Biomechanics Applied in Ergonomic Furniture Design

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Furniture as a functional object must satisfy both artistic and scientific requirements. In particular, ergonomic factors are very important in furniture design in terms of human health and productivity. To make furniture designs at the ideal intersection of science and art, it is necessary to approach furniture design with a scientific systematic.

furniture biomechanics ergonomics

1. Introduction

Furniture occupies an important place in today's consumer culture because it satisfies both the physiological and psychological needs of people. The history of woodworking and furniture is intertwined with the development of civilization. From the ceremonial chair of Tutankhamun to the rococo armchair and from the Louis XV center table to the postmodern Carlton bookcase, the furniture used homes has consistently reflected the aspirations, fashions, and technology of its time. Human beings have been utilizing furniture since ancient times in order to address basic needs, such as sitting, lying, eating, etc.

There are three key design elements to consider when creating any kind of furniture. The first is functional design, which involves determining the intended function of furniture and identifying the primary benefits it is expected to provide (**Figure 1**) [1]. Aesthetic design, on the other hand, focuses on the artistic aspects of furniture design, encompassing features such as form, texture, color, and shape, while taking into consideration the influence of relevant cultures or fashion trends, as well as the demands of consumers [2][3][4][5]. Engineering design, which is the last key element of design, is the process of determining the most appropriate ergonomic criteria, materials, construction techniques, and manufacturing technologies [6][7][8][9][10][11][12].

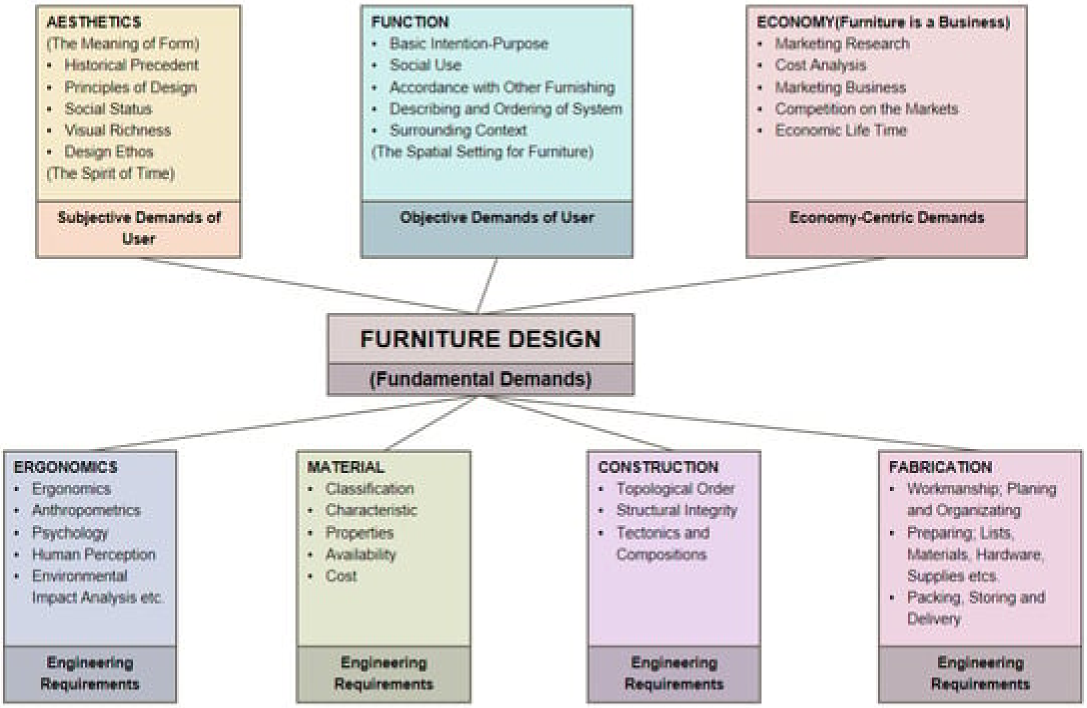

Figure 1. Considerations that affect furniture design.

Ergonomics is a crucial engineering factor that affects furniture design and has a significant impact on human health and productivity. Ergonomics can be defined as the discipline of studying the design of working and living environments in accordance with human characteristics. The human body has certain physical limitations in the structural sense. Products designed for use interact with the human body under certain conditions during use. This interaction is especially present in the form of one-to-one in seating furniture. In other words, various parts of the human body and some parts of the seating furniture are in contact during the sitting action. When using a piece of furniture, it is important to ensure that the physical dimensions of the user and the product are compatible with each other. This compatibility can only be achieved by understanding the physical characteristics of the human body. To create ergonomic furniture, it is necessary to recognize the anthropometric dimensions, anatomical properties, and the biomechanical structure of the human body. Furniture that does not comply with human anthropometry and anatomical structure is uncomfortable and can cause long-term health problems. The ergonomics of furniture play a crucial role in its suitability for the human body's physical structure.

Biomechanics is often defined as the application of mechanical principles to the study of living organisms [13][14]. In the early 1970s, the term biomechanics was adopted by scientists worldwide to refer to the study of the mechanics of living organs.

2. Biomechanics Utilized in Different Types of Furniture

To obtain a comprehensive understanding of the biomechanics used in furniture design, it is necessary to characterize the typical studies investigating the use of biomechanics. The following is a summary of typical studies on the application of biomechanics in furniture according to the type of furniture, classified as common furniture, special furniture, and transportation vehicle seats.

2.1. Common Furniture

Seating furniture is a commonly used and highly interactive type of furniture in daily life. This interaction is typically experienced on a one-to-one basis with the furniture. Therefore, the application of biomechanics in furniture design is mainly focused on seating furniture. Many efforts have been made to improve the anthropometry and ergonomics of seating furniture from the perspective of human–furniture interactions to improve the comfort of sitting and human health [15]. The subjective evaluation of the user can only provide qualitative information. Analyzing the human–seat interface and understanding the influence of body weight distribution on seat comfort are beneficial for ergonomic and functional seat design [16]. A method for measuring the pressure distribution on the contact surface is one of the most widely used means to analyze the biomechanics of human sitting from an objective point of view [17]. The design of the seat support can decrease the user's muscle fatigue level during extended use, suggesting that biomechanical analysis of the subject can account for the level of comfort experienced. [18]. A study showed that the most important design parameter affecting seat comfort is the backrest angle and that the inclination of the seat pan and the friction coefficient have a complex combination of effects on muscle activity and spinal joint forces [15][19][20][21][22]. Increasing the backrest angle from 90° to 105° decreases the reaction forces between L5 and the sacrum. As a result, muscle activation is significantly reduced, which is an important factor in increasing the overall comfort value [15][22][23]. This also showed that women are more suitable than men to use lightweight armchairs. A synchronized seat significantly reduces lumbar lordosis when the backrest is tilted [19]. However, continuous lordosis sitting is more detrimental to lumbar spine health than anterior lordosis sitting and may lead to cumulative damage to the soft tissues of the spine [15][24]. Similarly, studies have shown a linear relationship (or correlation) between upholstery thickness and seat comfort [16]. To obtain more qualitative information about what is happening inside the participant's body, Mahantesh et al. [25] conducted human digital modeling and rapid upper limb assessment (RULA) analysis of office chairs, with the aim of improving the safety of office seating and improving the user's physical health and well-being at work. However, sitting comfortably is not the same as sitting healthily, and sitting at a computer for long periods can lead to static loading on the body [26]. Therefore, by monitoring posture, muscle activity, and spinal contraction in women typing on an office chair with armrests and an exercise ball, it was found that the advantages of the body load sitting on an exercise ball may not outweigh the disadvantages [27].

Furthermore, researchers with expertise in biomechanics have examined common household furniture to better understand its impact in daily life. Lifting a child into or out of a motorized seat, bathtub, crib, infant carrier, and highchair has been reported to be a stressful activity for mothers [28][29]. Therefore, when designing furniture for infants and toddlers, it is important to consider not only the suitability for infants and toddlers but also the health and comfort of their caregivers. One researcher analyzed the lumbar joint reaction forces and muscle activation in mothers as they lifted their babies out of the baby cribs designed with varying bed heights. The study established a milestone for the implementation of computer-aided ergonomic methods in furniture design [30]. In addition, the team evaluated the musculoskeletal stress levels associated with the use of two different types of kitchen furniture cabinets [31]. The results showed that kitchen base cabinets with drawers were more ergonomic than kitchen base cabinets with doors.

As an important group in the world, the physical health and comfort of students while studying has also received much scientific attention. Based on the RULA, it was found that most preschool students experience mismatch between the anthropometric dimensions of the students and the dimensions of the chair and desk [32][33]. This issue is present in primary and secondary schools as well as universities. The primary reason for this is that the furniture provided is largely modular and the classroom areas are limited, leading to a considerable decrease in overall comfort and functionality [34][35]. Therefore, some researchers aim to find the ideal design parameter dimensions of student desks and chairs based on relevant anthropometric information and considering the biomechanics of students in the sitting position and the design of relevant desks and chairs [36]. The proper design of desks and chairs based on ergonomics increases efficiency, promotes the quality of education, leads to correct posture in students, and reduces the risk of musculoskeletal disorders [37].

Most of the studies above analyze and examine the biomechanics of common furniture from a comfort-oriented perspective, which is advantageous for designing ergonomic and practical furniture. Nevertheless, much of the research still concentrates on seating design. Furniture, in fact, has a vast range of applications, and biomechanics can have broad applications in the furniture design procedure. In future research, biomechanics can be conducted to study the human–furniture interactions of various other pieces of furniture, including tables and beds. Previous scientific studies have mainly examined the biomechanics of static postures during use. However, a biomechanical approach that analyzes dynamic movements in relation to the actions performed during use is necessary for a comprehensive understanding.

2.2. Special Furniture

Approximately 1% of the world's population uses wheelchairs [38]. A wheelchair is a type of specialized furniture product for people with physical disabilities that is used for mobility, social participation, and healthy living. For manual wheelchair users, maneuvers such as turning, going uphill, and passing curbs are difficult, and they use their upper extremities for prolonged periods, putting them at risk of injury from upper extremity use [39][40][41]. Therefore, the primary goal of incorporating biomechanical principles in the design of specialized furniture, such as wheelchairs, is to mitigate the risk of physical harm to users and enable them to independently perform daily activities. Differences between surfaces highlighted the importance of assessing wheelchair propulsion capabilities on a range of surfaces through a kinetic analysis of manual wheelchair propulsion during activation on selected indoor and outdoor surfaces [40]. Wearable sensors were installed on the wheelchair to track the wheelchair user throughout their weekly motion. Based on the monitoring results, the efficiency of wheelchair use can be optimized in future wheelchair design in terms of wheelchair–user interaction principles [41][42]. Dubowsky et al. [43] validated an upper extremity model for manual wheelchair users to reduce upper extremity injuries during use. The use of electric drives has become a new development in personal transportation. The wheelchair with cam-thread drive (WCD) is a new type of electric wheelchair. Field tests, laboratory measurements, and biomechanical analysis of the WCD and comparison with a typical wheelchair with push-rim drive (WPD) revealed that the WCD is a sustainable form of personal transportation that requires less human biological force to propel and exerts less stress on the human motor system, and therefore, can be used for rehabilitation [44].

The world's population is aging at an irreversible rate. For most elderly people, daily activities such as sit-to-stand transitions and walking pose significant challenges for most elderly individuals. Previous commercially available sit-to-stand assistive devices are relatively large and require sufficient upper limb strength for use, making them unsuitable for elderly people with declining physical functions [15][45]. The utilization of biomechanics, such as the abovementioned research on wheelchairs, can reduce upper extremity injuries and help users perform independent behaviors such as sit-to-stand transitions in daily living. To this end, some researchers have developed active walker systems [46], user-adaptive support systems [47], etc. The parameters of this user adaptive support system are determined according to the user's physical dimensions and disability and illustrate the effectiveness of the method of adjusting the position of the handrail, the height of the bed and the position of the feet. According to the survey, falls are the leading cause of accidental injury and death among older adults. Nearly 24% of falls in the elderly are caused by falling out of bed. According to biomechanical evaluation, protective floor mats can reduce the risk of injury from falls bed to some extent [48][49]. The increase in the elderly population has led to a significant increase in the number of nursing homes and an increase in the demand for caregivers. Wearable lower extremity assistive devices and stretchers with assistive features aim to reduce the physical burden on caregivers and family members of patients [50][51].

As stated above, the primary objective of using specialized furniture in biomechanics is to aid users in reducing upper limb injuries and facilitating their fundamental daily activities in a secure setting [26]. At the same time, it reduces the physical burden on caregivers when caring for the patient. The use of biomechanics in the design of special furniture is relatively mature. In future research, the design of specialized furniture can simultaneously focus on enhancing its practicality and aesthetic value at the same time. In addition, further studies should explore the design of furniture that enhances the indoor mobility and quality of life for wheelchair users from a biomechanical perspective.

2.3. Transportation Vehicle Seats

In the automotive industry, customer demand for vehicle performance and comfort is increasing. As a result, car manufacturers consider car seats or interior comfort as an important selling point and as a way to differentiate themselves from their competitors [52][53]. However, these seats are currently designed mainly based on user experience, traditional knowledge, and extensive, time-consuming, and expensive prototyping and experimental or field testing [54][55]. For example, experimental tests are first conducted to obtain a fatigue analysis view. Road tests are then conducted using seat pressure distribution (SPD) and electromyography (EMG) to elaborate the fatigue process [56]. Comfort in mass-produced vehicles can be measured using digital human models (DHMs) [54]. The advent of the human hip finite element (FE) model enables the prediction of the pressure distribution between the human body and the seat surface through its detailed and realistic geometric description [52]. Biomechanical methods have emerged to analyze fatigue more accurately and to design more comfortable car seats. Grujicic et al. [53] utilized musculoskeletal modeling and simulation techniques to investigate the primary factors contributing to fatigue in long-distance truck drivers. The study finds that interaction factors between the driver and the car seat, including the backrest angle, coefficient of friction at the interface between the body and the car seat, longitudinal track position, and availability of lumbar support, impact both driver fatigue and comfort [53][56]. The use of biomechanical knowledge is more scientific and objective than subjective comfort assessment and less costly and more efficient than experimental testing. In addition, torso posture and biomechanical logic should be introduced into seat design and evaluation, incorporating seat geometry into comfort, safety and ergonomic design solutions. As the market shifts from human driven to autonomous vehicles, the need to account for postural variation in seat design increases [57][58][59].

As in the automotive seat industry, comfort has been an important factor for passengers in choosing an airline and the aircraft for many years, and it makes sense to design a comfortable interior and seat to attract passengers. Some studies show that a seat pan design using spring–foam technology can be lighter and more comfortable than conventional foam cushion materials [55][60]. Comfort is established by six factors: anthropometry, climate, sound, vibration, illumination, and smell. “Anthropometry” was the most important factor influencing comfort, meaning that the legroom and seat width are inadequate for the size of different parts of the human body [61]. The seat and inclination need attention in relation to anthropometrics [62]. Simulation of passengers’ perceived comfort at different launch angles is one of the approaches. The results of such analysis could be explained by embedding a discomfort triggered adjustment (DTA) process in existing comfort models to address the cycle of discomfort development, the trigger, and the friction between movement desire and the practical constraints until the joy of comfort [63]. Some studies have found that staggered seats were significantly better in terms of comfort and privacy based on short-term evaluations [64][65]. In summary, research on aircraft seats is mainly carried out by means of experimental simulations, which are costly, and the object of their study is mainly the comfort of the seats.

In conclusion, the above research clearly indicates that there is a lack of research performed on the biomechanics of furniture design, with the main focus being on comfort, human health, and ergonomics for seating furniture. When designing special furniture, reducing upper limb injuries, and ensuring applicability are the primary design considerations. Future research can consider the conceptual design and styling of furniture from the perspective of human–furniture interaction using biomechanical knowledge.

3. Biomechanical Analysis and Testing Methods

According to the literature review and summary, it can be inferred that research on human biomechanics concentrates on sports biomechanics, musculoskeletal biomechanics, and ergonomic biomechanics [49][66][67]. Commonly used research methods and tools include mechanical models, computer-aided ergonomics, experimental testing, and other methods.

3.1. Mechanical Models

At present, most research on human movement biomechanics is based on the establishment of simplified mathematical–mechanical models, or the establishment of complex multibody dynamics models, including multiple parts of the human skeleton and muscle [68][69]. What to include in a model depends on the intended use of the model [70]. The simplest biomechanical motion models typically reduce the human body to a mass and do not take into account its own rotation and deformation. For example, the simplest model used to study walking is the inverted pendulum [71]. For complex motions, mathematical models are simplified compared to the real body, but they generate a formidable number of equations [72]. According to GB/T 17245 [73]; a regression equation can be established to predict the body segment mass and center of mass, expressed as Equation (1):

$$Y = B0 + B1X1 + B2X2 \quad (1)$$

where Y is the body segment mass *m* (unit: kg) or body segment center of the mass position *mc* (unit: mm), and the body segment center of the mass position *mc* is the distance from the starting point of the center of the mass measurement to the center of mass of the body segment; $X1$ is the body weight, unit: kg; $X2$ is the body height, unit: mm; $B0$ is the constant term of the regression equation; $B1$ is the regression coefficient of the body weight; and $B2$
is the regression coefficient of the body height.

GB/T 17245 specifies the coefficients of the binary regression equation coefficients for calculating the body segment mass, the center of the mass position, and the overall center of the mass position of the human body based on body weight and height. A model for calculating the center of the mass position of the human body based on the mass of the body segments can be established. According to theoretical mechanics, if the object consists of several parts, and its *i*-th part mass is m_i and the center of mass is (x_i, y_i, z_i), the center of mass of the object (x_c, y_c, z_c) is shown in Equation (2):

$$\begin{cases} x_c = \frac{\sum m_i x_i}{\sum m_i} \\ y_c = \frac{\sum m_i y_i}{\sum m_i} \\ z_c = \frac{\sum m_i z_i}{\sum m_i} \end{cases} \quad (1)$$

According to Equation (2), the equation for calculating the center of mass of the human body based on the geometric model of the body center of mass calculation can be expressed as Equation (3):

$$x_c = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i-1}^{n} m_i},\ y_c = \frac{\sum_{i=1}^{n} m_i y_i}{\sum_{i-1}^{n} m_i},\ z_c = \frac{\sum_{i=1}^{n} m_i z_i}{\sum_{i-1}^{n} m_i} \quad (2)$$

where *n* is the number of human body segments divided by Equation (3). The human body mass center coordinates can be obtained.

The model of the human center of mass provides a basic description of the principles governing human movement, enabling people to comprehend the trajectory, velocity, acceleration, and other factors associated with motion [68]. Human motion biomechanics problems are more analyzed by a multi-rigid body model. According to the actual needs, a multi-rigid body model can be a simple local joint model or a complex whole body model [74]. As shown in **Figure 5** [70][75], a more complete model for human motion simulation should include: (1) a skeleton model; (2) a muscle path model; (3) a musculotendon actuation model; (4) a muscle excitation–contraction coupling model; and (5) a motor task goal model.

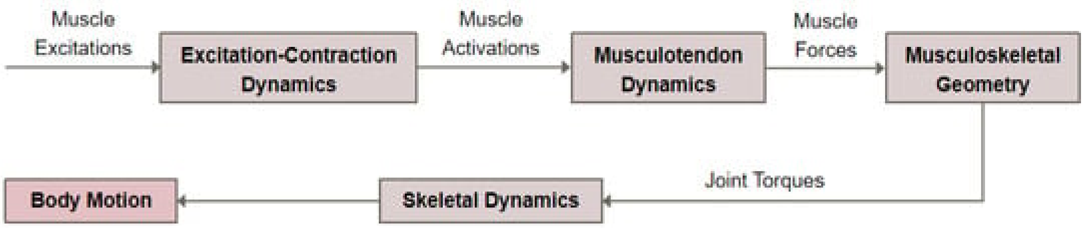

Figure 5. Diagram components included in a multi-joint model of movement.

(1) Skeleton model

If the human musculoskeletal system under consideration has *n* degrees of freedom (DoF) and the corresponding joint angles are generalized displacements, the relationship between the motion and muscle forces in this musculoskeletal system can be expressed by the following matrix Equation (4):

$$M(\bar{q})\ddot{\bar{q}} + C(\bar{q})\dot{\bar{q}}^2 + \overline{G}(\bar{q}) + R(\bar{q})F_{MT} + \overline{E}(\bar{q},\dot{\bar{q}}) = 0 \quad (3)$$

where $M(\bar{q})$ is the system mass matrix (*n* × *n*), M $M(\bar{q})\ddot{\bar{q}}$ ¨ is a vector of inertial forces and torques, $C(\bar{q})\dot{\bar{q}}^2$ is a vector of centrifugal and Coriolis forces and torques, $\overline{G}(\bar{q})$ is a vector of gravitational forces and torques, $R(\bar{q})$ is the matrix of muscle moment arms (*n* × *m*, *m* is the number of muscles), FMT is a vector of musculotendon forces (*m* × 1), $R(\bar{q})F_{MT}$ FMT a vector of musculotendon torques, and $\overline{E}(\bar{q},\dot{\bar{q}})$ is a vector of external forces and torques applied to the body by the environment.

However, Equation (4) is often redundant because the number of muscles with unknown contractile forces is more than the number of equations (*m* > *n*). Equation (4) can be simplified so that each degree of freedom corresponds to a muscle moment, yielding an equation in the form of Equation (5):

$$M(\bar{q})\ddot{\bar{q}} + C(\bar{q})\dot{\bar{q}}^2 + \overline{G}(\bar{q}) + T_{MT} + \overline{E}(\bar{q},\dot{\bar{q}}) = 0 \quad (4)$$

where TMT is the net joint moment (*n* × 1), which is equal to $R(\bar{q})F_{MT}$ FMT.

(2) Muscle path model

The position of the start and end points of a muscle affects the force arm that the muscle exerts across the joint. The multiplication of this force arm by the muscle force is the magnitude of that muscle's contribution to the combined moment that produces the joint motion. As shown in Equation (4), the force arm is usually a function of the angle of the joint.

(3) Musculotendon actuation model

The current widely used Hill-type muscle model can be represented by two differential equations in Equation (6):

$$\begin{cases} \dot{a} = f_1(u, a) \\ l_M = f_2(\dot{l_M}, l_{MT}, a) \end{cases} \tag{5}$$

where u is the muscle excitation, a is the muscle activation ($0 \leq a \leq 1$), l_M is the muscle fiber length, l_{MT} is the total length of the muscle–tendon association. The muscle strength F_{MT} can be obtained by solving the above two differential Equations (5) and (6), and then integrating the following Equation (7):

$$\begin{cases} \dot{a}_m = \frac{1}{\tau_{rise}}(u^2 - ua_m) + \frac{1}{\tau_{fall}}(u - a_m) \\ u = u(t) \\ a_m = a_m(t) \end{cases} \tag{6}$$

(4) Muscle excitation–contraction coupling model

Muscles cannot be activated or relaxed instantaneously. The delay between muscle excitation (u, which represents the net neural drive) and muscle activation (a_m) is usually modeled as a first-order process in Equation (8):

$$\begin{cases} \dot{a}_m = \frac{1}{\tau_{rise}}(u^2 - ua_m) + \frac{1}{\tau_{fall}}(u - a_m) \\ u = u(t) \\ a_m = a_m(t) \end{cases} \tag{7}$$

Implicit in the formulation of Equation (8) is the assumption that muscle activation relies solely on a single variable u. However, there may be other forms of coupled muscle excitation–contraction models.

(5) Motor task goal model

Equations (1)–(3) can be combined to form a model of the neuromusculoskeletal system. The inputs to this system are the muscle excitations, and the outputs are the body motions. Measurements of the muscle EMG and body motions can be used to estimate muscle forces during movement. Alternatively, the goal of the motor task can be modeled and used together with dynamic optimization theory to calculate the set of muscle excitations needed for optimal performance.

The above multiphysical model is generally driven by joint torque, and is only suitable for analyzing motion rules. Some mature dynamic analysis software has established a typical musculoskeletal model, which greatly facilitates the user to conduct biomechanical simulation analysis [74][75][76][77][78][79].

3.2. Computer-Aided Ergonomics

Due to the complexity of human body systems, simple models often have difficulty explaining complex problems in practical applications. This has led to the development of human biomechanical models in the direction of complexity and detail, with simulation playing an increasingly important role as a necessary means to solve the described complex problems [68]. In recent years, computer modeling and simulation technology have developed to a new high level, and this approach can provide a more quantitative explanation of how the neuromuscular and musculoskeletal systems interact to produce motion. In particular, simulations of standing, walking, jumping, and pedaling can provide insight into how the leg muscles work together in each task to achieve a common goal [26][70]. The primary simulation software utilized comprises LifeMOD, OpenSim, AnyBody Technology, VIMS, SIMM, and ANSYS finite element software [74][75][76][77][78][79][80]. Among them, the skeletal muscle model of VIMS software cannot define the muscle unit that generates the key dynamic force, so it is mainly used for kinematic analysis. SIMM software is mainly used to study joint kinematics and the characteristics of muscle forces and moments, and it can represent the kinematic characteristics of joints, but the kinematic model of joints is not directly available in SIMM. LifeMOD, Opensim, and AnyBody Technology are the three most widely used human simulation software programs.

LifeMOD is a common simulation software for gait analysis [81][82][83], which can study the changes in human biomechanical parameters and the coupling between human and mechanical systems [84][85] under different working environments [81][86][87][88].

Opensim has fine control over muscle morphological parameters, low computational error, and fast computation [89][90], and it is used in many other fields, such as walking dynamics analysis [91], motion performance studies [92][93][94][95], surgical procedure simulation [87][96], and medical device design [82][83][89][97].

AnyBody Technology is the most complex but most functional muscle and bone modeling software tool currently available [43][44][45][70][92][98], which can customize the parameters related to the human body model and directly invoke the human body model from the model database. It can model the environment in the simulation and interface with the presence of other software (such as SolidWorks, ANSYS, Abaqus, etc.) [99][100]. It is widely used in research fields, such as clinical medicine [43][101][102], automotive industrial design [53], aerospace, rehabilitation medical engineering [87][103], product design [19][20][21][31], work environment design [30][44], and sports and equipment [104][105][106].

In addition to the abovementioned simulation software, software such as MATLAB and FEM are used in furniture design [51][52][93]. The main technical challenges faced in current human biomechanics-based modeling and simulation research are (1) how to accurately calculate joint muscle forces and accuracy verification problems; (2) kinetic parameters in human motion derived from kinematic data; and (3) neuromuscular multistructural hierarchy and multiscale control of motion biomechanics modeling. In the future, the following directions are likely to be the key directions for sports biomechanics modeling and simulation research: (1) Personalized musculoskeletal modeling and analysis—with the rapid development of new sensor technologies, the research of personalized musculoskeletal modeling means and analysis and evaluation methods that reflect individual differences will become a trend. (2) Neuromuscular control simulation—with the continuous development of computer technology, the study of neuromuscular model control based on deep learning and reinforcement learning strategies is expected to become a research hot topic in the crossover field.

3.3. Experimental Test Methods

Compared to the mechanical model and computer-aided ergonomics mentioned above, experimental testing of human biomechanics is more mature. Researchers have developed test methods such as kinematic parameter monitoring [27][39][43][47][99][100][105][106], physiological parameter monitoring [22][27][38][41][44][56][106], and kinetic parameter monitoring [16][18][39][44][46][56][103][104][105] by combining advanced experimental techniques from computer, medical, biological, and mechanical disciplines to study the motion characteristics of the human body.

At present, the primary technical challenges in human biomechanics for the experimental testing of furniture design include (1) the challenge of detecting the internal motion of the skeletal system, and (2) the challenge of obtaining precise measurements across different time and space scales. In the foreseeable future, the research and development of intelligent, flexible, biobased electronic measurement instruments and special dynamic test system development will be the key development directions of new test equipment research and development. In terms of testing technology, non-interference-based motion posture recognition based on image or video deep learning models and the inversion of kinetic parameters through kinematic data combined with mechanical models will also be research directions that need to focus on breakthroughs. Additionally, expanding the range of measurable metrics is a crucial aspect of the current experimental sports body testing. For instance, by examining and analyzing kinematic, kinetic, electromyographic, and electrocardiographic parameters together, a more comprehensive understanding of the athletes' technical, physical, fatigue, and psychological state can be obtained.

Most of the current research combines mechanical models, computer-aided ergonomics, and experimental tests for biomechanical analysis. First, the human motion is simplified and analyzed by the mechanical model. Then, biomechanical simulation software is used to simulate the human–machine coupling model [26]. Finally, the results are verified using experimental tests. As mentioned above, the accuracy of computer-aided ergonomics and experimental testing should be further improved in future research so that biomechanics can be improved and applied to furniture design more often.

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