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Development of an anthropometry-based ergonomic automatic bike design for children with cerebral palsy

Nilma Zola[1], **Annisa Annisa**[2], **Dally Rahman**[3*)]
[1]Universitas Negeri Padang, Padang, Indonesia
[2]Special Education, Faculty of Social and Business, Universitas Mercubaktijaya, Padang, Indonesia
[3]Department of Medical-Surgical Nursing and Emergency Nursing, Faculty of Nursing, Universitas Andalas, Padang, Indonesia

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ABSTRACT

This study aimed to develop and validate an anthropometry-based ergonomic Automatic Bike design to support safe and comfortable motor training for children with cerebral palsy who use wheelchairs. A Design and Development Research (DDR) approach was employed involving three purposively selected participants. The study included user needs analysis, anthropometric measurements, ergonomic design development, and expert validation by engineering and special education specialists. User-centered anthropometric data were translated into ergonomic design specifications, producing an adjustable Automatic Bike that accommodates users' physical characteristics. Expert validation yielded an overall mean score of 2.79/3.00, indicating high feasibility in terms of ergonomics, safety, functionality, and usability. The validated design provides a promising foundation for prototype development and future user-based evaluation of assistive cycling technology for children with cerebral palsy.

Corresponding Author:

Dally Rahman,
Andalas University
Email: dallyrahman@nrs.unand.ac.id

Introduction

Children with cerebral palsy (CP) experience permanent disorders of movement and posture caused by disturbances in the developing brain, frequently accompanied by sensory, perceptual, communication, and functional limitations that reduce independence in daily activities (Bax et al., 2005; Rosenbaum et al., 2007). Continuous motor training is therefore essential to maintain physical function, improve mobility, and support long-term participation in daily life (Damiano, 2006; Novak et al., 2020). However, the implementation of regular rehabilitation remains challenging because therapeutic activities generally depend on continuous assistance from physiotherapists, teachers, or family members. This dependency often limits the frequency and continuity of training while increasing rehabilitation costs, resulting in insufficient opportunities for children to develop their motor abilities (Sakzewski et al., 2014; Palisano et al., 2012; Gannotti et al., 2014). These limitations highlight the need for assistive technologies that enable safer and more independent motor training.

Cycling has been recognized as an effective therapeutic intervention for children with cerebral palsy because it improves lower-limb strength, motor coordination, balance, cardiovascular endurance, and functional mobility while increasing motivation to participate in rehabilitation programs (Chen et al., 2012; Fowler et al., 2010; Williams & Pountney, 2007; Armstrong et al., 2019). Nevertheless, most conventional bicycles and many adaptive cycling devices are designed using generalized dimensions that do not adequately accommodate the diverse anthropometric characteristics and motor limitations of children with cerebral palsy. As a result, users frequently experience poor sitting posture, limited pedal reach, discomfort, and reduced training effectiveness, indicating that current assistive cycling devices have not fully addressed individual ergonomic requirements (Cook & Polgar, 2015; Pheasant & Haslegrave, 2018; Sanders & McCormick, 1993).

Ergonomic product development requires compatibility between product dimensions and users' physical characteristics to improve comfort, safety, and usability (Bridger, 2018; Kroemer & Grandjean, 2009). Anthropometric approaches provide objective body-dimension data that enable designers to determine appropriate seat dimensions, pedal positions, handgrip locations, and supporting structures according to users' body measurements (Helander, 2006; Pheasant & Haslegrave, 2018). Previous studies have consistently demonstrated that anthropometry-based design improves ergonomic performance and reduces the risk of discomfort and injury during product use (Bridger, 2018; Kroemer & Grandjean, 2009). Despite these advantages, the application of anthropometric principles in developing adaptive cycling devices specifically for wheelchair-using children with cerebral palsy remains limited.

This limitation represents an important research gap because children with cerebral palsy exhibit considerable variations in body height, pelvic width, lower-limb length, sitting posture, and motor control, all of which directly influence the effectiveness of rehabilitation equipment. Existing adaptive bicycles primarily emphasize additional supporting components, such as safety belts and body stabilizers, while giving limited attention to individualized ergonomic dimensions derived from users' anthropometric characteristics (Cook & Polgar, 2015; Bridger, 2018). Consequently, there remains a need to develop an assistive cycling device that integrates user needs analysis with anthropometric measurements to produce a safer, more comfortable, and more accessible design for motor training (Liu et al., 2005; Rakhmaeva & Kamalova, 2026; Tomoum et al., 2010).

Based on these considerations, this study develops an anthropometry-based ergonomic Automatic Bike specifically designed for wheelchair-using children with cerebral palsy. Unlike previous studies that mainly focused on adaptive features, the present study integrates user needs analysis and anthropometric measurements as the primary basis for determining the ergonomic dimensions of the device (Bell et al., 2020; Grammatikopoulou et al., 2009; Hildreth et al., 1997; Mokhy et al., 2020). This user-centered design is expected to provide a more appropriate assistive technology for motor training while establishing an evidence-based foundation for future prototype development and rehabilitation technology research.

Method

This study employed a Design and Development Research (DDR) approach to develop an anthropometry-based ergonomic Automatic Bike for children with cerebral palsy. The research followed four systematic stages: (1) user needs analysis, (2) anthropometric data collection, (3) ergonomic design development, and (4) expert validation (Richey & Klein, 2007; Ellis & Levy, 2010; Richey & Klein, 2014). The study was conducted at the Rumah Gadang Cerebral Palsy Foundation, Padang, Indonesia, involving three wheelchair-using children with cerebral palsy selected through purposive sampling. Participants were selected because they met the inclusion criteria of being able to participate in anthropometric measurements and representing the intended users of the proposed device. User needs were identified through observations of motor-training activities and semi-structured interviews with parents and caregivers to determine the functional, safety, comfort, and accessibility requirements of the Automatic Bike (Creswell & Creswell, 2018; Sugiyono, 2022; Branch, 2009; Brown & Green, 2020).

Anthropometric measurements were subsequently performed using standardized measuring instruments while participants were seated in their wheelchairs to ensure consistency and measurement accuracy. The measured variables included sitting height, shoulder width, pelvic width, thigh length, lower-leg length, sitting knee height, forward reach distance, wheelchair backrest height, wheelchair width, and the optimal distance between the sitting position and both the hand and foot pedals. These anthropometric data were translated into ergonomic design parameters to determine the dimensions of the main frame, seating system, hand-pedal position, foot-pedal position, and adjustable pedal mechanism. The design was developed into two-dimensional engineering drawings followed by three-dimensional models while incorporating ergonomic principles to ensure compatibility with users' physical characteristics and operational safety (Pheasant & Haslegrave, 2018; Bridger, 2018; Kroemer & Grandjean, 2009; Helander, 2006; Sanders & McCormick, 1993).

The completed design was validated by experts in engineering and special education using a structured validation instrument that assessed ergonomics, safety, functionality, dimensional suitability, usability, and overall feasibility (Tessmer, 1998; Plomp & Nieveen, 2013). Suggestions from the validators were incorporated into the design refinement process to produce the final design. Quantitative data from the validation sheets were analyzed descriptively using mean scores and feasibility categories, whereas qualitative data obtained from expert comments were analyzed through descriptive content analysis to support design revisions and improve product quality (Miles et al., 2014; Creswell & Creswell, 2018).

Results and Discussions

User Needs Analysis

The observational findings conducted at the Rumah Gadang Cerebral Palsy Foundation in Padang revealed that all participants used wheelchairs as their primary mobility devices in daily activities. In addition to serving as mobility aids, wheelchairs functioned as the main platform from which the children participated in educational activities and motor training programs.

Based on interviews with caregivers and parents, motor training activities were largely dependent on assistance from teachers, physiotherapists, or family members. This situation limited the frequency and intensity of training, as exercise sessions depended on the availability of support personnel. Furthermore, no movement-training device was available that enabled children to perform exercises more independently while maintaining adequate levels of safety and comfort.

The needs assessment indicated that the proposed device should be operable directly from the user's wheelchair without requiring transfers to another seat. In addition, the device should provide easily accessible pedal positions, a stable structural framework, and dimensions that correspond to the physical characteristics of the users.

Anthropometric Data as the Basis for Design Development

Anthropometric data collected in this study focused on body dimensions directly related to training activities using the Automatic Bike. The measurements indicated that the average sitting height of the participants while seated in their wheelchairs was approximately 50 cm from the floor surface. These anthropometric measurements were subsequently utilized as the basis for determining the overall height of the device, the positions of the hand and foot pedals, and the dimensions of the supporting frame. The objective was to ensure that users could perform motor training activities in a comfortable and ergonomically appropriate posture.

The findings from the needs analysis and anthropometric measurements were then integrated to formulate the ergonomic design specifications of the Automatic Bike.

Table 1. Ergonomic Specifications of the Automatic Bike

Component	Specification
Overall height of the Automatic Bike	90 cm
Width of the Automatic Bike	40 cm
Length of the Automatic Bike	50 cm
User sitting height	50 cm
Hand pedal height from the floor	90 cm
Foot pedal height from the floor	25 cm
Adjustable foot pedal range	25–50 cm
Distance between hand pedal and foot pedal	65 cm

Based on these specifications, the Automatic Bike was designed to accommodate users while remaining seated in their wheelchairs. The hand pedals were positioned at a height corresponding to the natural arm position of the user during sitting, allowing pedaling activities to be performed more comfortably. Meanwhile, the foot pedals were equipped with an adjustable height mechanism to accommodate variations in physical characteristics and motor abilities among children with cerebral palsy.

Ergonomic Design of the Automatic Bike

The following dimensions should be presented in the figure 1: 1) Overall device height = 90 cm; 2) User sitting height = 50 cm; 3) Hand pedal height = 90 cm; 4) Foot pedal height = 25 cm; 5) Adjustable foot pedal range = 25–50 cm; 6) Distance between hand and foot pedals = 65 cm; 7) Device length = 50 cm; 8) Device width = 40 cm.

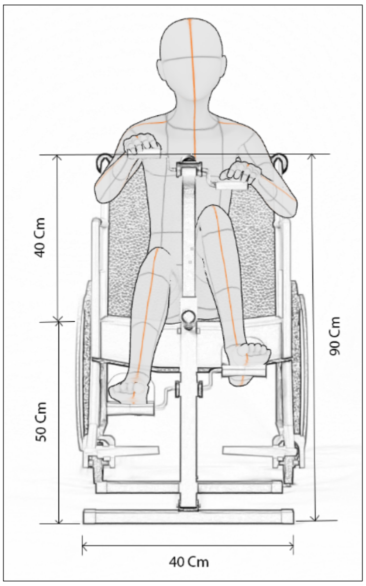

Figure 1. Ergonomic Design of the Automatic Bike Based on User Anthropometric Data

The ergonomic design illustrates the relationship between the dimensions of the Automatic Bike and the user's body position while seated in a wheelchair. All dimensions were determined based on anthropometric considerations to ensure that users can comfortably reach both the hand and foot pedals without changing their sitting posture. This design approach aims to enhance comfort, safety, and effectiveness during motor training activities.

Two-Dimensional (2D) Design of the Automatic Bike

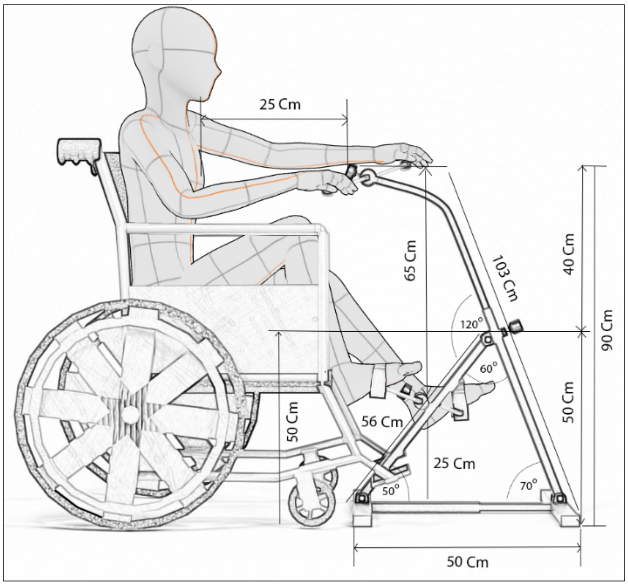

Figure 2. Two-Dimensional (2D) Design of the Automatic Bike

The two-dimensional design presents detailed measurements of the major components incorporated into the Automatic Bike. The design illustrates the main frame structure, hand-pedal system, foot-pedal system, wheelchair positioning area, and the adjustable foot-pedal mechanism.

The 2D visualization serves as a technical reference for the development of the three-dimensional model and the subsequent prototype assembly process.

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Three-Dimensional (3D) Design of the Automatic Bike

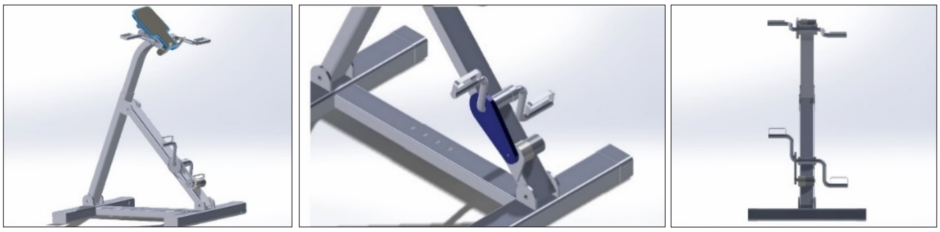

Figure 3. Three-Dimensional (3D) Model of the Automatic Bike

The three-dimensional model was developed to provide a more realistic representation of the final Automatic Bike design. The model demonstrates the integration of all components developed during the design stage, including the main frame, hand-pedal system, foot-pedal system, adjustable pedal-height mechanism, and wheelchair accommodation area.

The visualization results indicate that the Automatic Bike has relatively compact dimensions, with a length of 50 cm and a width of 40 cm, making it suitable for use in therapy rooms and educational settings with limited space. Furthermore, the positions of the hand and foot pedals were adjusted according to user characteristics, enabling simultaneous training of both upper and lower extremities.

Design Validation Results

The developed ergonomic Automatic Bike design was evaluated by engineering and special education experts to assess its safety, functionality, comfort, and suitability for children with cerebral palsy. The engineering validation conducted by Dr. Mukhlidi Muskhir, S.Pd., M.Kom yielded an average score of 2.88 out of 3.00, indicating a highly feasible design. The validator stated that the developed device provides substantial benefits for children with motor impairments, utilizes safe materials, and has strong potential for further development through interdisciplinary collaboration with engineering experts.

Similarly, the validation conducted by Dr. Nurhastuti, M.Pd., a special education expert, resulted in an average score of 2.70 out of 3.00, also categorized as highly feasible. The validator concluded that the Automatic Bike adequately addresses user needs and is appropriate for progression to the next stage of development.

The present study demonstrates that integrating user needs analysis with anthropometric measurements provides a more user-centered approach to developing assistive cycling technology for children with cerebral palsy. Unlike many existing adaptive bicycles that primarily incorporate supportive components such as safety belts or body stabilizers, the proposed Automatic Bike determines its ergonomic dimensions directly from users' physical characteristics. This approach addresses an important limitation of previous assistive devices, which often neglect individual body dimensions despite the substantial variability in posture, limb length, and motor ability among children with cerebral palsy (Cook & Polgar, 2015; Pheasant & Haslegrave, 2018; Sanders & McCormick, 1993). Consequently, anthropometric integration represents the principal contribution of this study toward improving the compatibility between assistive technology and user characteristics.

The ergonomic specifications of the Automatic Bike, including the overall height, frame dimensions, hand-pedal position, and adjustable foot-pedal mechanism, were established from anthropometric measurements obtained from the target users. The adjustable foot-pedal range (25–50 cm) is particularly important because it accommodates differences in lower-limb length while allowing users to maintain an appropriate sitting posture during motor training. This finding is consistent with ergonomic principles stating that products designed according to users' body dimensions improve comfort, accessibility, and operational efficiency while reducing the risk of musculoskeletal discomfort and fatigue (Bridger, 2018; Kroemer & Grandjean, 2009; Helander, 2006; Pheasant & Haslegrave, 2018). Therefore, the developed design not only satisfies dimensional requirements but also strengthens the ergonomic quality of assistive rehabilitation equipment.

The expert validation results further support the feasibility of the proposed design, with an overall mean score of 2.79 out of 3.00, indicating high feasibility across ergonomics, safety, functionality, and usability. Rather than merely confirming product acceptability, these findings demonstrate that the integration of anthropometric data successfully fulfilled the primary evaluation criteria established by both engineering and special education experts. Engineering feedback emphasized the structural safety and development potential of the design, whereas the special education evaluation confirmed that the device appropriately addressed the functional needs of children with cerebral palsy. These complementary perspectives reinforce previous findings that user-centered assistive technologies developed through interdisciplinary collaboration are more likely to achieve both technical reliability and functional effectiveness (Sanders & McCormick, 1993; Cook & Polgar, 2015; Alper & Raharinirina, 2006).

Another important contribution of this study lies in establishing a systematic design framework for assistive cycling devices based on anthropometric evidence rather than relying solely on generalized product dimensions. By translating user measurements into engineering specifications, the proposed design provides a practical reference for future prototype development and rehabilitation equipment intended for wheelchair users with cerebral palsy (Hobson & Molenbroek, 1990). This user-centered design strategy may improve accessibility, comfort, and training participation while supporting more individualized rehabilitation programs, consistent with contemporary ergonomic design principles (Bridger, 2018; Kroemer & Grandjean, 2009).

Despite these promising findings, several limitations should be acknowledged. The study involved only three participants and focused on expert validation of the design rather than prototype implementation or user performance testing. Consequently, the practical effectiveness of the Automatic Bike in improving motor function, rehabilitation outcomes, and long-term usability remains to be established. Future research should therefore develop a functional prototype, conduct usability testing with a larger and more diverse sample of children with cerebral palsy, and evaluate the clinical effectiveness of the device under real rehabilitation conditions.

Conclusions

This study successfully developed an anthropometry-based ergonomic Automatic Bike design tailored to the physical characteristics and functional needs of wheelchair-using children with cerebral palsy. By integrating user needs analysis with anthropometric measurements, the proposed design provides ergonomic dimensions that support comfort, safety, accessibility, and functional suitability during motor training activities. Expert validation confirmed that the design is highly feasible, indicating its potential as a user-centered assistive technology for rehabilitation. These findings demonstrate that incorporating anthropometric principles into the design process can produce a more appropriate and evidence-based assistive device, providing a strong foundation for future prototype development and user-based evaluation.

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