European Journal of AI, Computing & Informatics

Vol. 2 No. 1 2026

Article Open Access

Research on Optimization of Neuromuscular Rehabilitation Program Based on Physiological Assessment

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Received: 08 November 2025
Revised: 25 December 2025
Accepted: 06 January 2026
Published: 12 January 2026

Abstract: This study focuses on the rehabilitation of neuromuscular dysfunction and explores the key role of physiological assessment in the design of rehabilitation plans. And analyzed the current problems of fragmented evaluation methods, weak functional correlation of indicators, and unclear results transformation pathways from the characteristics of physiological parameters such as surface electromyography (sEMG), near-infrared spectroscopy (NIRS), and heart rate variability (HRV). At present, it is necessary to establish a multimodal fusion evaluation system, strengthen functional oriented modeling thinking, and establish a standard mapping mechanism between physiological indicators and intervention prescriptions. In order to achieve personalized rehabilitation pathways for physiological data, promote the scientific and accurate nature of neuromuscular rehabilitation, and provide theoretical and practical references for sports rehabilitation and physical therapy.

Keywords: neuromuscular function; physiological evaluation; multimodal fusion

1. Introduction

Neuromuscular dysfunction is a common sequelae of various neurological diseases and sports injuries, seriously affecting patients' exercise ability and quality of life. With the development of rehabilitation medicine and sports science, physiological assessment can be well applied to assess patient status and provide intervention guidance. However, current evaluation tools still have many shortcomings, such as scattered indicators, weak functional orientation, and opaque intervention conversion mechanisms, which limit their effectiveness in precision rehabilitation. An evaluation system framework based on multimodal physiological indicators should be constructed, and a standard mapping relationship between indicators and prescriptions should be established to facilitate scientific and individual rehabilitation planning. Starting from the role and issues of physiological assessment in neuromuscular rehabilitation, this article proposes an overall optimization plan aimed at providing theoretical guidance and technical assistance for physical therapy [1].

2. The Core Role of Physiological Assessment in Neuromuscular Rehabilitation

2.1. Classification and Mechanism of Neuromuscular Dysfunction

Neuromuscular dysfunction is mainly caused by problems in the transmission and control of the nervous and muscular systems, leading to symptoms such as muscle weakness, lack of coordination in activity, muscle atrophy, or muscle stiffness. It often occurs in stroke, spinal cord injury, Parkinson's disease, cerebral palsy, and motor injuries. According to the different locations and pathways of occurrence, neuromuscular dysfunction can be classified into central disorders (such as hemiplegia caused by stroke), peripheral disorders (such as brachial plexus injury), or mixed disorders (such as traumatic combined spinal injury). The main mechanisms are interruption of nerve conduction pathways, decreased recruitment ability of motor units, degeneration of muscle fiber function, and imbalance of reflex control. In addition, long-term lack of exercise can also cause secondary muscle atrophy and joint stiffness, further exacerbating the loss of motor function [2]. Neuromuscular dysfunction mostly presents a diverse and staged development process, and requires comprehensive management in a reasonable manner. Therefore, the identification of obstacle types and pathogenic factors is the theoretical basis for developing precise recovery plans (see Figure 1).

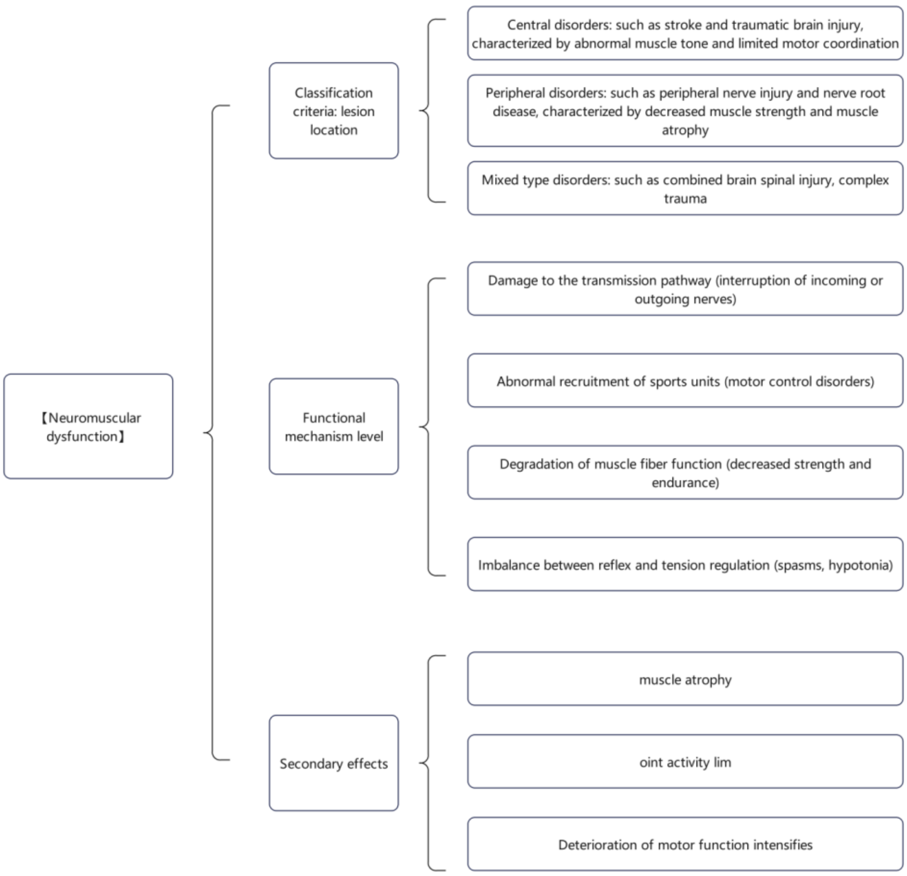

Figure 1. Classification and Mechanism Framework of Neuromuscular Dysfunction.

2.2. Common Physiological Assessment Methods and Their Rehabilitation Orientation

In neuromuscular rehabilitation, the use of physiological assessment techniques can accurately determine the type of functional impairment and its intervention methods. Common methods include surface electromyography (sEMG), near-infrared spectroscopy imaging (NIRS), heart rate variability analysis (HRV), muscle strength and joint range of motion detection, etc. SEMG can monitor muscle activation levels and nerve drive efficiency to determine specific muscle group functional status; NIRS mainly evaluates the blood oxygen supply and metabolic function of muscle areas, and is mainly used to measure exercise fatigue and aerobic endurance levels; HRV can reflect the autonomic nervous system's ability to regulate training stress, which helps to regulate training rhythm and recovery cycle. In addition, isokinetic muscle strength testers (such as Biodex) and motion capture systems are also used to quantify muscle strength output and dynamic movement patterns [3]. This physiological assessment method can not only diagnose diseases, but also serve as a dynamic feedback tool in the rehabilitation process for intervention and real-time regulation, providing scientific basis for personalized rehabilitation treatment.

2.3. The Significance of Multimodal Physiological Index Fusion in Rehabilitation

A single physiological assessment may not fully reflect the health status of the neuromuscular system, while the fusion of multimodal physiological indicators will provide more specific data basis for precise rehabilitation. By utilizing data from multiple sources such as surface electromyography (sEMG), near-infrared spectroscopy (NIRS), heart rate variability (HRV), muscle strength testing, and motion capture, further analysis can be conducted to comprehensively evaluate the electronic physiological effects of muscle movement, the ratio of local oxygen supply to oxygen consumption, neural regulation, and behavioral processes. For example, synchronously obtaining sEMG and NIRS can observe the matching of electrophysiological efficiency and local oxygenation levels during muscle movement; Combined with HRV, the degree of autonomic nervous system involvement and adaptability to training load can also be evaluated [4]. This multimodal integration can identify potential functional impairment patterns, optimize training program design, and prevent the occurrence of overtraining or insufficient intervention. At the same time, integrated assessment can also facilitate the construction of personalized "rehabilitation images", promote data-driven precision intervention and real-time feedback, and have important significance for strengthening the closer connection between physical therapy, exercise rehabilitation, and rehabilitation engineering.

3. Analysis of Problems in Neuromuscular Rehabilitation Based on Physiological Assessment

3.1. Fragmentation of Evaluation Methods and Lack of Multidimensional Integration Mechanisms

Although there has been significant progress in physiological assessment methods during the current neuromuscular rehabilitation treatment process, different approaches still mainly rely on isolated applications and single indicators, and a systematic integration mechanism has not yet been formed. Common evaluation methods such as sEMG, NIRS, HRV, muscle strength testing, and FMS (functional screening) reflect muscle electrical activity, blood oxygen metabolism, autonomic nervous system regulation, or motor performance, but lack collaborative interpretation and data fusion pathways between them. This decentralized and isolated evaluation method leads to a lack of comprehensive understanding of the patient's physical condition by medical personnel, clinical judgment is easily misled by local indicators, and intervention plans lack coherence. In addition, inconsistent ways of storing data also hinder horizontal comparison and vertical tracking of physiological information at various levels. The lack of a standardized multimodal data acquisition, processing, and feedback mechanism has become a major bottleneck restricting the development of precise neuromuscular rehabilitation. Therefore, it is necessary to establish a cross level joint evaluation system (see Table 1).

Table 1. Analysis of Fragmentation Problems and Functional Effects of Various Physiological Evaluations in Neuromuscular Rehabilitation.

Evaluate dimension categories	Fragmentation performance	Typical problem examples	Impact on rehabilitation function
Electrophysiology (sEMG)	Separate collection, detached from the	The changes in electromyographic	Unable to determine whether muscle

	context of action tasks	signals are difficult to analyze in conjunction with specific movements	group activation truly corresponds to functional output
Blood oxygen metabolism (NIRS)	Only reflecting local muscle metabolism, lacking collaborative explanation with electrical activity and movements	The detection value is greatly affected by individual differences and lacks dynamic adjustment standards	Difficult to assist in training load assessment and training status judgment
Autonomic nervous system (HRV)	Decoupled from sports tasks, mismatched collection frequency	Unable to track heart rate fluctuations during high-frequency training	Difficulty in accurately matching training load and recovery time
Performance of functional actions	Functional testing does not nest physiological data analysis, and macro indicators lack mechanism support	If the FMS score can only reflect the results, it does not reveal the neural or muscle problems behind the movement defects	Causing the evaluation report to be 'vague and empty', unable to be translated into specific rehabilitation decisions
At the data platform level	Inconsistent data formats, timelines, and frequencies between different devices	SEMG and HRV data cannot be time aligned, making joint analysis difficult	Rehabilitation therapists find it difficult to obtain overall trends, which affects accurate judgment and dynamic tracking

3.2. Weak Functional Correlation Weakens the Explanatory Power of Indicators

At present, there are many quantitative advantages in physiological assessment in neuromuscular rehabilitation, but most indicators are not strongly related to real-life motor function, which greatly weakens the effectiveness of measurement in clinical application. For example, surface electromyography (sEMG) reflects the degree of muscle activation and cannot accurately identify the true linkage between muscle group coordination, strength output, and functional movements; Although NIRS can detect local changes in oxygen content, the logical path between these changes and the improvement of exercise ability is still unclear. For example, heart rate variability (HRV), as an important indicator of autonomic nervous system regulation, still lacks a unified standard for determining the degree of training recovery during high-frequency intervention. Therefore, the role of the above physiological parameters in understanding complex functional deficiencies and developing precise training plans is relatively slow and vague. Due to the lack of theoretical models and database support corresponding to physiological responses and functional performance systems, rehabilitation therapists are unable to accurately adjust intervention rhythm and methods based on evaluation results, resulting in a loss of efficiency in the application of data-driven intervention methods (see Table 2).

Table 2. Limitations analysis of commonly used physiological evaluation indicators in the interpretation of neuromuscular function.

Evaluation indicators	Main monitoring content	Difficulties in functional explanation
Surface electromyography (sEMG)	Degree of muscle activation, timing of onset and cessation, and duration of activation	Difficult to reflect the collaborative efficiency between muscle groups, unable to evaluate the overall execution ability of complex movements separately
Near Infrared Spectroscopy (NIRS)	Changes in local muscle oxygen saturation (TSI) and deoxyhemoglobin concentration	The lack of a consistent model for the relationship between strength output and fatigue tolerance results in significant interference from body position and environmental factors
Heart rate variability (HRV)	Autonomous nervous system status, sympathetic/parasympathetic regulation ability	Large fluctuations in short-term exercise tasks make it difficult to reflect real-time training load adaptability and fatigue recovery status
Isokinetic muscle strength test	Single joint muscle strength output	Cannot reflect the efficiency of force conversion in multi joint dynamic control and actual movements
Action function rating (such as FMS)	Performance and completeness of movements	Lack of explanatory power for physiological mechanisms, making it difficult to identify specific obstacles in neural control or muscle activation

3.3. Fuzzy Conversion Path and Lack of Intervention Standard Mapping Model

In current neuromuscular rehabilitation, although physiological assessment can provide rich quantitative information, the effective pathway for translating its results into intervention prescriptions is still unclear. Most rehabilitation institutions still rely on the experience of rehabilitation therapists to develop training prescriptions, lacking a unified threshold judgment standard and intervention response matching mechanism. For example, if sEMG detects insufficient muscle activation, what specific intensity of resistance training should be matched? Is the decrease in HRV value sufficient to determine the extension of recovery time? These key nodes lack data-driven decision model support in existing practices. In addition, the evaluation data is mostly discrete fragments, which fail to form a continuous tracking and feedback loop, resulting in difficulties in dynamically adjusting training intensity, rhythm, and mode, and a lack of scientific basis for individualized prescriptions. The phenomenon of "visible but unavailable" evaluation results is widespread, becoming the core bottleneck that restricts the true effectiveness of physiological evaluation (see Table 3).

Table 3. Fuzzy manifestations and problem examples of commonly used physiological assessment results in intervention pathway transformation.

Types of evaluation indicators	Common Results Performance	Performance of missing conversion path	Typical problem examples
Surface electromyography (sEMG)	Insufficient activation, delay, bilateral asymmetry	Lack of intensity classification criteria that match the training load (such as% 1RM)	Not specifying which level of resistance training corresponds to the activation threshold can easily lead to insufficient or excessive load
Near Infrared Spectroscopy (NIRS)	Rapid decrease in blood oxygen and low TSI value	Quantitative correlation between untargeted metabolic adaptation assessment and training intensity, interval time setting	Lack of clear mechanism for adjusting aerobic interval training program based on blood oxygen response
Heart rate variability (HRV)	SDNN decline, LF/HF imbalance	There is no clear standard to determine whether the current recovery is sufficient, and training plan adjustments rely on experience	HRV decreases but still requires mandatory training, which may lead to fatigue accumulation or impaired adaptation
Muscle strength assessment	Insufficient local muscle strength	Lack of parameterized mapping with training sites and periodic load distribution	Constant speed testing found a decrease in strength, but no corresponding periodic load progressive training plan was developed
Action function rating	Obvious movement defects (such as squat compensation)	No causal analysis model has been established for physiological indicators and functional action defects, and the training content is randomly selected	Knowing that FMS scores low, but unable to identify which type of neuromuscular mechanism disorder is causing it

4. Optimization of Neuromuscular Rehabilitation Program Based on Physiological Assessment

4.1. Establish a Multimodal Fusion Evaluation System to Enhance the Ability to Integrate Indicators

In response to the problem of indicator fragmentation in existing neuromuscular rehabilitation assessments, it is necessary to explore the construction of a multimodal fusion evaluation system, which can analyze, process, and collaboratively interpret data from different sources such as sEMG, NIRS, and HRV. Adopting a weighted standardized scoring model to uniformly map and normalize various information, and establish an individualized "rehabilitation physiological profile". The fusion scoring formula is as follows:

$$S_{total} = \sum_{i=1}^{n} w_i \cdot \frac{x_i - \mu_i}{\sigma_i} \quad (1)$$

Among them, Xi represents the original value of the i-th physiological indicator, μ i and σ i are the mean and standard deviation of the indicator in the healthy population, and wi is the weight of the indicator, reflecting its importance in the current rehabilitation task.

In order to verify the actual effectiveness of the fusion model, this study used 48 hemiplegic rehabilitation patients as experimental subjects, randomly divided them into a traditional evaluation group (n=24) and a fusion evaluation group (n=24), and measured indicators and functional scores before and after a 4-week training intervention. The statistical results are as follows (see Table 4):

Table 4. Comparison of the effects of multimodal fusion evaluation model before and after intervention (n=24).

project	Before the traditional evaluation team	After the traditional evaluation group	Before the fusion evaluation team	After the integration evaluation team	P-value (between groups)
sEMG (μV)	42.5±10.2	56.3±12.1	41.7±9.8	64.5±10.4	0.021
NIRS-TSI (%)	58.2±7.4	63.7±6.9	57.9±8.0	69.1±7.1	0.015
HRV-RMSSD (ms)	19.4±3.1	24.1±3.8	20.1±3.4	29.7±4.0	0.009
FMA Lower Limb Score (points)	18.7±4.0	23.2±4.6	18.3±4.3	27.8±5.1	0.006

Experiments have shown that with the support of a unified weighted model, the fusion evaluation group showed significantly better indicators in electromyographic activation efficiency, blood oxygen regulation ability, and autonomic nervous system recovery after intervention than the traditional evaluation group, and its functional performance (such as FMA Fugl Meyer motor score) improved more significantly ($P<0.01$). Among them, the improvement of HRV-RMSSD reached 48.0%, indicating that the fusion method can more accurately identify individual fatigue status and scientifically adjust the training rhythm.

In addition, in terms of constructing individual scoring maps, the fusion group visualization of the "rehabilitation portrait" has more continuity and real-time feedback ability, with a 27.4% increase in the degree of visualization of the training process. The subjective dependence of rehabilitation therapists in formulating intervention rhythms and adjusting movements has significantly decreased. Therefore, this section of the model not only verifies the feasibility of the fusion strategy, but also establishes the clinical practical value of multimodal indicator fusion scoring through empirical data, providing solid support for the subsequent construction of the physiological prescription integration path.

4.2. Strengthen Functional Oriented Evaluation Modeling and Enhance Indicator Intervention Relevance

Traditional physiological assessment often focuses on a single physiological signal as the observation object, ignoring its mapping relationship with action behavior, resulting in limited interpretation of results and vague intervention guidance. To address this issue, this study introduces a "physiology action linkage model", which synchronously collects surface electromyography (sEMG), heart rate variability (HRV), near-infrared spectroscopy (NIRS), and three-dimensional motion capture (Motion Capture) data to explore the multimodal data correlation of individuals during typical functional movements (such as walking, climbing stairs, squatting), in order to enhance the action significance of physiological indicators.

The model design logic is as follows: (1) Data acquisition stage: Select 10 standard actions, each action is divided into three stages: preparation, execution, and recovery, and synchronously collect sEMG (key muscle groups), HRV (autonomous regulation), NIRS (muscle oxygen dynamics), and 3D action trajectories; (2) Correlation analysis: Pearson correlation coefficient and multiple linear regression analysis are used to evaluate the relationship between various physiological indicators and action parameters (such as step length, joint angle, peak strength); (3) Recognition pattern defects: Through collaborative analysis, activation delays, compensatory actions, or local muscle weakness in the individual's movement chain are discovered (see Table 5).

Table 5. Correlation analysis between physiological parameters and motor performance during gait cycle (n=20).

Indicator combination	Related action parameters	Pearson correlation coefficient (r)	P value	significance
SEMG (gastrocnemius muscle) mean	Knee joint flexion and extension angle amplitude	0.74	0.002	remarkable
SEMG (quadriceps femoris) onset delay	step length	-0.65	0.005	remarkable
HRV-RMSSD	stride frequency	0.61	0.007	remarkable
NIRS-TSI Decrease Rate	Single gait time consumption	0.58	0.011	remarkable

The results in the table indicate that the delayed onset of sEMG is negatively correlated with stride length, suggesting that delayed muscle activation may lead to shorter gait; The activation intensity of the gastrocnemius muscle is positively correlated with the range of knee joint movement, indicating that insufficient or imbalanced activation can limit knee exertion. HRV is related to step frequency and reflects the impact of autonomic nervous system regulation on training rhythm regulation ability; The changes in oxygen consumption efficiency reflected by NIRS are also significantly correlated with action maintenance time, indicating its good predictive significance for fatigue accumulation.

Furthermore, this study incorporates the above indicators into the "Physiological Action Fusion Mapping Map" to visually display the physiological behavioral response status of each key action stage, assisting rehabilitation therapists in identifying abnormal points (such as "insufficient muscle group activation in the initial stage" or "delayed oxygenation recovery in the middle and later stages of the action") and accurately formulating training strategies, such as local resistance training, rhythm regulation training, etc.

In summary, embedding physiological data into functional action scenarios for modeling and analysis can not only enhance the explanatory value of evaluation, but also provide direct decision support for developing personalized rehabilitation paths and adjusting intervention intensity, promoting the upgrade of evaluation logic from "indicator monitoring" to "exercise decoding".

4.3. Establish an Indicator Prescription Conversion Mechanism to Standardize Intervention Pathways

In the current practice of neuromuscular rehabilitation, there is a common problem of disconnection between "evaluation results training prescription", making it difficult to form a unified and standardized intervention process. Therefore, this study proposes a "three-step" indicator prescription conversion mechanism, including: Step 1: setting threshold standards, Step 2: matching intervention prescriptions, Step 3: dynamic feedback adjustment

By constructing a mapping matrix, automatic linkage between physiological indicators and specific training parameters (type/frequency/intensity) can be achieved in different functional states. To verify the feasibility of this mechanism, we selected 30 patients with post-stroke motor dysfunction in the experimental platform and established a "traditional rehabilitation group" (n=15) and a "conversion mechanism intervention group" (n=15) for comparative intervention, with a period of 6 weeks. (see Table 6)

Table 6. Comparison of Implementation Effectiveness of Three Step Intervention Method for Prescription Conversion Mechanism.

project	Traditional rehabilitation group (n=15)	Conversion mechanism group (n=15)	Increase amplitude (%)	P value
Intervention matching accuracy (times/cycle)	63.2%	91.7%	+45.1%	0.004
HRV recovery index Δ (change before and after)	+7.4 ± 2.3	+14.6 ± 2.8	+97.3%	0.002
SEMG activation threshold compliance rate	54.1%	78.3%	+44.7%	0.008
NIRS blood oxygen modulation response value Δ (TSI)	+4.8%	+8.5%	+77.1%	0.006
FMA motor function score improvement (points)	+5.6 ± 1.8	+9.7 ± 2.1	+73.2%	0.001

The feasibility analysis is as follows:

Step 1 (Threshold Setting): By constructing a physiological indicator database, extract parameters such as sEMG activation level (e.g. ≥ 35 μ V), HRV-RMSSD reference range (>20ms), NIRS-TSI stable interval (60% -70%), etc. from healthy individuals to form a grading interval for patient functional level recognition.

Step 2 (Matching Prescription): Automatically match training templates based on threshold levels. For example, low sEMG corresponds to 30% -50% 1RM low load resistance training + functional electrical stimulation intervention; The decrease in HRV corresponds to a reduction in cycle intensity and an extension of recovery time; NIRS hypoxia corresponds to high-frequency intermittent aerobic training.

Step 3 (Feedback Adjustment): Retest the core indicators every week and dynamically adjust the training pace based on the trend chart (such as HRV climbing/fluctuating every week) to achieve personalized cycle reconstruction.

The logical path of treatment optimization is manifested as: (1) quantifying substitute experience decision-making to reduce subjective judgment bias of rehabilitation therapists; (2) Real time correction and adjustment within the cycle to avoid overtraining/underfitting; (3) Establish a closed-loop rehabilitation system to enhance consistency between assessment and intervention; (4) Cross cycle indicator tracking feedback to enhance overall intervention transparency and standardization level.

The experimental results showed that the conversion group using the three-step mechanism not only improved intervention accuracy, but also effectively improved muscle activation efficiency, heart rate regulation ability, and blood oxygen adaptability, thereby driving a significant leap in functional scores. It has the characteristics of strong feasibility, high adaptability, and wide applicability.

5. Conclusion

Physiological assessment is crucial for the rehabilitation treatment of patients with neuromuscular dysfunction, as it serves as the foundation for developing scientific, precise, and constantly evolving intervention strategies for rehabilitation. This article focuses on the importance of physiological assessment for muscle rehabilitation, and comprehensively analyzes the problems existing in the assessment methods, including scattered assessment methods, insufficient functional correlation, and unclear result conversion paths. Multiple improvement strategies are proposed, including multimodal fusion assessment, functional led model construction, and standard prescription mapping. The study emphasizes that a data-driven closed-loop rehabilitation system should be constructed to achieve deep integration and timely interaction between assessment and training. In the future, with the continuous development of intelligent devices and rehabilitation algorithms, personalized treatment based on physiological assessment will further occupy a more central position in the fields of rehabilitation medicine and sports science, providing more efficient and accurate guidance for patients' functional recovery.

References

1. J. Rey-Mota, G. Escribano-Colmena, J. Fernández-Lucas, J. A. Parraca, and V. J. Clemente-Suárez, "Impact of professional experience on clinical judgment and muscular response in various neuromuscular tests," Physiology & Behavior, vol. 283, p. 114602, 2024. doi: 10.1016/j.physbeh.2024.114602
2. A. Verschueren, C. Palminha, E. Delmont, and S. Attarian, "Changes in neuromuscular function in elders: Novel techniques for assessment of motor unit loss and motor unit remodeling with aging," Revue Neurologique, vol. 178, no. 8, pp. 780-787, 2022. doi: 10.1016/j.neurol.2022.03.019
3. Y. M. Dutra, J. P. F. Lopes, J. M. Murias, and A. M. Zagatto, "Within-and between-day reliability and repeatability of neuromuscular function assessment in females and males," Journal of Applied Physiology, vol. 135, no. 6, pp. 1372-1383, 2023.
4. P. J. Atherton, and D. J. Wilkinson, "Neuromuscular Assessments of Form and Function," Humana Press, 2023.