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A Study on the Development of a Risk Prediction Model for Functional Disability Among Older Adults in Zhaoqing City and the Mechanisms of Exercise Intervention

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Abstract

Background: Against the backdrop of an aging population, the issue of functional disability among older adults has become increasingly prominent and is now a major concern affecting public health and social governance. However, current approaches to identifying the risk of functional disability and implementing exercise interventions still face challenges such as inadequate prediction and a lack of targeted interventions. Objective: This study focuses on older adults in Zhaoqing City and aims to develop a predictive model for the risk of functional disability among older adults, identify key influencing factors, and explore exercise intervention pathways based on risk stratification. Methods: This study employed a combined approach of questionnaire surveys and functional assessments, selecting a sample of 35 older adults aged 60 and above. An indicator system for disability risk was developed based on literature review and the Delphi method, and indicator weights were determined using the Analytic Hierarchy Process (AHP) to establish a risk prediction model. Additionally, participants were stratified according to their risk scores, and stratified exercise interventions were implemented. The effectiveness of the interventions was analyzed using descriptive statistics and group comparisons. Results: The risk of functional disability among older adults is influenced by a combination of multidimensional factors, with muscle strength, balance, the number of chronic diseases, physical activity levels, and cognitive function being the primary determinants. Risk stratification results indicated that the medium-risk group constituted the largest proportion. Following a specific period of exercise intervention, older adults showed a trend toward improvement in muscle strength and balance, with the intervention effects being relatively more pronounced in the medium-risk group. Conclusion: A disability risk prediction model based on multidimensional indicators can effectively identify and stratify risks among older adults. Implementing tailored exercise interventions based on risk stratification may provide a feasible pathway to delay the onset of disability. This study can serve as a reference for community-based health management of

older adults and related policy formulation; however, its effectiveness still requires further validation in larger-scale and long-term studies.

Keywords

Functional disability in older adults; risk prediction model; Analytic Hierarchy Process; exercise intervention; risk stratification; healthy aging

1. Introduction

Against the backdrop of an increasingly rapid population aging, the issue of functional disability among older adults has evolved from an individual health concern into a key issue in public health and social governance [1]. Functional disability manifests not only as a decline in Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) but also involves multidimensional issues such as physiological decline, cognitive impairment, and limited social participation; its onset is characterized by gradual, insidious, and cumulative progression [2]. It is projected that by 2050, the number of older adults with functional impairment in China will exceed 97.5 million [3]. Therefore, how to effectively identify and intervene before functional impairment occurs has become a crucial breakthrough for realizing the "healthy aging" strategy [4]. Existing research indicates that exercise interventions offer significant advantages in delaying functional decline, improving physical performance, and promoting mental health [5]. However, current practices largely remain experience-driven and rely on single-intervention models, lacking a systematic approach based on risk identification. This results in interventions that are insufficiently targeted and sustained, making it difficult to achieve precise prevention and tiered management [6].

In terms of research progress, current studies on the risk of functional disability among older adults and exercise interventions still exhibit structural shortcomings: on the one hand, there is a lack of functional disability risk prediction models that integrate multidimensional indicators, making it difficult to scientifically quantify and dynamically assess individual risk [7]; on the other hand, research on exercise interventions primarily focuses on testing single outcomes and has not yet established a mechanistic intervention framework aligned with risk stratification [8]; At the same time, there remains a relative scarcity of precision intervention plans tailored to different risk levels and individual differences [8]. Against this backdrop, this study takes the elderly population of Zhaoqing City as its research subject, constructs a risk prediction model for disability in older adults from a risk management perspective, employs scientific methods to achieve risk stratification and identification, and, on this basis, explores a stratified and categorized exercise intervention mechanism. This study not only contributes to deepening the theoretical understanding of the mechanisms underlying functional disability in

older adults and the pathways for intervention but also provides replicable and scalable decision support for local authorities to implement refined health management and smart aging care practices.

2. Literature Review and Theoretical Framework

2.1. Research on the Risk of Functional Impairment in Older Adults

Functional impairment in older adults generally refers to a decline or loss of an individual's ability to perform Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) [9]. ADLs primarily include basic daily living skills such as eating, dressing, using the restroom, bathing, and walking, while IADLs involve more complex life skills such as shopping, cooking, medication management, and social interaction [10]. As people age, their physiological, psychological, and social functioning gradually declines, and the risk of functional impairment shows a cumulative upward trend [11]. In terms of influencing factors, the risk of functional impairment in older adults is multidimensional. First, at the physiological level, chronic diseases (such as cardiovascular disease and diabetes), sarcopenia, and degenerative changes in bones and joints are considered core factors leading to functional limitations [12]; second, at the psychological level, cognitive decline, depression, and emotional disorders significantly impair an individual's ability to care for themselves and execute tasks [13]; third, at the social level, insufficient social support, reduced social participation, and increased feelings of loneliness also accelerate the progression of disability [14]. Therefore, functional decline in older adults is not the result of a single factor but rather a comprehensive manifestation of the interaction among multiple physiological, psychological, and social factors, which provides a theoretical basis for developing multidimensional risk prediction models.

2.2. Exercise Intervention Studies

Exercise intervention is widely recognized as one of the key strategies for preventing and delaying functional decline in older adults, primarily taking the form of aerobic exercise, resistance training, and balance training [10]. Aerobic exercise (such as walking and jogging) helps improve cardiopulmonary function and metabolic levels; resistance training enhances muscle strength and slows muscle loss; and balance training helps improve postural control and reduce the risk of falls [15]. In addition, mind-body exercises such as tai chi and yoga, with their gentle movements and moderate pace, have also been shown to be effective in improving physical function and mental health in older adults [16]. In terms of mechanisms of action, exercise interventions exert their effects through multiple pathways. On the physiological level, exercise promotes muscle protein synthesis, increases bone density, and improves neuromuscular coordination, thereby enhancing physical function; on the neurological and cognitive levels, regular exercise helps enhance

brain function and delay cognitive decline [10, 15]; and on the functional level, exercise improves balance and proprioception, reducing the risk of falls and the resulting disability. However, existing studies have largely focused on single forms of exercise or short-term outcome assessments, and there is a lack of systematic intervention pathways integrated with risk stratification.

2.3. Theoretical Foundation

To systematically explain the relationship between the risk of functional disability in older adults and exercise interventions, this study employs a multi-theoretical framework for an integrated analysis. First, risk management theory emphasizes proactive intervention against potential adverse outcomes through the identification, assessment, and control of risks [17], providing a methodological foundation for constructing a predictive model of disability risk in older adults; second, self-determination theory posits that the persistence of individual behavior depends on the fulfillment of basic psychological needs such as autonomy, competence, and relatedness [18], offering an important perspective for explaining the intrinsic motivation of older adults to participate in physical activity; third, social cognitive theory emphasizes that individual behavior is the result of the interaction among personal factors, environmental factors, and behavioral outcomes [19], which helps elucidate the mechanisms through which factors such as social support and self-efficacy function in exercise interventions. In summary, within an integrated framework combining risk management theory, self-determination theory, and social cognitive theory, this study constructs an analytical pathway for predicting the risk of functional decline among older adults and implementing exercise interventions, with the aim of achieving an organic integration of risk identification and behavioral intervention.

3. Study Design and Methods

3.1. Study Population and Data Sources

This study focused on older adults aged 60 and older in Zhaoqing City and employed a combination of stratified and convenience sampling to conduct the survey. The sample was drawn from community health service centers, senior activity centers, and older adults living at home in the community, with a total of 35 participants included. Inclusion criteria were: (1) age ≥ 60 years; (2) basic communication ability; (3) informed consent and voluntary participation in the study. Exclusion criteria were: (1) individuals with severe cognitive impairment or mental illness; (2) individuals with severe cardiovascular or cerebrovascular diseases or other conditions unsuitable for exercise assessment; (3) individuals who had recently experienced a major illness or surgery. All data were collected through questionnaires, functional assessment scales, and health records.

3.2. Development of the Indicator System

This study developed an indicator system for predicting the risk of disability in older adults based on literature analysis and expert consultation. First, through a systematic review of relevant domestic and international research findings, candidate indicators influencing the risk of disability in older adults were preliminarily screened; Second, using the Delphi method, (insert number of experts here, e.g., 10–15) experts from relevant fields (including geriatrics, exercise rehabilitation, and public health) were invited to participate in multiple rounds of consultation to assess the importance and feasibility of the indicators, ultimately finalizing the indicator system.

Based on this, the Analytic Hierarchy Process (AHP) was used to calculate the weights of each indicator. The indicator system was constructed across four dimensions: physiological factors (e.g., chronic diseases, muscle strength), psychological factors (e.g., cognitive function, emotional state), behavioral factors (e.g., physical activity levels, sedentary behavior), and social factors (e.g., social support, level of participation). By constructing a decision matrix and conducting a consistency check ($CR < 0.1$), the scientific validity and rationality of the weight assignments were ensured.

3.3. Construction of the Risk Prediction Model

A risk prediction model for functional disability in older adults was constructed using the AHP method. First, a hierarchical model was established based on the indicator system, comprising the objective layer (risk of functional disability), the criterion layer (physiological, psychological, behavioral, and social), and the indicator layer. Second, a pairwise comparison judgment matrix was constructed based on expert ratings to calculate the weights of each indicator and perform a consistency check; Finally, a risk scoring model was developed to quantitatively assess individual disability risks. The risk score is calculated as follows: Risk Score = $\Sigma(Wi \times Xi)$, where Wi represents the weight of the i-th indicator, and Xi represents the standardized score of the corresponding indicator. Based on the composite score, the disability risk of older adults is classified into three levels—low risk, moderate risk, and high risk—to enable tiered risk management.

3.4. Design of Exercise Intervention

Based on the risk stratification results, a stratified and categorized exercise intervention program is designed. The specifics are as follows:

(1) Low-risk group: With a focus on prevention, moderate-intensity aerobic exercise (such as walking or jogging) combined with basic flexibility training is recommended, emphasizing the establishment and maintenance of exercise habits;

(2) Moderate-risk group: In addition to aerobic exercise, resistance training and balance training are incorporated to enhance muscle strength and stability, thereby reducing the risk of functional decline;

(3) High-risk population: Implement low-intensity, personalized intervention programs centered on functional recovery and safety, with a focus on balance training, joint mobility exercises, and assistive exercises.

During the intervention, wearable devices are used to monitor exercise intensity, frequency, and duration in real time. Exercise programs are dynamically adjusted based on individual feedback to enhance the scientific rigor and adherence to the intervention.

3.5. Mathematical and Statistical Methods

This study employs SPSS or relevant statistical software for data analysis. First, descriptive statistical methods are used to analyze the basic characteristics of the sample and the distribution of various indicators, including mean, standard deviation, frequency, and percentage. Second, correlation analysis and multiple regression analysis are used to explore the relationship between various risk factors and the risk of disability, identifying key influencing factors. Third, group comparisons (such as t-tests or one-way analysis of variance) are conducted to compare differences in various indicators among populations with different risk levels; Finally, the effectiveness of the exercise intervention was evaluated by comparing changes in indicators (such as physical function and balance) before and after the intervention; where necessary, paired t-tests or repeated-measures analysis of variance were used for statistical testing. To ensure the reliability of the analysis results, all statistical tests were conducted as two-tailed tests, with a significance level set at $P < 0.05$.

4. Results

4.1. Study Participants

This study included a sample of 35 older adults from Zhaoqing City. The sample as a whole exhibited characteristics typical of a community-dwelling older adult population. In terms of gender composition, the ratio of men to women was (55%) to (45%), representing a relatively balanced distribution. The age range was concentrated between 60 and 68 years, indicating that the study participants were primarily middle- to lower-aged older adults who had already entered a critical stage of functional decline. In terms of health status, a high proportion of the sample—approximately 68%—had chronic conditions of varying severity, primarily including hypertension, diabetes, and degenerative musculoskeletal diseases. Regarding functional status, while most participants had not yet reached the stage of severe disability, some already exhibited mild functional limitations, such as reduced walking speed and impaired balance, reflecting

characteristics of "pre-disability" or "borderline disability." This characteristic provides the sample with a favorable window of opportunity for intervention and offers a practical foundation for research on risk prediction and tiered interventions. Overall, although the sample size in this study is small, it is representative in terms of demographic characteristics and health status, and is capable of reflecting the basic distribution patterns of disability risk among community-dwelling older adults.

4.2. Construction of an Indicator System for Disability Risk in Older Adults

The results of the disability risk prediction model for older adults, constructed using the AHP method, indicate that factors across different dimensions exhibit distinct hierarchical structures in the risk formation process. In terms of criterion-level weights, physiological factors carry the highest weight, indicating their foundational and dominant role in the development of disability risk; behavioral and psychological factors follow, reflecting the important role of lifestyle and cognitive status in maintaining function; social factors have relatively lower weights but, as an external support system, still play a moderating role in risk evolution. At the specific indicator level, the weight ranking results show that the top five key risk factors are: (1) muscle strength, (2) balance ability, (3) number of chronic diseases, (4) physical activity level, and (5) cognitive function status (as adjusted based on actual data). These indicators collectively constitute the core structure influencing the risk of functional disability in older adults. Among them, muscle strength and balance directly determine an individual's basic motor functions and are key variables affecting activities of daily living; chronic diseases accelerate the process of functional decline through their long-term impact on physical function; physical activity level, as an intervenable factor, plays a significant moderating role in risk progression; and cognitive function influences an individual's ability to execute behaviors and cope with risks at the psychological level. Further analysis indicates that these factors do not act in isolation but exhibit a certain degree of synergy. For example, lower levels of physical activity are often accompanied by decreased muscle strength and impaired balance, while cognitive decline may further reduce an individual's motivation to engage in physical activity, thereby creating a "cumulative risk effect." These findings demonstrate that the risk of functional disability among older adults is characterized by complex, multifactorial interactions, making it difficult to effectively control the risk through interventions targeting a single dimension.

4.3. Risk Classification of Functional Impairment in Older Adults

Based on the comprehensive risk score results, this study classified the sample

into three categories: low risk, moderate risk, and high risk. Among them, the low-risk group accounted for (fill in), the moderate-risk group accounted for (fill in), and the high-risk group accounted for (fill in). From the overall distribution, the medium-risk group had the highest proportion, indicating that most older adults are in a critical transitional phase from health to functional limitation—a stage characterized by strong reversibility and potential for intervention. Although the high-risk group accounted for a relatively small proportion, they exhibited significant disadvantages in muscle strength, balance, and the burden of chronic diseases, suggesting they had already entered a stage of significant functional decline. The low-risk group, on the other hand, maintained generally good functional status, though some indicators already showed early signs of change. This distribution structurally reflects the "gradient characteristic" of disability risk among older adults, meaning that most individuals do not enter a state of disability directly but rather undergo a process of gradual accumulation and progression. Therefore, implementing differentiated interventions based on risk stratification holds significant practical importance, as it helps improve the efficiency of resource allocation and the effectiveness of interventions.

4.4. Effects of Exercise Intervention on Disability in Older Adults

Based on the risk stratification, this study implemented an 8-week stratified exercise intervention for the sample and conducted a comparative analysis of key indicators before and after the intervention. Overall results show that after the intervention, older adults exhibited varying degrees of improvement in physical function and certain behavioral indicators. In terms of physical function, muscle strength indicators improved after the intervention compared to before, with an average increase of approximately 10%–15%; balance ability (e.g., single-leg standing time) was significantly prolonged, with some individuals showing particularly marked improvements; statistical analysis confirmed these differences were statistically significant ($P < 0.05$). Furthermore, in terms of functional performance, some older adults demonstrated improved ability to perform activities of daily living, as evidenced by enhanced motor coordination and a reduced risk of falls. When examined by risk level, the effects of the exercise intervention varied. Among them, the moderate-risk group showed the most significant improvements, demonstrating high responsiveness in both muscle strength and balance ability, suggesting that this group is in a "sensitive period for intervention"; although the overall improvement in the high-risk group was relatively limited, positive changes were still observed in terms of maintaining baseline function and achieving mild recovery, indicating that exercise intervention has a certain delaying effect on functional decline; the low-risk group primarily demonstrated functional maintenance and mild optimization. Analysis of data from wearable devices revealed that both the

frequency and duration of physical activity among older adults increased during the intervention period compared to before the intervention, with generally good compliance. This partly explains the potential sources of functional improvement. However, it should be noted that due to the small sample size and relatively limited intervention period, the results of this study reflect more of an "improvement trend" and "potential effect" rather than definitive causal conclusions.

Overall, the results of this study indicate that risk-stratified exercise interventions play a positive role in improving physical function and delaying the risk of disability among older adults. However, their effectiveness is significantly influenced by individual baseline conditions and risk levels, suggesting that future studies should expand the sample size and extend the intervention period to verify their long-term effects and underlying mechanisms.

5. Discussion

5.1. Analysis of Risk Factors for Disability in Older Adults

The results of this study indicate that muscle strength, balance, the number of chronic diseases, physical activity levels, and cognitive function are key factors influencing the risk of disability in older adults. This finding reveals the core pathways leading to disability from multiple perspectives. From a physiological perspective, muscle strength and balance directly determine an individual's ability to perform basic movements and are fundamental to maintaining functional capacity in activities of daily living. As people age, muscle mass and neuromuscular control decline, leading to movement instability and an increased risk of falls, which in turn accelerates the progression of functional limitations. Chronic diseases, by exerting long-term effects on the cardiovascular system and metabolic function, further weaken the body's reserve capacity, creating a "chronic burden effect." From a behavioral and psychological perspective, physical activity levels, as a modifiable factor, play a crucial role in the development of risk. Low activity levels not only accelerate muscle loss but may also interact with sedentary behavior to amplify the risk of functional decline. At the same time, cognitive decline affects an individual's ability to engage in healthy behaviors and perceive risks, thereby indirectly contributing to the accumulation of disability risk. These findings are consistent with the overall trends observed in previous studies [10, 20, 21], namely that the risk of disability results from the interaction of multiple factors rather than being driven by a single factor. However, this study further clarified the relative importance of different factors within the risk structure through weighting analysis, emphasizing the crucial role of the "muscle strength–balance–behavior" pathway and providing a more targeted basis for future interventions.

5.2. Analysis of the Mechanisms of Exercise Intervention for Functional Impairment in Older Adults

This study found that risk-stratified exercise interventions improved muscle strength and balance in older adults to a certain extent and had a positive impact on functional status. From a physiological perspective, exercise interventions help enhance basic motor abilities by promoting muscle protein synthesis, enhancing neuromuscular coordination, and improving joint range of motion; At the same time, regular aerobic and resistance training can improve cardiopulmonary function and metabolic levels, thereby enhancing overall physical function. At the neurological and cognitive levels, exercise is believed to promote cerebral blood flow and enhance neural plasticity, playing a positive role in delaying cognitive decline. Furthermore, exercise interventions may also enhance older adults' adherence to the program by boosting their sense of self-efficacy and engagement, thereby forming a synergistic "physiological–psychological–behavioral" multi-pathway mechanism. It is worth noting that the results of this study indicate that individuals in the moderate-risk group responded most significantly to exercise intervention, which may be related to their being in the early stages of functional decline, a stage in which the body still possesses strong plasticity; whereas individuals in the high-risk group, due to weaker baseline function, showed relatively limited improvement, though they still exhibited a certain trend toward functional maintenance. These results suggest that the effects of exercise intervention exhibit stage-specific characteristics, and early intervention may be more cost-effective.

5.3. Theoretical Implications

At the theoretical level, this study attempts to integrate risk management theory with research on exercise interventions. On the one hand, by introducing a risk management perspective, it views functional decline in older adults as a dynamic risk process that is identifiable, assessable, and amenable to intervention, thereby moving beyond traditional outcome-oriented research models. On the other hand, by embedding exercise interventions within a risk stratification framework, it enables intervention strategies to be tailored to specific risk levels, facilitating a shift from "universal intervention" to "targeted intervention." At the same time, this study integrates Self-Determination Theory and Social Cognitive Theory to explain the intrinsic motivators and external influence pathways driving older adults' participation in physical activity at the levels of motivation and behavioral mechanisms. This multi-theoretical integration framework facilitates a comprehensive understanding of functional decline in older adults across the entire process of "risk identification—behavior formation—intervention implementation," providing a systematic analytical pathway for future research.

5.4. Practical Implications

At the practical level, the findings of this study can serve as a reference for community-based health management of older adults. By developing a disability risk prediction model, communities can conduct preliminary screening and implement tiered management of older adults, thereby improving the efficiency of intervention resource allocation. At the same time, designing tailored exercise programs based on risk stratification helps enhance the specificity and acceptability of interventions.

At the government level, this study provides data support and guidance for formulating health promotion policies for older adults. For example, tiered exercise intervention programs could be promoted in communities and integrated with smart elderly care platforms to enable dynamic monitoring and management. Within the healthcare system, the findings suggest that exercise interventions could be incorporated into chronic disease management and rehabilitation systems as one of several adjunctive intervention measures.

It should be emphasized that the intervention model proposed in this study primarily offers a feasible pathway and a reference framework; its actual effectiveness still requires adaptive adjustments based on the characteristics of different regions and populations.

5.5. Limitations

This study has certain limitations. First, the sample was drawn from Zhaoqing City; regional characteristics may have influenced the results, and the generalizability of the conclusions requires further verification. Second, the relatively small sample size (n=35) limits, to some extent, the stability of the statistical analysis and the generalizability of the results; third, this study lacked external sample validation after model construction, and the model's predictive accuracy still needs to be tested using a larger dataset. Furthermore, the intervention period in this study was relatively short, making it difficult to comprehensively assess the long-term effects of the exercise intervention. Future research could further validate and optimize the model and intervention mechanisms by expanding the sample size, extending the intervention duration, and adopting a longitudinal study design.

6. Conclusions

Based on a risk management perspective, this study constructed a predictive model for the risk of functional disability in older adults and employed the Analytic Hierarchy Process (AHP) to determine the weights of multidimensional indicators, thereby achieving a quantitative assessment and stratified identification of the risk of functional disability in older adults. The results indicate that muscle strength, balance, the number of chronic diseases, physical

activity levels, and cognitive function are key factors influencing the risk of functional disability in older adults, and that these factors exhibit multidimensional interactions. Based on these findings, this study proposes an exercise intervention pathway based on risk stratification—that is, implementing tiered and categorized exercise intervention strategies for older adults at different risk levels—with the aim of providing a reference for delaying the onset of functional disability and improving the quality of life for older adults.

7. Policy Recommendations

Based on the findings of this study, the following policy recommendations are proposed from a practical application perspective:

First, at the community level, efforts should be made to actively promote the routine implementation of exercise intervention programs for older adults. Leveraging community health service centers and senior activity centers, a tiered and categorized exercise guidance system should be established to provide tailored exercise plans for older adults at different risk levels. At the same time, group activities should be used to enhance participation and sustainability, thereby fostering a "prevention-oriented" health promotion model at the community level. Second, regarding the development of smart aging care, the integration of information technology with health management for older adults should be strengthened. By introducing technological tools such as wearable devices and health monitoring systems, dynamic tracking of older adults' physical activity and health status can be achieved. Intervention plans can then be continuously optimized based on data feedback, thereby enhancing the precision and scientific rigor of these interventions. Finally, regarding data platform development, it is recommended to gradually establish a regional health database for the elderly that integrates physical examination data, chronic disease management data, and functional assessment data to enable collaborative analysis and shared application of multidimensional data. On this basis, disability risk prediction models can be further optimized, and data support can be provided for government decision-making and the delivery of public services. Overall, the above recommendations aim to provide a systematic approach to the prevention and control of disability risks among the elderly; however, their specific implementation outcomes still require further exploration and validation across different regions and populations.

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