REVIEW ARTICLE

# User-Centered Ergonomics in Orthotic Design: A Perspective on Assistive Technology

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## Abstract
Orthosis as an integral and important part of Assistive Technology (AT) play a crucial role in enhancing mobility, stability, and functional independence for individuals with physical impairments. The design and biomechanical application of these orthotic devices must align with user-centric ergonomic principles to ensure maximum efficiency, comfort, and user compliance. This paper highlights the fundamental ergonomic considerations in orthotic designs including biomechanical alignment, load distribution, energy conservation, and human factors like cosmesis, ease of donning and doffing, safety and adaptability. Emphasis is placed on how ergonomically guided orthotic interventions can prevent secondary musculoskeletal problems, reduce rehabilitation time, and contribute to long-term adherence. By addressing the interaction between the human body and orthotic devices, this paper underscores how ergonomics contributes to functional outcomes, quality of life, and long-term adherence in rehabilitation. By aligning engineering design with human factors, the application of ergonomic principles in orthotic design bridges the gap between technology and patient-centered care.

## Keywords
Assistive Technology; Assistive Device; Ergonomics; Orthosis; Biomechanics; Anthropometry

## Introduction
Orthotic devices which are an integral part of Assistive Technology are critical rehabilitation aids or assistive devices that restore function, improve mobility, and alleviate discomfort in people with musculoskeletal or neuromotor disorders. Historically, orthotic design has emphasized mechanical support and alignment. However, recent breakthroughs in materials science, biomechanics, and user-centered design have turned the emphasis to ergonomics, which focuses on the interaction between the user and the orthosis, ensuring that orthoses not only support the body but also integrate seamlessly into the user's daily life. This mini-review article investigates the ergonomic concepts that support good orthotic design for both upper and lower limbs, presenting a conceptual framework that balances mechanical performance and human

aspects. While biomechanical modifications are frequently related with clinical efficacy, including ergonomic principles guarantees that orthoses are safe, pleasant, user-friendly, and adaptable to long-term daily usage. These principles are critical for minimizing secondary problems and improving compliance. Ergonomic design also considers psychosocial elements like aesthetic appeal and ease of donning and doffing which have a substantial impact on user acceptance. Biomechanical parameters alone are insufficient to represent the overall success of an orthotic intervention and defeat the purpose of such an important and integral part of Assistive Technology until and unless not designed ergonomically.

**Figure 1: Ergonomically designed lower limb orthoses with bevelled trim lines and contouring**

*(source: www.nth.nhs.uk)*

**Aim & Objectives**

To investigate and compile the main ergonomic concepts that affect the design of orthoses for the upper and lower limbs, with an emphasis on functional performance, user comfort, and biomechanical alignment.

## Material & Methods

A multidisciplinary conceptual synthesis was conducted, integrating insights from:

- Biomechanics: Joint kinematics, load distribution, and movement efficiency
- Materials Engineering: Lightweight composites, tenable stiffness, and adaptive interfaces
- Human Factors: Cognitive load, ease of use, and psychosocial acceptance

Design domains were mapped into six categories: anthropometry and alignment; joint kinematics and kinetics; interface and load distribution; material and actuation choice; donning/doffing and maintenance; and psychosocial acceptance.

A conceptual review of the literature currently available on ergonomic concerns in orthotic design was carried out using a number of databases including biomechanical and clinical features such as load distribution, pressure relief, energy conservation, and illness prognosis.

Aspects like as material properties, device contouring, and weight reduction were also considered in relation to user comfort and health. For both upper and lower limb orthoses, we investigated human-centric design approaches such as anthropometric customization, ease of donning and doffing, adaptability to activity-specific requirements, and functional engagement with the environment when utilizing this type of assistive device.

## Results

Applying ergonomic principles to orthotic design optimizes gait patterns, improves postural stability, reduces energy expenditure, and minimizes secondary complications like joint strain and skin breakdown. Lightweight, well-contoured, and customizable devices lead to higher patient satisfaction, increased adherence, and improved rehabilitation outcomes. The domain specific advantages of an ergonomically designed orthosis are:

**1. Anthropometry and Alignment**

Precise alignment with anatomical joint centres reduces compensatory movements and secondary injuries. Modular adjustability accommodates swelling, activity variation, and growth in paediatric populations.

**2. Joint Kinematics and Kinetics**

Upper limb orthoses benefit from segmented, low-inertia designs that preserve distal dexterity. Lower limb orthoses must balance sagittal-plane support with controlled frontal and transverse motion to maintain energy-efficient gait.

**3. Interface and Load Distribution**

Contoured interfaces with graded stiffness and shear-reducing liners minimize peak pressures and skin breakdown. Distributed strapping systems offer trade-offs between stability and soft-tissue compression.

**4. Material and Actuation**

Compliant composites and tenable stiffness elements enable energy storage and return during ambulation. Passive designs often outperform powered systems in daily adherence due to reduced weight and complexity.

**5. Donning, Maintenance, and Cognition**

Simplified donning mechanisms and intuitive feedback systems reduce cognitive and time burden, increasing daily wear time. Low-maintenance components improve long-term usability.

**6. Psychosocial Acceptance**

Aesthetic appeal, perceived stigma, and contextual usability (e.g., climate, clothing compatibility) influence long-term compliance. Co-design with users enhances acceptance and sustained use.

**Figure 2: Synergistic relationship between biomechanical and ergonomical principles (source: www.braceability.com)**


## Discussion

Upper and lower limb orthoses that are ergonomically constructed improve functional efficiency, strain reduction, and alignment, resulting in increased mobility and upper limb dexterity. They decrease the likelihood of skin irritation, joint stress, and tiredness while increasing patient satisfaction and compliance. Lightweight, curved, and flexible orthoses promote usage and acceptance in rehabilitation. Ergonomic concerns include simplicity of use, visual appeal, and psychological acceptability, all of which influence long-term compliance in the usage of this form of Assistive Device.

Ergonomics demands more human-centric approach while designing orthoses by using the concepts of anthropometry, biomechanics, psychology, and human physiology at one place. Involving user in the designing process through multiple iterations and feedback at par with their physical, functional and psychosocial needs may lead to an evidence-based practice inspired through successful case studies.

Clinical adoption should prioritize outcome metrics that reflect real-world use: comfort, wear time, functional independence, and psychosocial impact. Biomechanical metrics alone are insufficient to capture the holistic success of an orthotic intervention.

Ergonomic orthotic design requires deliberate trade-offs. Excessive mechanical support may impair mobility and reduce adherence, while overly permissive designs risk instability. A layered framework—comprising personalized alignment, graded mechanical interface, adaptive energy management, and user-centered interaction—supports iterative optimization. Embedding sensor-driven feedback, artificial intelligence and modular upgrades like robotic exoskeleton allows progressive tuning as patient function evolves. Interdisciplinary research collaborations, focusing on ergonomics is essential to innovate and optimize orthotic solutions that meet diverse patient needs effectively.

**Figure 3: ergonomically designed upper limb orthoses enhances user's compliance and orthotic outcomes. (Source: Chaneco Orthotics, UK)**


## Conclusion

The use of ergonomic principles in orthotic designs helps to bridge the gap between mechanical performance and patient-centered care. Thus, ergonomically designed orthoses not only improve biomechanical outcomes, but they also enhance comfort, flexibility, and long-term adherence, resulting in increased independence and quality of life in people who require this assistive device as an orthotic support.

## Relevance of the Study

Assistive Device when designed ergonomically such as upper and lower limb orthoses enhance comfort, compliance, and function, ensure proper biomechanical alignment, prevent secondary complications, improve independence, and aesthetics, ultimately leading to better patient outcomes and long-term clinical effectiveness with good quality of life.

More specifically has the following bearings:

**1. Improved Patient Comfort & Compliance**

Orthoses designed with ergonomic principles reduce pressure points, skin irritation, and discomfort.

Better comfort leads to higher acceptance and consistent use, which is essential for rehabilitation.

**2. Optimized Biomechanical Alignment**

Ergonomic design ensures the orthosis aligns correctly with anatomical joints (e.g., knee, ankle, wrist).

This reduces compensatory movements, abnormal gait patterns, or overuse injuries.

**3. Enhanced Functionality & Independence**

Ergonomically designed orthoses maximize functional mobility (walking, grasping, daily activities).

Patients regain independence faster, improving their quality of life.

**4. Reduction of Secondary Complications**

Proper load distribution prevents pressure ulcers, contractures, and joint deformities.

In lower limb orthoses, ergonomic gait support reduces energy expenditure and fatigue.

**5. Custom Fit & Adaptability**

Ergonomic principles encourage the use of custom-molded and adjustable designs.

This allows for individual variations in anatomy, growth (in children), or progression of conditions.

**6. Psychological & Social Benefits**

Devices that are aesthetically acceptable, lightweight, and user-friendly improve self-esteem.

Patients are more likely to wear the device in social settings.

**7. Facilitates Rehabilitation & Recovery**

Ergonomic orthoses promote correct movement patterns during therapy.

They assist in muscle retraining, proprioception, and neuromotor control.

**8. Long-Term Cost-Effectiveness**

By reducing complications, improving compliance, and avoiding repeated redesigns, ergonomic orthoses lower the overall cost of care.

The clinical relevance lies in better patient outcomes. Ergonomic orthoses ensure comfort, safety, compliance, functional independence, and long-term rehabilitation success.

## Authors Contribution

Both authors have contributed equally.

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## Conflict of Interest

There are no conflicts of interest.

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## Declaration Of Generative Ai And Ai Assisted Technologies In The Writing Process

During the preparation of this work, the author(s) did not use any generative AI or AI assisted technologies.

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