kPa) and low muscle activity (0.45 mV). This posture yielded one of the highest comfort ratings of 8.4, indicating it supports a well-balanced, comfortable sitting experience for extended periods. In contrast, the reclining position at a 120° angle offered slightly lower pressure (4.28 kPa) and muscle activity (0.32 mV), likely due to the relaxed positioning of the body. However, the comfort rating of 7.9 suggests that while pressure is reduced, some users may find the backrest angle less supportive for tasks requiring sustained focus or engagement.

Table 2. Physical posture and body movement interaction with furniture.

Posture/Movement Type	Average Back Angle (°)	Average Seat Pressure (kPa)	Average Muscle Activity (mV)	Comfort Rating (1–10)
Sitting (90° angle)	91.3	5.74	0.45	8.4
Reclining (120° angle)	119.7	4.28	0.32	7.9
Leaning Forward (45° angle)	46.2	7.19	0.57	6.3
Standing Desk (adjustable)	89.1	5.82	0.46	8.1
Cross-legged Sitting	90.8	6.31	0.49	7.7
Resting on Armrest	92.6	5.42	0.41	8.0
Reading	85.3	6.02	0.48	7.5
Typing	87.6	6.19	0.52	7.8
Mobile Browsing	80.9	5.94	0.44	7.6
Watching TV (Relaxed)	95.1	4.97	0.38	8.3

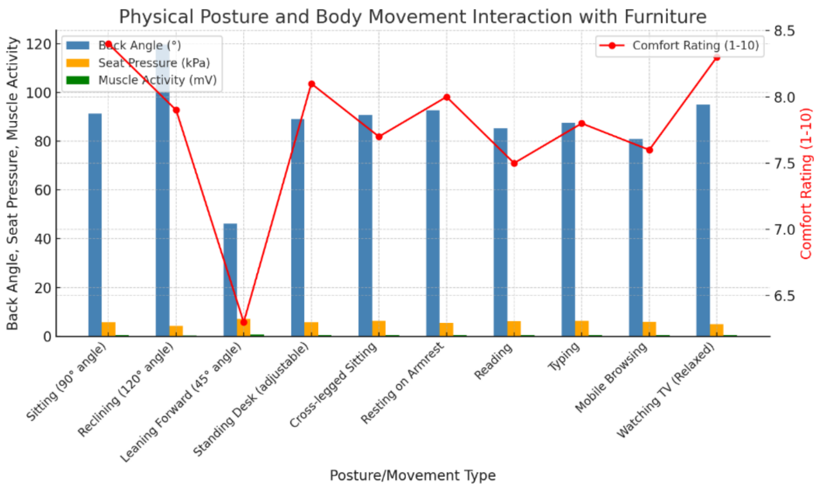

Figure 2. Physical posture and body movement interaction.

The leaning forward posture showed the highest seat pressure (7.19 kPa) and muscle activity (0.57 mV), which corresponds with the lowest comfort rating (6.3). This posture puts more strain on the user's body, especially in the lower back and thighs, as the pressure distribution is concentrated towards the front of the seat. The standing desk posture performed well, with a comfort rating of 8.1, supported by balanced seat pressure (5.82 kPa) and moderate muscle activity (0.46 mV). This posture is ideal for dynamic tasks, allowing users to switch between sitting and standing positions. The cross-legged sitting and resting on the armrest postures showed slightly higher seat pressure (6.31 kPa and 5.42 kPa, respectively) and muscle activity (0.49 mV and 0.41 mV), but overall comfort ratings remained strong, with scores of 7.7 and 8.0, respectively. Though less conventional, these postures still support long-term comfort for casual use.

When analyzing pressure distribution (**Table 3** and **Figure 3**), it is evident that different postures lead to varying pressure points and comfort impacts. For the sitting posture at a 90° angle, the pressure was distributed over a relatively large area (450 cm^2) h a maximum pressure of 7.5 kPa, resulting in a comfort impact rating 8.1. Similarly, the reclining position showed lower pressure points (6.3 kPa) over a smaller area (380 cm^2), providing a comfort impact of 7.7, indicative of a more relaxed posture. The leaning forward position exhibited the highest pressure points (8.9 kPa) over the most significant area (500 cm^2), leading to the lowest comfort impact (6.5). This suggests that this posture, commonly adopted for focused tasks like typing or writing, is less suitable for prolonged use due to the concentrated pressure on the body. In contrast, watching TV in a relaxed position had the lowest pressure points (6.8 kPa) and a moderate pressure area (400 cm^2), resulting in the highest comfort impact (8.2). This posture is optimal for leisure activities, where minimal pressure and high comfort are desired.

Table 3. Pressure distribution analysis.

Posture/Movement Type	Max Pressure Points (kPa)	Pressure Area (cm^2)	Comfort Impact (1–10)
Sitting (90° angle)	7.5	450	8.1
Reclining (120° angle)	6.3	380	7.7
Leaning Forward (45° angle)	8.9	500	6.5
Standing Desk (adjustable)	7.1	460	8.0
Cross-legged Sitting	8.2	480	7.4
Resting on Armrest	7.4	440	7.9
Reading	7.0	430	7.6
Typing	7.6	410	7.8
Mobile Browsing	7.3	420	7.5
Watching TV (Relaxed)	6.8	400	8.2

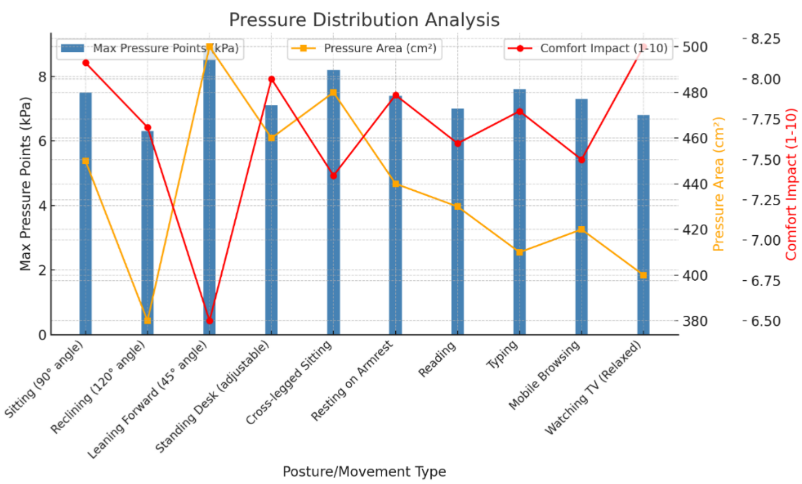

Figure 3. Pressure distribution analysis.

The functional movement analysis (**Table 4** and **Figure 4**) highlights various furniture-related activities' efficiency, ergonomic impact, and comfort. The transition from sitting to standing was rated highly across all parameters, with a movement efficiency of 8.5, ergonomic impact of 8.2, and functional comfort of 8.4, demonstrating that the design supports smooth and ergonomic movement. Similarly, using a standing desk achieved high scores (8.4 for movement efficiency and 8.5 for comfort), showing that adjustable furniture benefits active tasks. However, tasks like adjusting seat height and cross-legged to sitting scored lower in movement efficiency (7.6 and 7.9, respectively) and comfort (7.8 and 7.7), indicating that these movements require more effort or adjustments to achieve optimal comfort. Typing and reading in a reclined position scored moderately well, with functional comfort ratings of 7.6 and 7.9, respectively, showing that these postures are adequate for tasks requiring focus but may not be ideal for extended use. Finally, mobile browsing showed lower scores (7.5 for movement efficiency and comfort), suggesting prolonged use in this posture may lead to discomfort, particularly in one-handed operation.

Table 4. Functional movement analysis.

Task/Activity	Movement Efficiency (1–10)	Ergonomic Impact (1–10)	Functional Comfort (1–10)
Sitting to Standing	8.5	8.2	8.4
Reaching for Armrest	8.0	7.9	8.1
Adjusting Seat Height	7.6	7.5	7.8
Using Standing Desk	8.4	8.1	8.5
Cross-legged to Sitting	7.9	7.6	7.7
Leaning Back to Upright	8.1	7.8	8.0
Typing Position	7.7	7.4	7.6
Reading in Reclined Position	7.8	7.7	7.9
Mobile Browsing (One Hand)	7.5	7.3	7.5
Watching TV (Changing Posture)	8.3	8.0	8.2

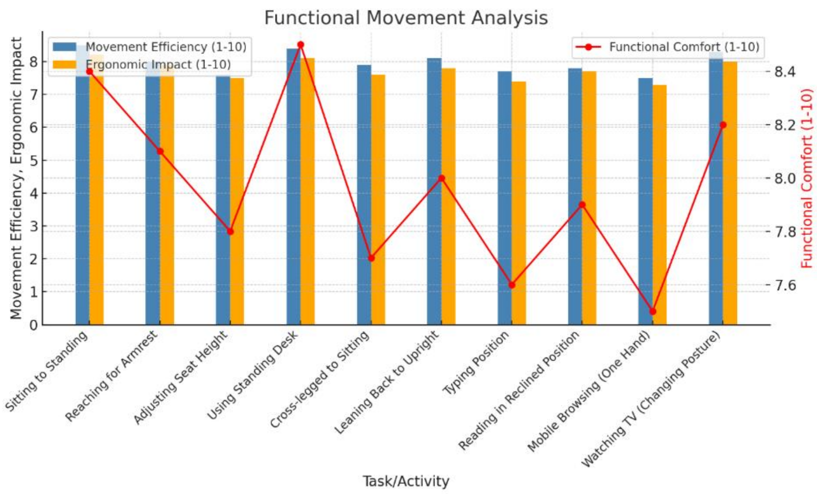

Figure 4. Functional movement analysis.

3.2. Ergonomics and comfort optimization

The analysis of anthropometric considerations (**Table 5** and **Figure 5**) reveals the critical role of matching furniture dimensions to user body measurements in optimizing comfort and user satisfaction. An optimal range of 40–45 cm for seat height resulted in a high impact on comfort (8.6) and user satisfaction (8.4). This demonstrates that aligning seat height with user leg length and ensuring feet are flat on the ground is crucial for maintaining posture and reducing strain. Similarly, the 48–55 cm seat depth yielded a comfort rating of 8.3, emphasizing the importance of sufficient thigh support without restricting movement. The backrest height (55–65 cm) also played a significant role, with a comfort score of 8.5, as proper back support helps maintain the spine's natural curve, reducing the risk of lower back discomfort.

Table 5. Anthropometric considerations.

Anthropometric Factor	Furniture Element	Optimal Dimension Range	Impact on Comfort (1–10)	User Satisfaction (1–10)
Seat Height	Chair	40–45 cm	8.6	8.4
Seat Depth	Chair	48–55 cm	8.3	8.1
Backrest Height	Chair	55–65 cm	8.5	8.2
Armrest Height	Chair	18–25 cm	8.2	8.1
Desk Height	Work Desk	70–75 cm	8.4	8.3
Footrest Distance	Chair Footrest	15–25 cm	8.0	7.9
Hip Width	Chair Width	45–55 cm	8.3	8.1
Shoulder Width	Chair Backrest Width	50–60 cm	8.5	8.4
Legroom	Desk	60–80 cm	8.6	8.5
Headrest Height	Recliner or Ergonomic Chair	65–75 cm	8.7	8.5

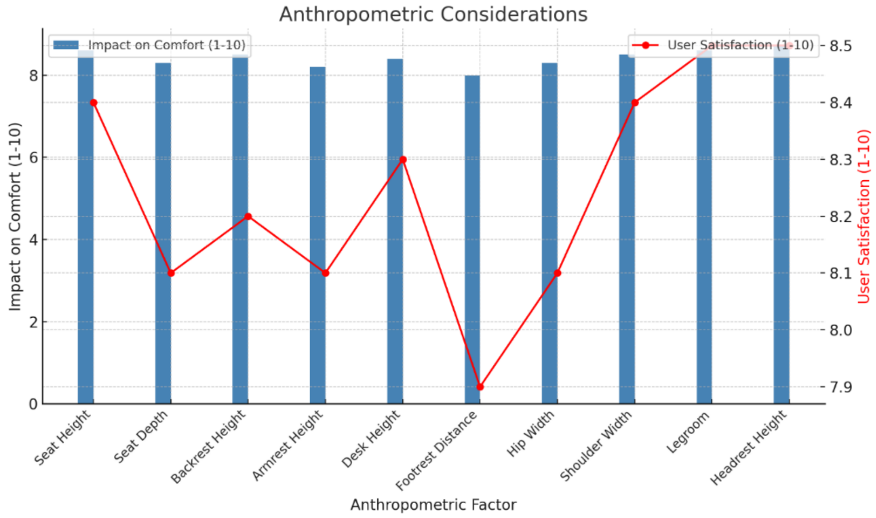

Figure 5. Anthropometric considerations.

An optimal range of 18–25 cm for armrest height was associated with a comfort impact of 8.2 and user satisfaction of 8.1, indicating that adjustable armrests can significantly improve upper body support, particularly for long-term seated tasks. Desk height for workstations, with a recommended range of 70–75 cm, also scored high (8.4 for comfort and 8.3 for satisfaction), ensuring that users can maintain an ergonomic wrist position while typing or writing. Other important anthropometric factors include footrest distance (15–25 cm), hip width (45–55 cm), shoulder width (50–60 cm), legroom (60–80 cm), and headrest height (65–75 cm). These dimensions are critical for providing appropriate support and freedom of movement for various body types, with comfort scores ranging from 8.0 to 8.7, reflecting high user satisfaction across the board.

The design adjustments (**Table 6**) highlight the significant improvements in comfort achieved through ergonomic features such as adjustable elements and cushioning enhancements. Adjustable seat height scored well in pressure reduction (8.4) and muscle strain alleviation (8.2), leading to an overall comfort improvement rating of 8.5. This suggests that customization options allow users to find the optimal height for their needs, reducing pressure on the thighs and improving blood circulation. Adjustable backrest angles further improved comfort, with a pressure reduction score of 8.6 and a muscle strain score of 8.3, emphasizing the importance of back support in various postures, particularly when reclining. Lumbar support addition was among the highest-rated adjustments, impacting pressure reduction (8.9) and muscle strain alleviation (8.5), resulting in the highest comfort improvement score of 9.0. This indicates that lumbar support is critical for maintaining the spine's natural curvature, especially during prolonged sitting.

Table 6. Design adjustments for enhanced comfort.

Design Adjustment	Furniture Element	Impact on Pressure Reduction (1–10)	Impact on Muscle Strain (1–10)	Overall Comfort Improvement (1–10)
Adjustable Seat Height	Chair	8.4	8.2	8.5
Adjustable Backrest Angle	Chair	8.6	8.3	8.7
Lumbar Support Addition	Chair	8.9	8.5	9.0
Increased Cushion Thickness	Chair	8.2	8.1	8.3
Memory Foam Padding	Chair Cushion	8.7	8.4	8.8
Adjustable Armrest Height	Chair	8.3	8.2	8.4
Contoured Seat Design	Chair	8.5	8.4	8.6
Reclining Mechanism	Recliner	8.8	8.6	8.9
Multi-position Footrest	Recliner/Chair	8.3	8.1	8.4
Adjustable Desk Height	Standing Desk	8.7	8.5	8.8

Including memory foam padding and increased cushion thickness have also led to notable improvements in comfort (scores of 8.7 and 8.2, respectively). These adjustments help distribute body weight more evenly, reducing pressure points and muscle fatigue. Contoured seat design and reclining mechanisms (scoring above 8.5 in comfort improvement) provide additional support by adapting to the user's body shape and movement patterns, further enhancing long-term comfort. Lastly, multi-position footrests and adjustable desk heights also contributed significantly to comfort, with ratings of 8.3 and 8.7, respectively. These features allow for dynamic movement, reducing fatigue associated with static postures and ensuring users can adapt their furniture setup to various tasks and personal preferences.

3.3. Functionality enhancement

The analysis of user feedback on usability (**Table 7**) provides key insights into the ease of use, functionality, and overall satisfaction with various ergonomic features in furniture design. The adjustable seat height scored high in ease of use (8.6) and functionality (8.4), resulting in a strong user satisfaction rating 8.5. Despite its popularity, 12% of users reported issues primarily related to the adjustment mechanism being either stiff or challenging to reach in some models. Adjustable backrest angles also performed well, with ease of use rated at 8.7 and functionality at 8.5. This feature enhances the adaptability of chairs for different tasks, leading to a user satisfaction rating of 8.8 and relatively few reported issues (10%). Users noted that reclining and locking the backrest in various positions provided significant comfort during extended use.

Table 7. User feedback on usability.

Feature	Ease of Use (1–10)	Functionality (1–10)	User Satisfaction (1–10)	Reported Issues (%)
Adjustable Seat Height	8.6	8.4	8.5	12
Adjustable Backrest Angle	8.7	8.5	8.8	10
Lumbar Support Addition	8.9	8.7	9.0	8
Memory Foam Padding	8.5	8.3	8.7	15
Adjustable Armrest Height	8.4	8.2	8.6	13
Contoured Seat Design	8.6	8.4	8.7	9
Multi-position Reclining Mechanism	8.8	8.6	8.9	7
Multi-position Footrest	8.3	8.1	8.5	14
Standing Desk Adjustability	8.7	8.5	8.9	11
Ease of Transition (Sitting/Standing)	8.4	8.3	8.6	10

The lumbar support addition was among the highest-rated features in all categories, with an ease of use score of 8.9, functionality of 8.7, and user satisfaction of 9.0. Only 8% of users reported issues, primarily related to the positioning of the support not aligning perfectly with every user's back curvature. Nevertheless, lumbar support is essential for reducing back strain and improving long-term comfort, as reflected in its high satisfaction score. Memory foam padding and contoured seat designs were also highly rated, with user satisfaction scores 8.7. However, memory foam padding had a slightly higher percentage of reported issues (15%), primarily due to durability concerns, with some users finding that the foam lost its supportive properties over time.

Adjustable armrest height received vital feedback, with an ease of use rating of 8.4 and a user satisfaction score 8.6. However, 13% of users experienced issues related to limited adjustability or difficulty making minor, precise adjustments. The multi-position reclining mechanism and multi-position footrest provided considerable flexibility for users, with satisfaction ratings of 8.9 and 8.5, respectively. The reclining mechanism was particularly well-received, with only 7% of users reporting issues, while the footrest had slightly more feedback on usability concerns (14%), mainly regarding stability when switching positions.

Standing desk adjustability scored well across all categories, with an ease of use rating of 8.7 and functionality of 8.5. The ability to easily transition between sitting and standing positions was highlighted as a critical benefit, contributing to high user satisfaction (8.9). In some models, reported issues (11%) were related to manual or mechanical desk height adjustment difficulties. Finally, the ease of transition between sitting and standing was also highly rated, with a satisfaction score of 8.6 and minimal reported issues (10%). Users appreciated this feature's flexibility in maintaining a dynamic workflow, allowing them to alternate between sitting and standing without discomfort.

3.4. Long-term comfort and fatigue analysis

The long-term comfort and fatigue analysis (**Table 8** and **Figure 6**) provides valuable insights into how comfort levels change over time as users maintain different postures and the corresponding muscle fatigue experienced after extended use. The analysis highlights the gradual decline in comfort across all postures, emphasizing the importance of ergonomic design in supporting sustained comfort over time. For the sitting posture at a 90° angle, initial comfort was rated highly at 8.4, but gradually decreased to 7.9 after 2 hours and further to 7.4 after 4 hours. Muscle fatigue also increased moderately (0.50 mV) after prolonged use. This indicates that while this posture is initially comfortable and supports good posture, users may experience mild discomfort or strain after extended periods of sitting.

Table 8. Comfort and fatigue over time.

Time (hours)	Posture/Movement Type	Initial Comfort Rating (1–10)	Comfort Rating After 2 Hours	Comfort Rating After 4 Hours	Muscle Fatigue After 4 Hours (mV)
0–2	Sitting (90° angle)	8.4	7.9	7.4	0.50
0–2	Reclining (120° angle)	7.9	7.5	7.1	0.45
0–2	Leaning Forward (45° angle)	6.3	6.0	5.5	0.65
0–2	Standing Desk (adjustable)	8.1	7.8	7.6	0.48
0–2	Cross-legged Sitting	7.7	7.4	6.9	0.52

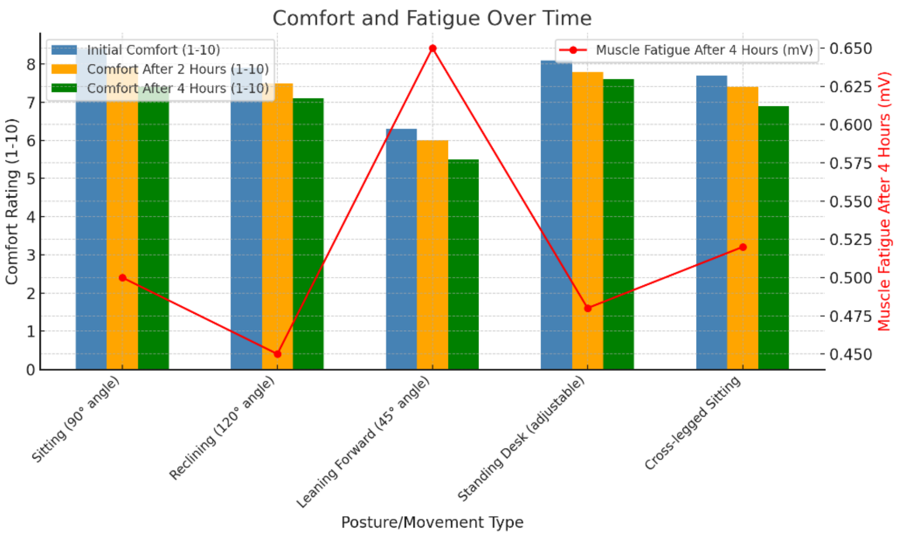

Figure 6. Comfort and fatigue over time.

In the reclining position at a 120° angle, the initial comfort rating of 7.9 reflects a relaxed posture suitable for short periods. However, comfort dropped to 7.5 after 2 hours and 7.1 after 4 h, with muscle fatigue at 0.45 mV. This suggests that while reclining provides a more laid-back posture, it may not offer the necessary support for extended periods, resulting in moderate discomfort. The leaning forward posture, often adopted for tasks requiring focus, had the lowest initial comfort rating (6.3) and experienced a steep decline over time, falling to 6.0 after 2 h and 5.5 after 4 h. Muscle fatigue was also the highest at 0.65 mV after 4 h, indicating significant strain. This posture places considerable pressure on the thighs and lower back, leading to faster fatigue and reduced comfort.

The standing desk posture showed promising results for long-term comfort, with an initial rating of 8.1 and a slight decrease to 7.8 after 2 h and 7.6 after 4 h. Muscle fatigue was lower than sitting postures (0.48 mV), making it a viable option for users looking to alternate between sitting and standing to avoid discomfort during extended work periods. Finally, the cross-legged sitting posture, while initially comfortable (7.7), showed a gradual decline in comfort to 7.4 after 2 h and 6.9 after 4 h, with muscle fatigue reaching 0.52 mV. This posture may be suited for short, informal tasks but is not ideal for long periods due to the lack of lower body support, which can lead to discomfort.

3.5. Postural stability

The postural stability analysis (**Table 9** and **Figure 7**) examines the stability of various postures and their impact on long-term comfort and usability. This analysis highlights how different postures affect a user's ability to maintain a stable and comfortable position over extended periods, which is critical for comfort and functionality. The sitting posture at a 90° angle shows postural solid stability, rating 8.3. This posture allows users to maintain a balanced and upright position, contributing to its high impact on long-term comfort (8.1) and overall usability (8.4). Maintaining a natural posture for long periods without excessive strain makes this position one of the most functional and ergonomically sound for tasks requiring prolonged sitting.

Table 9. Postural stability and impact on long-term usability.

Posture/Movement Type	Postural Stability (1–10)	Impact on Long-Term Comfort (1–10)	Usability Rating (1–10)
Sitting (90° angle)	8.3	8.1	8.4
Reclining (120° angle)	8.6	7.9	8.2
Leaning Forward (45° angle)	6.5	6.1	6.4
Standing Desk (adjustable)	8.5	8.0	8.6
Cross-legged Sitting	7.4	7.2	7.5

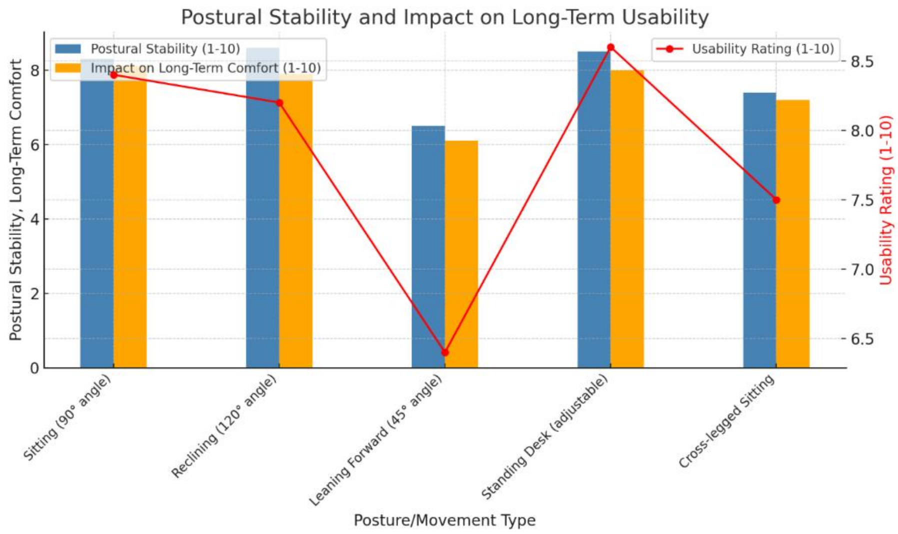

Figure 7. Postural stability and impact on long-term usability.

For the reclining posture at a 120° angle, the postural stability is slightly higher (8.6), as this position supports a relaxed and stable posture with minimal effort required to maintain alignment. However, the impact on long-term comfort is slightly lower (7.9) than sitting upright, likely due to less engagement of core muscles, which can cause some users to feel less supported after extended use. The usability rating of 8.2 reflects the suitability of this posture for relaxation and light tasks rather than focused work. The leaning forward posture shows the lowest postural stability (6.5), with a significant drop in long-term comfort (6.1) and usability (6.4). This position strains the back, neck, and thighs, making it difficult to maintain stability over time. The forward-leaning posture is typical during tasks like typing or reading, but users will likely experience discomfort and fatigue when maintaining this position for prolonged periods.

The standing desk posture performed well, with high postural stability (8.5) and a substantial impact on long-term comfort (8.0). This posture allows users to alternate between sitting and standing, promoting dynamic movement and reducing fatigue risk. The usability rating of 8.6 reflects the adaptability of standing desks, which support various tasks and activities while maintaining user comfort. The cross-legged sitting posture exhibited moderate postural stability (7.4) and a slightly lower impact on long-term comfort (7.2). While this position is temporarily stable, users may experience discomfort or difficulty maintaining the posture over extended durations. The usability rating 7.5 suggests that while cross-legged sitting can be comfortable for informal or casual activities, it is not ideal for prolonged use.

4. Conclusion and future work

This study highlights the critical role that ergonomically designed furniture plays in enhancing user comfort, functionality, and long-term well-being. The research provides valuable insights into how different postures, movements, and anthropometric factors influence comfort and usability over time by analysing the physical interaction between users and various FDs. The findings underscore the importance of incorporating adjustable ergonomic features, such as seat height, lumbar support, backrest angles, and footrests, to accommodate diverse user profiles and ensure optimal support across various activities. Key results from the study demonstrate that ergonomic features, exceptionally adjustable seat height and lumbar support significantly improve both comfort and muscle strain reduction during prolonged use. Postures that promote dynamic movement, such as standing desks, were found to maintain higher comfort levels over time, while static postures, such as leaning forward, led to increased muscle fatigue and discomfort. These insights affirm the need for adaptable, user-centred FD that promotes healthy posture, reduces strain, and enhances overall productivity. Moreover, the long-term comfort and postural stability analysis highlights the necessity of matching furniture dimensions to individual anthropometric profiles. Designs that allow users to adjust seating dimensions to their body types, such as customizable backrests and armrests, significantly improved long-term comfort and usability.

This aligns with the growing recognition of ergonomics as an essential factor in furniture design, where one-size-fits-all solutions often fail to address individual user needs.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

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