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Development of Techniques for Measuring Lower Limb Flexibility in the Elderly

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ABSTRACT

Flexibility is a key determinant of physical fitness and an integral part of overall health, influenced by muscle control and the range of joint motion. With age, joint mobility tends to decrease, impacting the independence and quality of life for seniors. Maintaining flexibility is thus essential for older adults. However, the body's compensatory mechanisms often obscure flexibility declines, complicating regular measurements. Conventional flexibility assessment relies on physical fitness testing and range-of-motion tools like rulers and goniometers. These contact and non-contact methods quantify joint range, though the latter has limitations in error verification. Advanced technologies include 2D body scanning and 3D measurement, offering precise data but are costly and less accessible for daily use.This study focuses on elderly lower limb flexibility, developing a new measurement technique by defining a flexibility unit, establishing measurement bases, and creating methods. It aims to create a tool integrating data logging and display apps for comprehensive flexibility assessment. This addresses human factors in flexibility measurement and innovates for elderly health industry development and business opportunities.In summary, this study advances flexibility measurement for elderly health industry development, providing data support and business opportunities, while innovating technology and services.

Keywords: Elderly, Lower limb flexibility, Flexibility measurement, Measurement technology development

INTRODUCTION

The swift evolution of science and technology has brought about a revolution in traditional manual labor, significantly enhancing production efficiency and the quality of life for modern individuals. In health, advancements have extended life expectancy, prompting a focus on high-quality living. However, society is facing an unprecedented aging challenge. The 2019 World Population Trends Report projects a global population of 9.8 billion by 2050, with over 1.5 billion aged over 65, making up 16% of the total. This trend underscores the severity of aging and the significant societal challenge it poses. Amidst this, the health industry's importance grows as a key to sustainable aging and a sunrise sector hard to replace by AI.

Healthy aging, as an ideal societal process, focuses on maintaining functional capabilities for a healthy life, with a central concern for the well-being of the elderly (WHO, 2015). Aging brings physiological changes like muscle strength loss and flexibility decrease. Flack (2011) noted a 3-8% muscle mass loss per decade, increasing fall risk, a health threat (Hans, 2021). Jiahui (2016) found a 23.8% activity impairment in Chinese seniors over 60, highlighting the challenge of maintaining daily activities.

Health fitness, a core health indicator, includes strength, endurance, cardiofitness, and flexibility. Flexibility, often overlooked, is vital for joint health. Softness assessment faces challenges like unclear bases and poor data precision. This study aims to redefine measurement concepts and explore methods by analyzing softness assessment status. It seeks to innovate measurement and develop professional, efficient tools. This study will build a scientific softness measurement technique to improve health, optimize elderly life quality, and guide the health industry's sustainable growth.

In summary, the progress in elderly physiological health emphasizes the importance of flexibility for life quality. Through lower limb softness measurement technology, we'll better assess and intervene in elderly health, aiding self-management and quality of life improvement.

LITERATURE REVIEW

Theoretical Basis of Human Factor Engineering

Human factors engineering, as an interdisciplinary science, focuses on understanding the interactions between humans, technology, and the environment. Against the backdrop of daily living difficulties for the elderly, human factors engineering provides a theoretical framework and methodologies for designing and improving living and activity environments suitable for older adults. These theories include but are not limited to:

1. Universal Design Principles: These principles emphasize that design should consider all users, including the elderly and those with mobility impairments. Measurement tools should have an intuitive interface, clear instructions, and simplified operation steps to reduce the cognitive load on the elderly (Story, Mueller, & Mace, 1998).
2. Anthropometry: By studying human body size data, tools suitable for the characteristics of the elderly population can be designed. Considering potential body size changes in the elderly, such as reduced height and limited joint mobility, tools should be adjustable to accommodate different user body conditions (Pheasant, 1991).
3. Cognitive Load Theory: When designing, the cognitive load on the elderly during the operation of measurement tools should be minimized. Simplified operating guides and clear feedback mechanisms can help the elderly understand and use the tools more easily (Sweller, Ayres, & Kalyuga, 2011).
4. Biomechanics: When designing measurement tools, the muscle strength and movement capabilities of the elderly should be considered to ensure that the use of the tools does not impose excessive physical burdens on

them. The operation of the tools should minimize the need for lifting, pushing, pulling, or maintaining postures for extended periods (Chaffin & Andersson, 2006).

5. Environmental Adaptability: Measurement tools should be easily usable in the living environments of the elderly, whether at home, in nursing homes, or medical facilities. The design of the tools should consider different environmental conditions such as lighting, space, and floor conditions (Bridger, 2003).

By applying these human factors engineering theories, it is possible to develop lower limb flexibility measurement technologies that meet the physiological and psychological needs of the elderly and provide accurate measurement results. These tools will assist the elderly in conducting daily self-monitoring more easily and also provide a foundation for the establishment of a flexibility database.

Study on Physiological Health of the Elderly

When analyzing the physiological health status of the elderly, it is necessary to consider the decrease in physical flexibility due to the lack of daily exercise as they age. The physiological health issues of the elderly are often related to the weakening of muscle strength, the reduction of bone density, the decrease in joint flexibility, and the degeneration of the nervous system (Spirduso, 1995). These physiological changes not only limit the activity ability of the elderly but also increase their risk of injury. In particular, the decrease in flexibility has become a key factor affecting the quality of life of the elderly. The reduction in flexibility is a significant indicator of physiological degeneration in the elderly. With the increase in age, the muscles and ligaments of the elderly gradually lose elasticity, leading to limited joint mobility (Norkin & White, 2016). This loss of flexibility not only affects the ability of the elderly to perform daily activities such as bending and stretching their legs but may also lead to pain and discomfort in the musculoskeletal system (Ryan et al., 2008). Regular flexibility training can not only improve the range of motion of joints, enhance the elasticity of muscles, reduce pain and stiffness, but also improve the quality of life of the elderly.

In summary, the progress in the research on the physiological health of the elderly emphasizes the importance of flexibility in maintaining the quality of life for the elderly. Through the design and research of lower limb flexibility measurement technology, we can not only more accurately assess the physiological health status of the elderly but also provide them with more targeted intervention measures. The development and application of these technologies will help improve the elderly's self-management ability and thus enhance their quality of life.

Softness Related Research

Flexibility is a key indicator of an individual's physical fitness, involving the range of motion of human joints in various directions. With the increase in age, the flexibility of the elderly often undergoes a natural process of decline, which not only limits their activity capabilities but may also lead to a series

of health issues. Flexibility is a multidimensional concept (Table 1), involving muscle control, joint mobility, and the elasticity of joints and surrounding structures (Qiuxia, 2008). Scholars such as Jie (2006) classify flexibility into active and passive types: active flexibility refers to the ability of muscles to actively contract and move joints, while passive flexibility is the maximum range of joint motion that can be achieved with the assistance of external forces, which is significant for assessing and training flexibility. Additionally, Sun Qingbin and others (2008) propose the concept of absolute and relative flexibility, where absolute flexibility reflects the flexibility of a specific body part, and relative flexibility considers the comparison between different parts, eliminating the impact of individual body differences.

When exploring the flexibility of the elderly, it is necessary to focus on both upper and lower limbs. Although upper limb flexibility directly affects daily activities such as dressing, combing hair, and reaching for high items (Chodzko-Zajko et al., 2009), the importance of lower limb flexibility should not be overlooked. The lower limbs play a supporting, weight-bearing, and balancing role in the overall body structure and are key factors in limb movement. Studies have shown that many joint mobility ranges decrease with age (Germain & Blair, 1983); among them, hip joint flexibility shows the most severe degenerative phenomenon (Thorsteinsson et al., 1975); scholars like Hou Man and others (2004) pointed out that lower limb flexibility is an important parameter for evaluating the physical condition of the elderly. As mentioned above, this study will focus on the lower limb flexibility of the elderly for in-depth research.

Table 1. Academic definition of softness (author's own).

Tme	Scholar	Research content
2016	Norkin & White	measurements of joint range of motion, the definition of flexibility is limited to structures such as bones, muscles and ligaments.
2012	Kay & Blazevich	The acute effects of static stretching on muscle performance and flexibility were systematically reviewed, and the relationship between flexibility and strength performance was indicated.
2010	Weppler & Magnusson	To explore the mechanism of increasing muscle malleability, softness is related to muscle extensibility and sensory changes.
2008	Ryan et al.	To study the effect of passive stretching on muscle-tendon stiffness in different time periods, softness is related to muscle stiffness.
2002	Wang Ruiyuan	Flexibility is the ability of the human body to complete large-scale motor skills during movement, that is, the movement ability of the human body joints in different directions.
1996	Magnusson et al.	The biomechanical response of repeated stretching of hamstring muscle was studied. The flexibility is related to the adaptability and biomechanical properties of muscle.

Soft Measurement Technology Research

To accurately assess softness in older adults, researchers have developed a variety of measurements. These methods have evolved from traditional manual measurement, such as ruler and Angle meter, to more advanced electronic measurement equipment and dynamic capture systems (Ayala et al., 2012). In the field of soft measurement, technology has evolved to provide more accurate and convenient assessment methods that can be adapted to the needs of different populations.At present, soft measurement technology is mainly divided into two categories: measurement tools and measurement methods. The following is a comprehensive summary of these techniques and approaches

Measuring Tool

Traditional tools such as rulers, goniometers, and inclinometers offer basic joint range-of-motion measurements at a low cost and simple to operate, ideal for initial flexibility assessments. However, they require user skill and are sensitive to environmental factors, posing challenges for elderly independent use. They also lack real-time feedback, potentially reducing data accuracy and timeliness.

Advanced electronic measuring equipment, including electronic goniometers and pressure sensors, offers enhanced precision and repeatability for quantifying muscle and joint flexibility across various positions. It minimizes human error with digital readings, facilitating trend analysis from multiple measurements. However, such equipment tends to be costly and complex to operate, often restricted to specific environments like laboratories or clinics, and may not be practical for routine home use.

Non-contact measurement tools encompass technologies like 2D image-based body measurement, 3D body scanning, and 4D scanning. These tools analyze joint motion range from video footage, offering a contact-free option suitable for large-scale assessments. However, they may incur significant measurement errors and are typically used in specialized settings like fashion and medicine due to equipment and site constraints, limiting their daily home use.

Method of Measurement

Static measurement methods involve assessing the basic level of flexibility by measuring the maximum range of joint motion in a static position, like the seated forward bend test. These methods are straightforward for preliminary evaluations but are limited to static conditions and may not fully capture flexibility under dynamic activities.

Dynamic measurement methods evaluate joint motion and muscle elasticity during exercise, ideal for assessing athletic performance or rehabilitation progress. These methods reflect flexibility in motion, requiring professional equipment or technical assistance, complex to operate, and challenging for home use.

Functional measurement methods assess the impact of flexibility on daily activities, such as stair climbing and sitting-to-standing movements, directly

correlating to daily life needs. These practical assessments are particularly beneficial for the elderly, aiding in fall risk prediction and mobility assessments. However, standardization is challenging due to individual variability.

The integration of these techniques and methods offers a robust tool for comprehensive softness evaluation. With advancing technology, future softness measurement will prioritize user-friendliness, data accuracy, and real-time feedback to cater to elderly health management and life quality enhancement needs. This study aims to develop user-friendly, efficient, and convenient softness measurement tools grounded in human factors engineering and elderly-specific needs. The goal is to empower older adults with easy and precise self-monitoring of softness, akin to height measurement. By applying these innovative tools and methods, we anticipate enhancing elderly self-health management and life quality experiences.

DEVELOPMENT AND VALIDATION OF NEW TECHNIQUES FOR LOWER LIMB FLEXIBILITY IN THE ELDERLY

Lower Limb Flexibility Measurement Tool for the Elderly

Based on the principle of anthropometry, this study first analyzed the range of motion of the lower limb joints to determine the key nodes and reference positions of measurement. Combined with a body size database for Asian populations, the new benchmark is broadly applicable. Specific steps include:

(1) Determination of key parameters: By analyzing the lower limb flexibility of the elderly, key evaluation indicators including range of motion, muscle length and joint stiffness were selected, especially considering the factors of muscle elasticity decline and joint degradation in the elderly.
(2) Ergonomic integration: In the design of tools, combining ergonomic theory, focus on reducing the tension and discomfort of elderly users. Tools should be light, portable and able to operate independently in a home environment for accurate measurement.

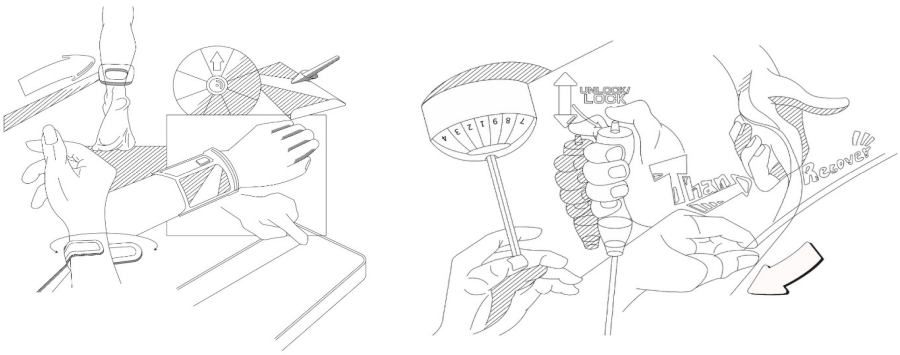

Figure 1: Soft measurement tool usage scenario (author's own).

In order to establish a new measurement method for lower limb flexibility in the elderly, this study developed a flexibility measurement tool suitable for home use (Figure 1). The design focuses on high flexibility, ease of

operation, portability and independent use, and a precision gear, ratchet and measuring tape system is adopted to ensure the accuracy and convenience of measurement. Combining static and dynamic measurement methods, standardized test procedures, movement instructions and data recording specifications were developed to comprehensively evaluate the flexibility of lower limbs in the elderly. Through multiple rounds of user testing in rehabilitation centers and community locations, feedback is collected to continuously optimize the design, improve the comfort and ease of operation of the device, and ensure that it can be used effectively in a variety of environments.

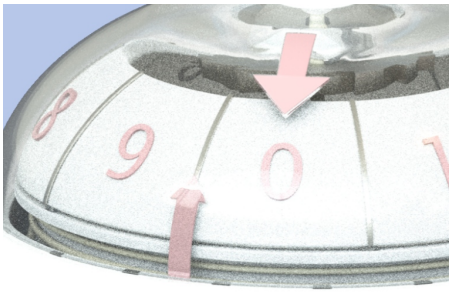

Figure 2: Soft measuring tool (author's own).

In the process of development and verification of new technical tools for lower limb flexibility measurement, this study designed and developed a flexibility measurement instrument for the elderly (Figure 2). According to user requirements and design opportunity points, it integrates functions such as top cover, ratchet set, display wheel and wire wheel to achieve high-precision flexibility measurement. By analyzing the measured data of older participants, the reliability and validity of the new technology are evaluated and compared with traditional flexibility testing methods to explore its application potential in the health management of older people. In the data analysis process, the measurement results of the new technology are compared with existing methods, and the design and software interface of the measurement tool is further optimized to ensure that it is suitable for long-term monitoring and use.

Measurement Program Development

In this project, we focused on the development of a mobile app called "Flexotone", which aims to help users assess and manage their body flexibility, especially for the elderly group. The app will offer a range of features to support users in maintaining and improving their physical health.

(1) Core functions: In the body assessment section, users can understand their own body flexibility through simple tests and obtain basic flexibility data.In the training plan section, according to the user's evaluation results, provide personalized training suggestions to help users improve flexibility.In the circumference recording plate, users

can record the data of each measurement and track the change trend of softness. A detailed body part assessment, including joint range of motion and muscle elasticity, is provided in the Body assessment plate.

(2) User interface: Includes the home page, setting page, etc. The home page is the main functional module to display the application, such as physical assessment, all courses, training plans, circumference record and physical assessment. In the Settings section, users can manage personal information, account security, privacy Settings, etc. The section of my page shows the user's measurement records and body type data, and the user can see how their flexibility has changed.

(3) Technical features: Portability is as a mobile application, users can use anytime, anywhere, without downloading additional applications.User friendliness is the interface design is simple and intuitive, easy to operate, suitable for users of all ages. Data security means that all user data is stored encrypted to ensure personal privacy and information security.

(4) Development technology: Mobile application development framework is the use of existing mobile application development framework and API to achieve application functions.Local storage is the use of the local storage capabilities of mobile devices to save user data and Settings. Cloud services realize data synchronization and backup through the cloud service platform.

Flexotone will be a comprehensive health management tool designed to help users, especially the elderly population, better manage their physical health. Through regular flexibility assessments and personalized training recommendations, users can improve their quality of life and health. The intended effect is to help the user understand their flexibility level and develop an appropriate exercise plan. To improve the quality of life and health of the elderly. Prevent potential health problems such as joint pain and limited mobility with regular flexibility assessments.

CONCLUSION

An Overview of the Contemporary Methodologies for Assessing Lower Limb Flexibility in the Elderly Population

In order to effectively assess and manage lower limb flexibility in the elderly, it is essential to develop accurate measurement techniques. These technologies must be designed with the physiological characteristics and practical needs of the elderly in mind to ensure that they are both safe and practical. For example, measurement tools should be designed to be easy to operate and to be easily used in the living environment of the elderly. In addition, measurement techniques should be able to provide immediate feedback to help older adults understand their flexibility status and guide them to appropriate flexibility training (Ayala et al., 2012). At present, common techniques for measuring lower limb flexibility in the elderly mainly rely on traditional methods, such as sitting forward flexion, joint range of motion test, and extension assessment of specific muscles. These methods often use simple measuring tools or visual inspection to assess flexibility and have some

applicability. However, a significant problem with existing methods is the difficulty of accurately quantifying flexibility in the elderly, especially in the face of muscle stiffness and joint degeneration caused by aging. In addition, the operability of traditional methods is poor, often requires other people's assistance or high technical level, which limits its wide application in the elderly population.

Problems and Challenges in the Measurement of Lower LIMB Flexibility in the Elderly

Traditional manual measurement methods have limitations in accuracy, which makes it difficult to obtain highly accurate values in the assessment of lower limb flexibility in the elderly. However, the advantage of these methods is that they are easy to use, do not require complex equipment, and are suitable for the elderly to take measurements at any time in their home environment. The lightness and burdenless use experience of the existing tools make them convenient in the daily life of the elderly. However, with the increasing demand for individualized health management, how to improve measurement accuracy while maintaining convenience has become one of the main challenges in the development of flexibility measurement technology.

Development Trend of Lower Limb Flexibility Measurement Techniques in the Elderly

Future technological development should focus on creating user-friendly, intelligent, and portable tools for elderly flexibility measurement:

(1) Convenience and Accessibility: New tools should simplify operations, allowing seniors to independently measure flexibility at home or outdoors without relying on specific locations or equipment. They should be compact, lightweight, and easy to carry, ensuring easy use in various settings.
(2) Intelligent and Automatic Positioning: Tools should feature automatic identification and alignment of measurement points, using sensors and algorithms to minimize human error and improve accuracy.
(3) Immediate Feedback and Personalized Guidance: Tools should provide real-time feedback, enabling users to understand flexibility results immediately. Intelligent analysis offers personalized guidance for tailored training and health management.
(4) User-Friendly Design: Ensure the design is accessible, with an intuitive interface and straightforward operation, minimizing physical and technical demands.

These trends aim to enhance lower limb flexibility measurement technology, making it more intelligent, personalized, and convenient for elderly health management.

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