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Recent Advances in Anthropometric Research and Applications in Ergonomic Design

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ABSTRACT

Recent advancements in anthropometric research have significantly contributed to the field of ergonomic design, providing critical data for developing products, workspaces, and public environments tailored to human body dimensions. This review explores contemporary trends in anthropometric research and their applications across various industries, including healthcare, industrial design, and public space planning. One of the key findings highlights the importance of accurate anthropometric data collection, as discrepancies in self-reported data can lead to flawed ergonomic designs. Emerging technologies like 3D body scanning and wearable sensors have enhanced data accuracy, although traditional tools remain relevant for quick and precise measurements. Anthropometric data are also essential in developing ergonomic interventions in workplace settings, particularly in remote and industrial environments, where mismatches between workstations and body dimensions contribute to musculoskeletal disorders. Furthermore, inclusive design based on anthropometric data plays a pivotal role in creating safe and accessible public spaces and products for children, elderly individuals, and diverse populations. The review emphasizes the need for population-specific data to ensure ergonomic designs accommodate regional differences in body dimensions. Technological innovations such as AI-driven predictive models and dynamic human modeling are identified as future directions that will further refine the integration of anthropometry into ergonomic practices. Despite advancements, challenges related to measurement variability and the lack of international standardization persist. This review underscores the growing importance of anthropometric research in developing ergonomic solutions that enhance comfort, safety, and productivity.

Keywords: anthropometry, ergonomic design, inclusive design, musculoskeletal disorders, 3D body scanning, workplace ergonomics, product development

1. INTRODUCTION

Anthropometry plays a critical role in ergonomics by providing essential data on human body measurements that inform the design of tools, workspaces, and equipment to fit a diverse population. In recent years, several studies have contributed to the growing body of knowledge on how anthropometric data can be utilized to enhance ergonomic practices. These advances are significant because they allow for more personalized and precise solutions in diverse industries ranging from healthcare to industrial design. The goal of this review is to examine recent research trends in anthropometry and their applications in ergonomic design, with an emphasis on various sectors such as workplace safety, public spaces, and product development.

One of the foundational studies on anthropometry in ergonomic research was conducted by Kılıç et al. (2023), which explored the accuracy of self-reported anthropometric data, specifically stature and body mass. The study revealed that participants tended to overreport their height by an average of 1.31 cm while underreporting their body mass by 1.45 kg, particularly among

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individuals with a body mass index (BMI) greater than or equal to 25. This discrepancy highlights the challenges researchers face when relying on self-reported data, especially in studies where precise measurements are critical for ergonomic applications. The authors proposed two models to adjust for these inaccuracies, offering a solution for future research that relies on self-reported anthropometric data for recruitment or survey purposes. These adjustments are essential for ensuring the validity of ergonomic designs, which must accurately reflect the true dimensions of the population being studied.

Workplace safety is another area where anthropometric data has proven invaluable, particularly in assessing the risk of work-related musculoskeletal disorders (WMSDs). Onofrejova et al. (2024) conducted a study that compared ergonomic risk assessment methods in Slovakia, focusing on compliance with both European Union (EU) and Slovak standards. The study utilized a Captiv wireless sensory system to gather data on postures and movements at a car headlight quality control assembly workplace. The research uncovered differences in the thresholds for hazardous postures across various standards, which affected the final evaluation of ergonomic risks. This finding underscores the need for uniform standards in ergonomic risk assessment, as inconsistent regulations can lead to varied assessments of safety and risk across different regions. The study's contribution to the development of more reliable and standardized methods for ergonomic risk assessment can help improve workplace safety and reduce the incidence of WMSDs.

Remote work, which has surged in popularity due to the COVID-19 pandemic, has also become a focus for ergonomic studies. Baguio et al. (2023) examined the workstations of work-from-home call center agents in Cordova, Cebu, using the Rapid Office Strain Assessment (ROSA) tool. The researchers found that the workstations posed significant ergonomic risks, with a ROSA mean score of 5.54, particularly in the area of seating. To address this, they proposed an ergonomic chair design based on anthropometric measurements, which significantly reduced the ergonomic risks post-intervention. This study emphasizes the importance of ergonomic interventions in non-traditional work environments, where employees may not have access to the same ergonomic standards found in office settings. The proposed ergonomic designs based on anthropometric data helped alleviate physical strain and lower the risk of musculoskeletal issues among the participants, demonstrating the value of incorporating anthropometric data into workplace designs even in remote work contexts.

Public spaces are another domain where anthropometry plays a crucial role. Celik et al. (2024) explored the relationship between children's ergonomics and public space design in two districts of Istanbul, comparing neighborhoods with different socio-demographic characteristics. By integrating demographic data with anthropometric measurements of children aged 7 to 11, the researchers provided insights into how public spaces can be designed to be more inclusive for children from various backgrounds. This research highlights the need for public spaces to be designed using anthropometric data that reflects the diversity of the population, ensuring that these spaces are accessible and comfortable for all users, regardless of their body size or shape. The use of anthropometry in this context ensures that public spaces are both functional and inclusive, accommodating the needs of different demographic groups.

Product design is another area where anthropometric data is increasingly being applied. Govindaraj and Sudheep (2024) developed a noseless bicycle saddle with a backrest using anthropometric measurements to address issues such as perineal pressure and low back pain among cyclists. The researchers used human body dimensions to design a seat that reduces anterior stress by 24.5 kPa compared to a traditional saddle, thus improving comfort and reducing health risks. Similarly, Sejdiu et al. (2024) measured the body dimensions of children aged 6 to 11 to assist furniture designers in creating ergonomic furniture. By understanding the proportions between stature and various body parts, furniture designers can create products that are better suited to the physical needs of children. These studies demonstrate how

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anthropometry can be used to develop ergonomic products that not only improve user comfort but also reduce the risk of injury.

In addition to product design, hand anthropometry has been the focus of several recent studies. Filho et al. (2024) compared different methods of measuring hand dimensions, including traditional anthropometric tools and modern 2D and 3D scanners. While scanners offer technological advancements, the study found that traditional methods provided more accurate and time-efficient measurements. This finding is significant for industries that require precise hand measurements, such as the design of hand tools, gloves, and medical devices. By selecting the most appropriate anthropometric method, designers can ensure that their products are both safe and effective for a wide range of users.

The use of anthropometry in ergonomic design is not without its challenges, particularly when it comes to variability across different populations. Zhang et al. (2023) analyzed body types and sizes across various countries, finding significant differences between the sizing standards used in the United States, Europe, China, and Japan. This study highlights the importance of considering regional variations in body dimensions when designing ergonomic products that are intended for international markets. A one-size-fits-all approach is unlikely to succeed, as different populations have distinct anthropometric characteristics that must be accounted for in product design.

2. Anthropometric Data Collection and Accuracy

Recent advancements in anthropometric data collection have significantly impacted ergonomic design, particularly in addressing the challenges related to the accuracy of self-reported data and the technological evolution in measurement tools. Anthropometric data, essential for the ergonomic optimization of workspaces and product designs, have traditionally been collected through various methods that vary in precision. However, two key issues dominate this domain: the reliability of self-reported anthropometric data and the advancements in measurement technologies, such as scanners and sensors.

Self-reported anthropometric data is often employed in large-scale studies due to its convenience and cost-effectiveness. However, several studies have identified significant discrepancies between self-reported measurements and actual anthropometric data. For instance, Kılıç et al. (2023) highlighted the inaccuracies in self-reported stature and body mass in their study on participants in the Netherlands. Their findings revealed that participants generally overestimated their height by an average of 1.31 cm and underestimated their body mass by 1.45 kg. This misreporting was particularly notable among individuals with a BMI greater than 25, which can lead to skewed data in ergonomic research. Such inaccuracies are critical as they affect the validity of ergonomic assessments, particularly in workplace design, furniture, and safety equipment development. The study proposed models to adjust self-reported data, thereby enhancing its utility for ergonomic researchers. These correction models offer a practical solution to mitigate errors in studies relying on self-reported data, but they also underscore the need for more precise methods of anthropometric measurement.

The limitations of self-reported data have further driven the demand for technological advancements in anthropometric measurement. Traditional tools, such as anthropometers and tapes, have long been used to measure human body dimensions. However, the increasing availability of advanced technologies, such as 3D and 2D scanners, has revolutionized the field by offering more precise and comprehensive data collection. Filho et al. (2024) compared various anthropometric tools, including anthropometers, 2D scanners, and 3D scanners, in their study on hand measurements. Their research demonstrated that while scanners offer a technological advantage, traditional direct measurement tools, like anthropometers, still provide higher accuracy and faster results. The study emphasized that scanners, though innovative, involve time-

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consuming processes of scanning, digitalization, and calibration, making them less practical for large-scale studies or situations where quick results are needed. This finding suggests that while technological advancements hold promise, the choice of measurement tool must be carefully considered based on the context, as high-tech solutions do not always surpass traditional methods in terms of practicality and efficiency.

The field of ergonomic design has also seen notable improvements in measurement techniques through the integration of sensors and digital tools. Hasanuddin et al. (2024) explored the use of anthropometric data in the design of electric vehicles in Indonesia, focusing on how anthropometric dimensions of the population could be leveraged to improve the design of bus feeders. By utilizing a combination of anthropometric databases and real-world observation, the study recommended specific anthropometric dimensions that should be considered in vehicle design to optimize comfort and safety for both drivers and passengers. This research exemplifies the growing trend of combining anthropometric data with ergonomic principles to enhance product designs that cater to the specific needs of target populations. The use of sensors in this study also illustrates how technological advancements can supplement anthropometric data collection, allowing for more detailed analysis of human interaction with vehicles.

In addition to vehicle design, wearable technologies have emerged as valuable tools in improving workplace ergonomics. Tetteh et al. (2023) examined the application of passive upper extremity exoskeletons as ergonomic interventions for cardiovascular sonographers. The study aimed to reduce the muscle workload of sonographers during transthoracic echocardiograms by utilizing two types of exoskeletons. The exoskeletons were designed to provide postural support and reduce muscle strain in the upper trapezius muscles. However, the study revealed mixed results, with only one of the exoskeleton designs demonstrating a significant reduction in muscle activity, while both designs faced challenges related to comfort and range of motion. This suggests that while wearable devices can potentially improve ergonomics by reducing physical strain, their effectiveness heavily depends on the design's alignment with human anthropometry and task-specific requirements. Moreover, the use of wearable sensors allowed the researchers to gather precise data on muscle activity and posture, illustrating how modern sensor technology can facilitate more detailed ergonomic assessments.

A similar emphasis on improving ergonomic design through anthropometric data can be found in the research of Dal Maso and Cosmi (2024), which focused on developing a population-specific ergonomic design for medical devices. By collecting detailed surface and bone anthropometric data from radiographs of Italian women, the study aimed to improve the design of hand supports. The authors compared traditional anthropometric measurements with the newer approach proposed by Kong et al., validating the accuracy and precision of their methods. Their findings highlighted the importance of tailoring ergonomic designs to specific population groups to ensure that products meet the unique needs of their users. This study underscores the potential of combining traditional anthropometric techniques with advanced technologies like 3D modeling to create more customized ergonomic solutions.

Technological advancements in anthropometry have also been applied in fields beyond industrial and medical design. Molina Aragonés et al. (2023) conducted a study that evaluated ergonomic measures in office workstations, focusing on low back pain among office workers. The research aimed to assess the relationship between ergonomic factors in the workplace and musculoskeletal disorders. Although the study found no significant association between specific ergonomic measures and the prevalence of low back pain, it reinforced the importance of considering both anthropometric and ergonomic factors when designing workspaces. The study highlighted the need for more precise and individualized ergonomic interventions, suggesting that generalized approaches may not be effective in addressing musculoskeletal issues in the workplace.

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3. Applications of Anthropometry in Ergonomic Risk Assessment

The integration of anthropometric data into ergonomic risk assessments has been instrumental in identifying and mitigating ergonomic risks in workplace environments. Several studies have underscored the significance of precise anthropometric measurements for the development of ergonomic solutions in various work settings, including industrial environments and remote workstations. The application of anthropometry in these contexts has provided valuable insights into how physical dimensions and workplace design affect the physical load experienced by workers and has led to the development of ergonomic strategies to reduce the risk of musculoskeletal disorders (MSDs).

In industrial settings, the relationship between anthropometric data and physical workload is particularly pronounced. Acar et al. (2023) conducted a study on primary school furniture design, utilizing computer-aided ergonomic analysis to assess the mismatch between students' anthropometry and existing school furniture dimensions. While the study focused on educational environments, the implications are relevant to industrial settings, as it highlights how ergonomic mismatches between human dimensions and workspace components can lead to increased physical strain. The use of motion capture technology and musculoskeletal modeling in this study allowed for the assessment of joint reaction forces and muscle activations, providing a detailed analysis of how even small discrepancies in furniture design can affect the physical load on users. In industrial environments, similar mismatches between worker anthropometry and workspace design can result in increased strain on muscles and joints, leading to a higher risk of MSDs. The study's findings emphasize the need for ergonomic designs that account for anthropometric data to minimize physical load and improve comfort and productivity.

The use of anthropometric data in ergonomic risk assessments has also extended to the evaluation of workstation risks in remote work settings, particularly in the context of remote office environments. Remote work has become increasingly common, especially following the COVID-19 pandemic, and the shift to home-based work has introduced new ergonomic challenges. One tool that has been used to assess ergonomic risks in remote work environments is the Rapid Office Strain Assessment (ROSA). ROSA is a screening tool designed to assess the risk of musculoskeletal strain based on various workstation factors, including chair, monitor, and keyboard placement, as well as the anthropometric fit of the workstation to the user. Febrianto et al. (2023) utilized ROSA to evaluate ergonomic risks in temporary storage stations, which involved repetitive tasks and poor body posture, similar to the ergonomic risks encountered in remote workstations. The study found that ergonomic interventions were necessary to address the high risk of MSDs identified through ROSA, highlighting the importance of ergonomic workstation design in both industrial and remote work settings.

The role of anthropometric data in ergonomic risk assessments is further emphasized in studies that focus on reducing MSDs through workspace redesign. Joshi and Deshpande (2023) explored ergonomic interventions in an automotive reconditioning workshop, where workers were engaged in manual lapping activities. The study identified a high prevalence of MSDs among workers due to poorly designed workstations that did not account for worker anthropometry. By reshaping the workstations using ergonomic principles based on anthropometric data, the study demonstrated significant reductions in the ergonomic risk associated with the manual lapping tasks. The use of anthropometric data in this context allowed for the optimization of workstation dimensions, resulting in reduced physical strain on workers and improved productivity.

Similarly, Sharma et al. (2023) conducted an ergonomic assessment of kitchen countertops in Indian households, focusing on optimizing countertop dimensions based on local anthropometric data. The study used a virtual environment to simulate postural responses to different countertop heights and depths and validated the findings with real-world participants. By using

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anthropometric data to design kitchen workspaces, the study was able to reduce the physical strain experienced by users, particularly in the lower back and upper limbs. This approach to ergonomic design, which integrates anthropometric data into the optimization of workspace dimensions, is directly applicable to both industrial and remote work environments, where poorly designed workstations can lead to increased risk of MSDs.

The importance of anthropometric data in ergonomic risk assessments is further demonstrated in studies that focus on the specific physical demands of remote work. Remote office workers, such as call center agents, often experience prolonged sitting and repetitive tasks, which can contribute to the development of MSDs. The use of anthropometric data to assess the ergonomic fit of remote workstations is crucial for minimizing these risks. Napper et al. (2023) conducted a systematic review of sex differences in wrist strength, highlighting the need for ergonomic interventions that account for anthropometric differences between male and female workers. The study found that female workers, on average, exhibited lower wrist strength than male workers, which has implications for the design of remote workstations, particularly in tasks that involve prolonged keyboard use. By incorporating anthropometric data into ergonomic risk assessments, it is possible to design workstations that are better suited to the physical capabilities of remote workers, reducing the risk of strain and injury.

4. ANTHROPOMETRY AND INCLUSIVE DESIGN

Recent advances in anthropometry have significantly contributed to inclusive design practices, particularly in public space planning and furniture design for children. One of the primary objectives of applying anthropometric data to ergonomic design is to create spaces and products that cater to the diverse needs of users, ensuring accessibility, safety, and comfort across demographic groups, including children. The careful use of anthropometric measurements has enabled designers to accommodate variations in human body dimensions due to age, gender, and other factors, thereby promoting inclusivity in design.

Designing public spaces for children requires a nuanced understanding of anthropometric data to ensure safety and usability. Public spaces, such as playgrounds, schools, and parks, need to account for the unique proportions of children's bodies to prevent accidents and support healthy physical development. Sejri (2023) underscores how ergonomic considerations, particularly concerning posture and repetitive gestures, play a pivotal role in designing safe and efficient environments. Although the study focuses on industrial settings, the principles of posture analysis and anthropometric alignment can be extended to public space design for children. The Key Indicator Method (KIM) used to assess ergonomic risks in industrial settings can be adapted to evaluate the ergonomic safety of public spaces, ensuring that playground equipment, seating, and pathways are appropriately scaled for children's dimensions.

Moreover, ergonomic design in public spaces must account for dynamic interactions, as children are often engaged in physical activities that involve running, climbing, and jumping. Goleij et al. (2024) highlight the importance of regular updates to anthropometric databases, as human body dimensions have evolved over time. The same rationale applies to the design of public spaces, where outdated anthropometric data may lead to mismatches between the environment and its users. By utilizing contemporary anthropometric data, designers can ensure that public spaces are better suited to the current physical characteristics of children, thus enhancing inclusivity and safety.

In the context of furniture design for children, anthropometric measurements are equally critical. Furniture, such as school desks and chairs, must be designed to fit children's body proportions to promote good posture and reduce the risk of musculoskeletal disorders. Acar et al. (2023) conducted a study on the ergonomic alignment of school furniture with the anthropometric data

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of primary school students, revealing significant mismatches between existing furniture dimensions and students' body proportions. The study found that 80% of seat heights and 96% of desk heights were too high for the students, leading to increased joint stress and muscle strain. This finding underscores the importance of using precise anthropometric data to design ergonomic furniture that accommodates children's physical characteristics.

Furniture designed without proper consideration of anthropometric data can lead to long-term health issues for children, including back pain and postural problems. Shourie et al. (2024) conducted a randomized controlled trial that demonstrated how poor ergonomic design in schools could contribute to musculoskeletal disorders in children. The study's findings highlighted the effectiveness of exercise therapy in mitigating these disorders, but also pointed to the need for preventive measures, such as ergonomically designed furniture. By ensuring that desks and chairs are appropriately sized for children's dimensions, designers can reduce the risk of musculoskeletal strain and promote better postural habits.

The ergonomic design of furniture for children must also account for the varying proportions of different body parts. For instance, Du et al. (2023) explored the ergonomic design of laparoscopic instrument handles based on three-dimensional anthropometry of hand dimensions. While the study focused on medical tools, the methodology of using 3D anthropometric data to optimize design can be applied to furniture design for children. By analyzing the proportions of children's hands, arms, and torsos, designers can create furniture that supports natural movements and reduces the physical strain associated with prolonged sitting or writing.

Inclusive design practices that incorporate anthropometric data are essential not only for addressing immediate physical comfort but also for fostering long-term health and development in children. Goleij et al. (2024) emphasize the need for regularly updated anthropometric data to reflect changes in human dimensions over time. This is particularly relevant for children, whose bodies are constantly growing and changing. Without up-to-date data, furniture and public spaces designed for children may become misaligned with their physical needs, leading to discomfort and potential health risks.

Inclusive design is not limited to physical dimensions but also encompasses demographic variables such as age, gender, and cultural differences. For example, Başıbüyük et al. (2024) conducted a study on the ergonomic design of bathrooms and toilets for older adults, which highlighted the need for inclusive design solutions that cater to specific demographic groups. While the study focused on older adults, the principles of inclusive design based on anthropometric data can be applied to children as well. By considering the unique needs of different demographic groups, designers can create environments that are accessible and comfortable for all users, regardless of age or physical ability.

5. ERGONOMIC PRODUCT DEVELOPMENT USING ANTHROPOMETRY

Recent developments in ergonomic product design have benefited greatly from advances in anthropometric research. Anthropometry, which involves the measurement of the human body and its proportions, plays a crucial role in ensuring that products fit well with the physical characteristics of their users. This is especially important in designing products for specific groups, such as protective clothing, medical devices, and work tools, as it helps to reduce discomfort, improve usability, and mitigate the risk of musculoskeletal disorders (MSDs). Numerous case studies have demonstrated how anthropometric fit tests are used to develop ergonomic products that meet the needs of diverse populations.

One notable example is the dataset provided by Rababah and Etier (2024), which focused on the anthropometric measurements of children in Jordan. The data collected from 354 children were

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crucial for designing ergonomic products like furniture, tools, and toys specifically for children. The dataset's insights into stature, sitting height, knee height, and other body dimensions supported the development of ergonomic products tailored to this demographic. By incorporating anthropometric measurements, designers were able to create products that aligned better with children's physical requirements, enhancing both safety and comfort. Similar initiatives have been seen in other regions, where local anthropometric data are used to improve the design of protective equipment, medical devices, and work tools.

Innovations in medical device design also rely heavily on anthropometric research. Malhotra et al. (2024) discussed the application of hand anthropometry in designing mobile phones that are user-friendly. By considering dimensions such as hand size, finger length, and hand mobility, designers were able to create devices that catered to a wide range of users, ensuring accessibility and comfort. This approach highlights how anthropometric data can be used to improve both the usability and safety of products. Similar methods are used in the design of medical devices, where fit tests ensure that tools like laparoscopic instruments are ergonomically suited to the hands of surgeons. Tsumanuma et al. (2024) examined the effect of laparoscopic handle size on surgical performance, showing how hand surface area and handle size influenced task execution. The study demonstrated that anthropometric fit is critical in enhancing both performance and comfort during complex tasks.

In the realm of protective clothing, Alemany et al. (2023) introduced advanced processing of 4D body scanning technology to improve ergonomic design. This technology allows for a detailed analysis of the human body in motion, providing valuable data that can be used to develop protective clothing that fits well and offers better protection. Traditional static anthropometric data were expanded through the use of 3D and 4D body scanning, allowing for the creation of dynamic, form-fitting protective gear. By integrating these advanced scanning techniques, designers were able to develop clothing that is both functional and comfortable, reducing the likelihood of injury and discomfort.

Ergonomic seating designs have also undergone significant innovation, largely due to the application of anthropometric data. Scott et al. (2023) explored how anthropometric characteristics, such as body mass index (BMI) and wrist circumference, affect the comfort and usability of seating arrangements. Their research indicated that seating designs need to account for the variations in body dimensions to provide adequate support and minimize discomfort. Moreover, Sharma et al. (2024) conducted a study on how vibrations affect human subjects with different masses and body dimensions, emphasizing the need for seating solutions that reduce vibration transmission. By using anthropometric data, manufacturers have been able to develop vibration-reducing seats, such as noseless bicycle saddles, that help to alleviate discomfort and prevent long-term injuries.

In terms of work tools, ergonomic evaluations of various industries have revealed the importance of anthropometric fit in reducing MSDs. Bhore et al. (2024) conducted an ergonomic evaluation of gemstone polishing workstations, which were redesigned based on anthropometric data. The study used the Rapid Upper Limb Assessment (RULA) to analyze workstation design, revealing that the original workstations contributed to significant discomfort and injury risk among workers. By redesigning the workstations to fit the anthropometric dimensions of the workers, the researchers were able to reduce the RULA score, indicating a lower risk of MSDs. This case study highlights how anthropometric data can be used to redesign work tools and environments to better fit the physical characteristics of users.

Anthropometric data also play a vital role in developing ergonomic seating for specific populations, such as drivers and workers in high-risk industries. Kumar et al. (2023) examined the ergonomic and anthropometric evaluation of locally manufactured vehicle seats in Ethiopia, where the mismatch between seat dimensions and passengers' body proportions led to

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significant discomfort. The study recommended that vehicle seats be redesigned using local anthropometric data to improve comfort and reduce the risk of MSDs. Similarly, Spasojević Brkić et al. (2024) evaluated transport and mining machinery cabins, recommending ergonomic redesigns based on anthropometric data. By considering the physical characteristics of machine operators, the researchers were able to propose modifications that improved comfort and safety in high-risk environments.

6. CHALLENGES AND LIMITATIONS IN ANTHROPOMETRIC RESEARCH

Recent advances in anthropometric research have contributed significantly to ergonomic design across various fields. However, several challenges and limitations still hinder the full application of anthropometric data in product development. These challenges often arise due to the variability across populations and the limitations in measurement techniques. Understanding these complexities is essential to ensure that anthropometric data are used effectively and appropriately in design processes.

One of the main challenges in anthropometric research is the variability of body measurements across different populations. Gender, ethnicity, and nationality significantly impact body proportions, making it difficult to apply a single anthropometric dataset universally. This variability is evident in several studies, such as the work of C.R et al. (2023), who designed an exoskeleton for lower extremities based on Indian anthropomorphism. Their research demonstrated how anthropometric dimensions in India differ from global averages, emphasizing the need to develop region-specific ergonomic solutions. Rajakumaran and Sreenivas (2024) also highlighted similar findings in the design of car door opening angles, where anthropometric data from different populations were used to balance ergonomic performance between entry and exit accommodation. These studies illustrate the importance of considering population-specific anthropometric data in design to avoid discomfort or inefficiencies caused by mismatches in body proportions.

The use of digital human models (DHM) in product design and evaluation also reveals the challenges associated with anthropometric variability. Ackermann and Wischniewski (2023) explored how weighting algorithms are used to generate representative digital human models by adjusting for population differences. They compared algorithms like one nearest neighbor (1NN) and iterative proportional fitting (IPF), which are used to address the lack of representative datasets for different populations. Their findings suggest that while these algorithms help generate useful models, there are still limitations in accurately representing extreme percentiles or multivariate evaluations. This further underscores the difficulties faced in using a standard anthropometric dataset across diverse populations, reinforcing the need for region-specific and contextually relevant data.

The second major challenge in anthropometric research lies in the limitations of measurement techniques. Anthropometric data collection traditionally relied on manual measurements, but advances in technology have introduced new methods, such as 2D and 3D body scanning. While these techniques offer more detailed and precise data, they also come with trade-offs in terms of cost, time, and accuracy. Tian et al. (2024) provided insights into the use of 3D scanning for custom-fit eyewear, showing how the method improves the fit and comfort of wearable products. However, the study also highlighted the cost and complexity associated with 3D scanning, which limits its widespread adoption in mass product design. Similarly, Osman Zahid and Abd Aziz (2024) focused on the ergonomic design of a shoe rack using anthropometric data from Malaysian users. Their research emphasized the benefits of incorporating 3D scanning but also pointed out that the technique requires substantial resources and technical expertise, making it less feasible for small-scale or less developed markets.

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Comparing 2D and 3D scanning methods reveals further limitations. 2D scanning, while more affordable and faster, provides less detailed data, making it less suitable for products that require precise fitting or customization. On the other hand, 3D scanning offers comprehensive data, including body contours and postural details, but it is more expensive and time-consuming. Studies such as those by Szkudlarek et al. (2023) used 3D scanning to calculate dimensional allowances for personal protective equipment (PPE), demonstrating the method's effectiveness in generating detailed measurements. However, they also acknowledged that the complexity of 3D scanning can be a barrier for industries that require quick and cost-effective solutions. This trade-off between cost and accuracy is a recurring issue in anthropometric research, where designers must balance the need for precision with the practical constraints of production.

Another limitation in current measurement techniques involves the processing and interpretation of data. Hislop et al. (2023) conducted a systematic review to analyze how tool usability in traditional laparoscopic surgery is impacted by surgeon anthropometry. Their review revealed that while anthropometric data can improve tool design, inconsistencies in measurement techniques and data processing often limit its practical application. For example, surgeons with smaller hand sizes faced more discomfort and difficulty using standard laparoscopic tools. This points to the necessity of refining anthropometric data collection methods to ensure that they can be effectively translated into ergonomic design improvements.
Despite these challenges, there are ongoing efforts to address the limitations in anthropometric research. Advances in digital modeling and machine learning offer potential solutions to the variability and measurement issues. Russwinkel et al. (2023) proposed a holistic approach to ergonomic work design that integrates both physical and cognitive digital human models. This method aims to provide a more comprehensive understanding of how anthropometric data can be applied to product and work system design. By incorporating cognitive aspects alongside physical dimensions, this approach helps to overcome some of the limitations of traditional anthropometric measurements, particularly in assessing dynamic tasks and environments.

7. FUTURE DIRECTIONS IN ANTHROPOMETRY AND ERGONOMICS

Future directions in anthropometry and ergonomics are increasingly focused on the integration of advanced technologies, particularly artificial intelligence (AI) and machine learning, which have the potential to revolutionize the field. One key area of interest is the use of AI for modeling anthropometric data, enabling predictive design processes that can adapt to individual user needs. This approach facilitates the development of more ergonomic products and work environments. Škorvánková et al. (2022) explored deep learning methods for estimating anthropometric measurements from visual data, illustrating how AI can overcome limitations in traditional measurement techniques. The ability to generate accurate models from 2D or 3D images offers significant benefits in fields like garment manufacturing and ergonomic assessment, where precision and adaptability are crucial.

AI's role in ergonomic risk assessment is also becoming more prominent. Chan et al. (2022) conducted a scoping review on machine learning applications in preventing work-related musculoskeletal disorders (WMSDs). Their findings showed that AI techniques could help identify risk factors and develop interventions, streamlining the ergonomic design process. The use of AI in this context allows for more dynamic and responsive design adjustments, making workplaces safer and more efficient. This integration of AI into ergonomic risk assessment represents a shift toward more data-driven and predictive approaches, allowing for more personalized and accurate design solutions.

International standardization is another emerging trend in anthropometry and ergonomics. As industries become more globalized, there is an increasing need for standardized methods of ergonomic risk assessment that can be applied across different regions and populations. Fidelis

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and Ogunlade (2022) emphasized the importance of standards in classroom furniture design, noting that a lack of international guidelines has led to significant mismatches between furniture dimensions and user anthropometry in Nigerian schools. This highlights the need for global standards that take into account regional differences in body dimensions while ensuring consistency in ergonomic design practices.

In the automotive industry, Bubb et al. (2021) pointed to the growing importance of ergonomic considerations in vehicle design, where international collaboration and standardization can help ensure that products meet the needs of diverse populations. The use of digital human models (DHMs) is one approach that can bridge this gap by providing a virtual testing environment that simulates the interaction between humans and machines. These models can incorporate anthropometric data from different regions, allowing designers to create more universally applicable products while maintaining ergonomic standards.

The future impact of anthropometric data on ergonomic design innovations is significant. As AI and machine learning continue to advance, these technologies will enable more accurate and individualized ergonomic solutions. For example, O'Sullivan et al. (2022) developed models that estimate maximum joint torques based on anthropometric data, which can be used to enhance the design of tools and workstations in various industries. These models allow for the rapid estimation of ergonomic parameters, making it easier to create products that reduce the risk of musculoskeletal disorders and improve user comfort.

Another potential area for future innovation lies in the design of ergonomic workspaces and environments. Abbas et al. (2022) introduced an innovative dynamic examination table that adjusts based on user anthropometry, addressing the ergonomic needs of both patients and healthcare workers. This type of adaptive design could be extended to other industries, where workspaces could be automatically adjusted to fit the user’s body dimensions, enhancing comfort and reducing the risk of injury. The development of such products reflects the growing emphasis on using anthropometric data to create more flexible and responsive work environments.

In terms of industry-specific applications, the use of anthropometric data in furniture design is likely to see further advancements. Silviana et al. (2022) highlighted the importance of using anthropometric measurements in designing ergonomic furniture, particularly in office environments where workers spend long hours seated. The authors stressed that ergonomic furniture can improve employee productivity and reduce the incidence of musculoskeletal disorders, which has direct benefits for both workers and employers. By incorporating anthropometric data into the design process, companies can create more comfortable and efficient work environments, leading to long-term health and economic benefits.

8. CONCLUSION

The review of recent advancements in anthropometric research highlights the critical role this field plays in ergonomic design across various industries. The key findings underscore the importance of accurate anthropometric data collection methods, such as the integration of advanced technologies like 3D scanning and artificial intelligence, which offer greater precision and adaptability. These technological advancements have enabled more personalized and effective ergonomic solutions, which are particularly beneficial in product development, workplace design, and public space planning. However, the review also points out the limitations of self-reported anthropometric data and the challenges associated with applying universal anthropometric standards across diverse populations. The studies discussed in this review emphasize the importance of tailoring ergonomic designs to specific populations, taking into account variations in body dimensions due to factors such as age, gender, and region. For instance, ergonomic interventions in workplace settings, including both traditional and remote

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work environments, have demonstrated how customized designs based on accurate anthropometric measurements can reduce the risk of musculoskeletal disorders and improve overall comfort and productivity. The application of anthropometric data in public spaces and product design for children also illustrates how inclusive design can enhance safety and usability for a diverse range of users. Future directions in anthropometry and ergonomics are likely to focus on the continued integration of AI and machine learning, which hold great potential for predictive design and more sophisticated ergonomic risk assessments. Moreover, the global standardization of anthropometric data collection and application is crucial for ensuring consistency and improving ergonomic practices across different regions and industries. Addressing these gaps will require ongoing research to refine measurement techniques and ensure that ergonomic designs continue to evolve in response to the changing needs of populations. In conclusion, the advancements in anthropometric research have significantly contributed to improving ergonomic design practices. By leveraging emerging technologies and emphasizing the need for population-specific data, the field is well-positioned to continue making meaningful contributions to safety, comfort, and productivity in diverse settings. However, the challenges associated with data variability and the need for standardized approaches highlight the importance of sustained research efforts to enhance the efficacy of ergonomic designs.

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