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Review

Impact of professional experience on clinical judgment and muscular response in various neuromuscular tests

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A B S T R A C T

Muscle testing is an integral component in assessing musculoskeletal function and tailoring rehabilitation efforts. This study aimed i. to identify an objective evaluation system sensitive to analyze changes in different muscular conditions in different neuromuscular tests across a spectrum of professional experience levels; and ii. to analyze differences in objective parameters and clinical judgment between participants of different levels of expertise in different muscular conditions in different neuromuscular tests. Participants included 60 subjects with Level I to III expertise who performed blinded neuromuscular tests on the middle deltoid and rectus femoris muscles of 40 volunteer subjects. The methodology centered on standardizing test protocols to minimize variability, employing EMG to quantify muscle activity, thermography to capture thermographic muscular response, and digital dynamometry to measure muscular resistance. The findings revealed that while traditional methods like thermography and electromyography provide valuable insights, digital dynamometry stands out for its sensitivity in detecting muscle condition changes in neuromuscular test. Moreover, the data underscored the pivotal role of advanced training and expertise in enhancing the precision and accuracy of neuromuscular diagnostics, since there were significant differences in objective parameters and clinical judgment between participants of different levels of expertise in the different muscular conditions in Middle deltoid and Rectus femoris neuromuscular tests analyzed, presenting higher expertise participant clinical judgment like objective validated instrument.

1. Introduction

Muscle testing plays a crucial role in clinical assessment, rehabilitation, and sports medicine, providing valuable insights into muscular function and performance [1]. It is widely used in various fields, including physical therapy, sports medicine, and rehabilitation, to assess muscle strength, flexibility, and endurance [2–6]. Clinical judgment, defined as the ability of healthcare professionals to interpret clinical findings and make informed decisions, is central to effective muscle testing and treatment planning [7]. Clinicians rely on their expertise and experience to interpret muscle testing results and develop appropriate treatment plans tailored to individual patient needs. Furthermore, electromyography (EMG) technology offers objective quantification of muscle activity, allowing for precise evaluation of neuromuscular function and performance [8]. Despite the widespread use of muscle testing in various clinical settings, differences in clinical judgment and EMG response among professionals with varying levels of experience have been noted, raising questions about the reliability and consistency of muscle testing outcomes [9].

Previous research has underscored the pivotal role of both clinical judgment and EMG assessment in the comprehensive evaluation of muscle function. Clinical judgment, honed through years of practical

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experience and theoretical knowledge, serves as a cornerstone in the diagnostic process, aiding clinicians in deciphering patient symptoms and formulating appropriate treatment plans [10]. Conversely, EMG technology offers a complementary objective measure by quantifying muscle activity during various tasks, providing valuable insights into the neuromuscular system's functionality and response to stimuli [11]. Despite the individual merits of clinical judgment and EMG assessment, there exists a paucity of research elucidating their interplay, particularly concerning professionals with varying levels of expertise. While some studies have hinted at the potential influence of expertise on clinical decision-making and EMG interpretation [12]. The precise nature of this relationship remains poorly understood. Moreover, the extent to which these factors interact across different muscle tests remains largely unexplored. Addressing this gap in the literature is paramount for advancing our comprehension of muscle testing practices, refining diagnostic accuracy, and optimizing patient care strategies in clinical settings.

In this line, it is essential to consider the concept of experience and its influence on professional expertise in muscle testing. Experience encompasses not only the number of years in practice but also the depth and breadth of clinical exposure, specialized training, and ongoing professional development. Professionals with extensive experience often develop a nuanced understanding of musculoskeletal anatomy, biomechanics, and functional movement patterns, allowing them to make more accurate clinical judgments and interpretations during muscle testing procedures [13]. Furthermore, experienced practitioners may possess refined palpation skills and a heightened ability to detect subtle changes in muscle function, contributing to the overall reliability and effectiveness of their assessments [14].

Specifically, thermography has emerged as a complementary tool in the assessment of muscle function, organic health, and tissue conditions, bridging the gap between traditional muscle testing methods and the need for non-invasive diagnostic techniques [15,16]. This imaging technique, which captures the heat emitted by the body, provides valuable insights into the physiological state of muscles and tissues, enabling the detection of inflammation, nerve damage, and other conditions that might affect muscle performance and recovery [17]. Recent studies have highlighted thermography's utility in sports medicine and rehabilitation, where it is used to monitor muscle overload, detect early signs of injury, and guide recovery protocols [18–20]. By visualizing temperature variations across the body, thermography offers a unique perspective on the internal workings of the musculoskeletal system [21]. The integration of thermography into muscle testing protocols represents a significant advancement in our ability to diagnose and manage musculoskeletal conditions. Unlike EMG, which quantifies muscle activity electrically, thermography provides a heat map of the body, revealing areas of increased metabolic activity that may signal underlying pathology or dysfunction [22].

In this line, the incorporation of digital dynamometers in clinical and sports settings has significantly advanced our understanding and assessment of muscle strength, offering a more precise and objective measure of muscular function. This technology allows clinicians and researchers to quantitatively assess the force output of muscles in various conditions, providing valuable data for diagnosis, rehabilitation, and training programs [23]. The use of digital dynamometers has been particularly instrumental in evaluating the effectiveness of therapeutic interventions and designing personalized rehabilitation protocols [24]. These devices are show their reliability and validity in measuring muscle strength, underscoring its utility in clinical practice and research (Bohannon, 2019; [25]).

Despite the individual merits of clinical judgment and EMG assessment, there exists a paucity of research elucidating their interplay, particularly concerning professionals with varying levels of expertise. While some studies have hinted at the potential influence of expertise on clinical decision-making and EMG interpretation, the precise nature of this relationship remains poorly understood. Moreover, the extent to which these factors interact across different muscle tests remains largely unexplored [26]. Addressing this gap in the literature is paramount for advancing our comprehension of muscle testing practices, refining diagnostic accuracy, and optimizing patient care strategies in clinical settings.

Building on the foundational insights gleaned from the utilization of advanced diagnostic tools in neuromuscular assessments, this study is designed with two primary objectives. Firstly, we aimed to identify an objective evaluation system (thermography, electromyography, and digital dynamometry) sensitive to analyze changes in different muscular conditions in different neuromuscular tests across a spectrum of professional experience levels. Secondly, the study aimed to analyze differences in objective parameters and clinical judgment between participants of different levels of expertise in different muscular conditions in different neuromuscular tests. The Hypothesis 1 was that thermography, electromyography, and digital dynamometry will each demonstrate sensitivity in identifying changes across different muscular conditions in neuromuscular tests, across a spectrum of professional experience levels. The Hypothesis 2 was that variations in objective parameters and clinical judgments will be significantly associated with the practitioner's level of expertise, with higher levels of experience correlating with increased accuracy in the interpretation of muscle testing outcomes.

2. Methods

2.1. Participants

A total of 40 volunteer participants were tested in the study (8 females and 32 males;32.2 ± 7.8 years; 75,4 ± 15,9 Kg; 1,72 ± 0.08 m; 25.6 ± 4.6 cm/m^2). Eligibility for inclusion required individuals to be in good health, physically active, and free from any diagnosed pathologies. On the other hand, potential participants were excluded from the study if they were taking any medication, had any diagnosed pathology, or experienced any muscular limitations. The research methodology and the practices utilized adhered to ethical guidelines and the principles of the Declaration of Helsinki, receiving approval from the European University ethics committee (2024-510). Prior to the commencement of the study, every participant was thoroughly briefed on the potential risks involved and provided written consent.

2.2. Procedure

To standarize the protocol for the Functional Neurology Clinical Testing, given its uniqueness in application, we followed the methodology described by ®NeuroReEvolution (http://nre-therapy.com/). The measurements were conducted by a Level III certified practitioner in ®NeuroReEvolution Functional Neurology Manual Muscle Test, ensuring the maximum degree of expertise in diagnosing and addressing qualitative clinical diagnosis of muscle proprioceptive reflexes response to eccentric (stretch) and isometric contraction. This certification includes, among other elements, the consideration and control of more than 25 errors and variables that can modify the muscle stretch response when manually tested, discovered by its founders from decades of expertise, research and clinical practice regarding physical assessments to patients. The non-consideration of said variables can result in inconsistent results among practitioners and clinical errors.

We conducted manual muscles tests to two different muscles, being rectus femoris and middle deltoid in three different situations:

1. Normotonic response of the musculature, means the muscles can contract and relax properly.
2. Hypotonic response of the musculature (inhibition), having the muscles altered the reflexogenic response to an isometric action, resulting in an eccentric contraction (failure of the test). This

response is elicited by presenting the participant with a target displaying an "II" [27] (Fig. 1).
3. Hypertonic response of the musculature, meaning that the muscles can contract but they don't show a proper inhibition response to a given inhibitory stimulus (parallel lines or shortening of the muscle belly). This response is elicited by presenting the participant with a target displaying an "X" [27] (Fig. 1)

Middle deltoid was assessed with the patient on a seated position and being asked for an isometric contraction holding the position of the limb at 90° of shoulder abduction and straight elbow, while the practitioner pushes downwards creating momentum to the joint. Rectus femoris was assessed with the patient laying on the back and with the hip at 90° of flexion, 0° of internal and external rotation, abduction and adduction, and the knee at 90° of flexion. An isometric strength test was conducted, being the vector of force application by the practitioner from cranial to caudal, pushing on the distal third of the patient's thigh. The practitioner instructed the patient to exert the maximal voluntary contraction during the tests.

In this study, three levels of expertise were analyzed: low, medium, and high, corresponding with Levels I, II, and III of the ®NeuroReEvolution certification, respectively. This classification system served as a foundational framework to explore the nuanced interplay between professional experience and neuromuscular assessment outcomes. During the muscle testing sessions, practitioners were instructed to follow standardized protocols and techniques for each muscle test. They were also provided with detailed instructions on how to position the subjects, perform the tests, and record the outcomes accurately. To ensure consistency and reliability, all practitioners underwent a training session prior to data collection to familiarize themselves with the study protocols and minimize inter-rater variability.

Data collected during the muscle testing sessions included:

- Electromyographic recordings, clinical observations, and subjective assessments of muscle strength and function. EMG data were analyzed by standard protocols with the mDurance EMG to quantify muscle activation patterns and detect any differences in electromyographic response across the different experience levels of practitioners [28].
- Peripheral Vascular Response assessed through infrared thermography, capturing changes in blood flow and inflammation indicators. Thermographic images were captured in line with the European Association of Thermology's guidelines [29]. The thermographic data acquisition was performed using a FLIR ONE Edge Pro (Teledyne FLIR, Oregon, USA), while the analysis of the thermal imagery was conducted utilizing FLIR Tools software.
- Dynamometry by a validated handheld dynamometer ActivForce (AF; Activbody, San Diego CA) [30], that was placed between the practitioner's hand and the patient's limbs to measure the resistance.

In the study's protocol, we enlisted 30 Level I participants (Weight: 78.2 ± 19.0 kg; Height: 1.73 ± 0.09 m; BMI: 26.0 ± 6.1; Age: 34.2 ± 9.0 years), 20 Level II participants (Weight: 72.6 ± 10.2 kg; Height: 1.72 ± 0.08 m; BMI: 23.5 ± 2.0; Age: 32.4 ± 7.5 years), and 10 Level III participants (Weight: 86.5 ± 11.9 kg; Height: 1.75 ± 0.03 m; BMI: 28.3 ± 3.4; Age: 32.8 ± 4.1 years). Each was tasked with administering the neuromuscular tests twice to 10 randomly selected volunteer subjects. The neuromuscular tests were conducted blind, meaning the practitioner, positioned to test either the deltoid or the rectus femoris, executed the assessment and recorded their clinical judgment without receiving any feedback. This methodology was designed to ensure an unbiased evaluation of each muscle's condition, reflecting the pure clinical acumen of the practitioners at their respective levels of expertise.

2.3. Statistical analysis

The statistical analysis conducted using SPSS version 22.0 incorporated standard statistical measures, including mean and standard deviation (SD), to evaluate the central tendency and variability of muscle strength exerted across three levels of expert evaluations in various muscle tests. Additionally, a one-way Analysis of Variance (ANOVA) with Bonferroni post hoc and Chi-square test were employed to examine the differences in muscle strength and the accuracy of clinical

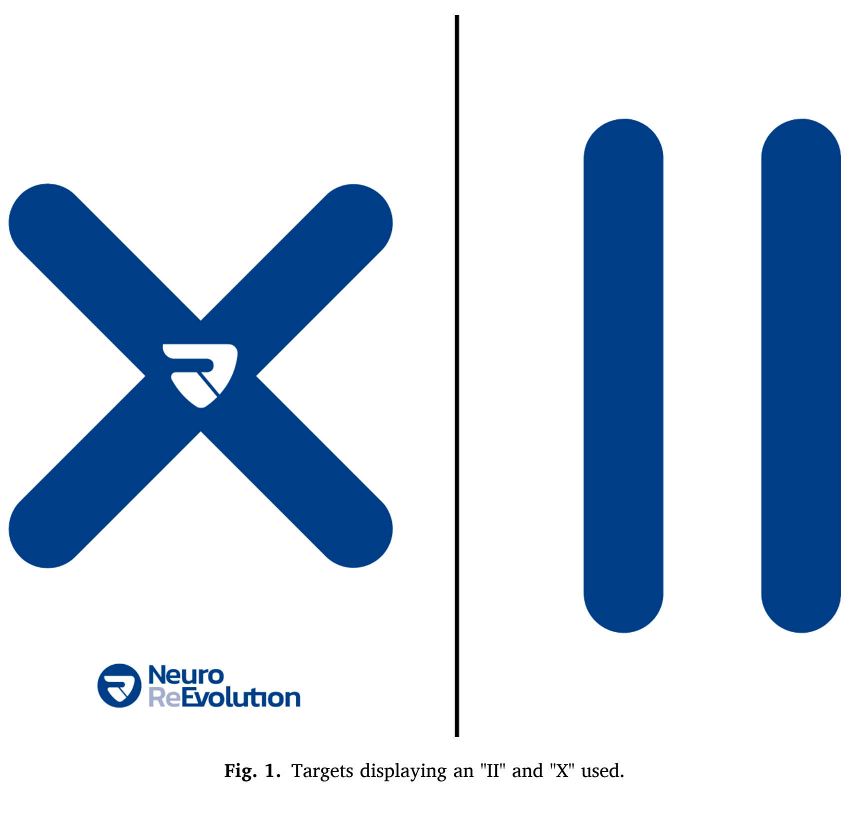

Fig. 1. Targets displaying an "II" and "X" used.

interpretations among the expert levels, respectively. Both the ANOVA and Chi-square analyses were predicated on a significance threshold of $p \leq 0.05$.

3. Results

In assessing the sensitivity of diagnostic tools within the muscle testing framework, our study reveals a noteworthy distinction. While thermography and electromyography analyses did not demonstrate the anticipated sensitivity for detecting changes across various muscular conditions—namely normotonic, hypotonic, and hypertonic states identified through muscle testing—the use of the handheld dynamometer emerged as notably effective. This precision instrument proved capable of sensitively identifying variations in muscle strength and condition, underscoring its utility in the nuanced assessment of muscle functionality. The data gleaned from the handheld dynamometer's application provided clear, quantifiable differences across the tested muscle states, offering a robust and reliable measure for evaluating muscular performance. These findings accentuate the handheld dynamometer's singular sensitivity in this context, suggesting its role in complementing broader neuromuscular assessments within clinical and sports medicine settings. The subsequent paragraphs present the specific data obtained from the handheld dynamometer analysis, delineating its contribution to comprehensive understanding of muscle test outcomes.

Table 1 presents a comparative analysis of clinical test outcomes, focusing on the percentages of correct responses and failures across different expertise levels among practitioners performing muscle tests on the Middle Deltoids and Rectus Femoris. This detailed breakdown showcases the outcomes for three distinct muscle states: Normotonic, Hypotonic, and Hypertonic. For the Middle Deltoids, the data reveal a nuanced pattern of correct responses and failures across the three levels of expertise (Level I, II, and III) for each muscle state. Interestingly, Level III practitioners achieved a 100 % success rate in identifying all three muscle states, a stark contrast to the varying degrees of success and failure rates observed in Levels I and II. Similarly, for the Rectus Femoris muscle tests, the trend of correct responses and failures again reflects a correlation with expertise levels. Level III practitioners consistently demonstrated a 100 % success rate across all muscle states, mirroring the pattern observed in the Middle Deltoids. The statistical analysis, including Chi-square (χ^2) values and p-values, underscores the significance of these findings, indicating strong statistical evidence for the observed differences in diagnostic outcomes across expertise levels. The remarkably low p-values across most comparisons highlight the robustness of these findings, suggesting that the observed patterns are unlikely to be due to random variation.

The ANOVA analysis across various muscle states for Middle Deltoids and Rectus Femoris muscles reveals a significant influence of expertise level on clinical test outcomes, evidenced by notable F-values and highly significant *p*-values (all $p < .01$). Specifically, the analysis for both muscles across Normotonic, Inhibited, and Hypertonic states consistently showed significant differences in response accuracy among expertise levels, with F-values ranging from 4.792 in Middle Deltoids Normotonic to 57.349 in Rectus Femoris Inhibited conditions. These results underscore the critical role of expertise in accurately conducting and interpreting clinical muscle tests, highlighting the need for comprehensive training and evaluation to improve diagnostic precision across all levels of clinical practice.

The analysis of clinical test performance across different muscle states in Middle Deltoids and Rectus Femoris reveals significant variations according to the level of expertise. For the Middle Deltoids, Normotonic state measurements showed a notable increase in mean scores from Level 1 (9.91 ± 3.83) to Level 3 (11.50 ± 3.44), with a significant difference ($p = .012$) between Levels 1 and 3. In contrast, the Hypotonic state exhibited a decrease in scores from Level 1 (9.76 ± 4.24) to Level 2 (7.98 ± 2.48), significantly differing at $p = .002$. The Hypertonic state further emphasized the disparity, with Level 3 (13.34 ± 4.15) significantly outperforming Level 1 (10.29 ± 4.32) at $p = .000$. Similarly, Rectus Femoris results indicated that expertise significantly influences test outcomes, particularly in the Normotonic and Hypotonic states, where Level 3 (21.92 ± 4.10 and 8.86 ± 2.68, respectively) significantly differs from Level 1 (15.71 ± 5.00 and 15.27 ± 4.59, respectively) at $p = .000$ in both cases. These findings highlight the critical role of expertise in clinical test performance, underlining the necessity for enhanced training and proficiency development among practitioners to ensure accurate muscle state assessments (Table 2).

4. Discussion

The initial study objectives were firstly, to evaluate the sensitivity of thermography, electromyography, and digital dynamometry in detecting changes in various muscular conditions across a range of neuromuscular tests and levels of professional experience; and secondly, to discern the impact of practitioners' expertise on objective parameters and clinical judgments within these assessments. Our hypotheses posited that all three diagnostic tools would exhibit sensitivity to muscular changes, and that a practitioner's level of expertise would correlate positively with the accuracy of clinical interpretations. The findings present a nuanced picture: while thermography and EMG fell short of the hypothesized sensitivity, digital dynamometry proved adept at identifying muscular changes, affirming its crucial role within the diagnostic toolkit. Moreover, the anticipated correlation between practitioner expertise and assessment accuracy was strongly evidenced, underscoring the integral value of experience in clinical efficacy.

In the landscape of muscle assessment tools, thermography, electromyography, and digital dynamometry each play pivotal roles, leveraging their unique capabilities to offer insights into muscle function and pathology. Thermography's non-invasive imaging of temperature differences highlights inflammation and vascular anomalies,

Table 1
Comparative analysis of clinical test outcomes (% of correct vs failures) across expertise levels in Middle Deltoids and Rectus Femoris musculature.

	Middle Deltoids											
	Normotonic				Hypotonic				Hypertonic			
Expertise level	Fail	Correct	χ^2	p	Fail	Correct	χ^2	p	Fail	Correct	χ^2	p
I	51.2	48.8	30.551	.000	78.0	22.0	158.265	.000	61.0	39.0	78.047	.000
II	47.6	52.4			4.8	95.2			39.4	60.6		
III	0	100			0	100			0	100		
	Rectus Femoris											
	Normotonic				Hypotonic				Hypertonic			
Expertise level	Fail	Correct	χ^2	p	Fail	Correct	χ^2	p	Fail	Correct	χ^2	p
I	52.4	47.6	30.109	.000	87.8	12.2	181.431	.000	46.3	53.7	48.285	.000
II	35.7	64.3			7.1	92.9			26.2	73.8		
III	0	100			0	100			0	100		

Table 2
Differences in handheld dynamometer (N) in Middle Deltoids and Rectus Femoris neuromuscular test in Normotonic, Hypotonic and Hypertonic conditions in the three expertise level analysed.

	Middle Deltoids			Rectus Femoris		
Expertise level	Normotonic	Hypotonic	Hypertonic	Normotonic	Hypotonic	Hypertonic
1	9.91 ± 3.83	9.76 ± 4.24	10.29 ± 4.32	15.71 ± 5.00	15.27 ± 4.59	18.31 ± 17.13
2	10.21 ± 3.15	7.98 ± 2.48	11.49 ± 3.35	16.14 ± 5.09	12.27 ± 3.99	17.58 ± 6.30
3	11.50 ± 3.44	7.68 ± 3.12	13.34 ± 4.15	21.92 ± 4.10	8.86 ± 2.68	26.24 ± 5.05
P	1 < 3 (0.012)	1 > 2 (0.002)	1 < 3 (0.000)	1 < 3 (0.000)	1 > 2 (0.000)	1 < 3 (0.000)
	2 < 3 (0.050)	1 > 3 (0.000)	2 < 3 (0.009)	2 < 3 (0.000)	1 > 3 (0.000)	2 < 3 (0.000)
					2 > 3 (0.000)	

underpinned by its sensitivity to skin temperature variations and methodological considerations like the importance of measuring temperature gradients and viewing angles to ensure diagnostic accuracy [22,31]. For this reason, it is understandable that it is not sensitive when it comes to detecting changes in reflex activity acutely, which is what is tested in neuromuscular tests. Regarding EMG, it serves as a quantitative tool analyzing muscle electrical activity, facilitating the diagnosis of neuromuscular disorders [32]. However, its efficacy is heavily reliant on the practitioner's expertise and the context of the test. Moreover, EMG primarily focuses on parameters of maximum voluntary contraction, thus, it also encounters limitations in accurately distinguishing changes in muscle reflex activity, such as those assessed in the neuromuscular tests utilized in this study. Conversely, digital dynamometry offers a direct and objective measurement of muscle strength, making it exceptionally valuable for evaluating therapeutic interventions and formulating rehabilitation protocols [33]. This effectively complements the more intricate analyses provided by thermography and EMG. The increased sensitivity of dynamometry compared to EMG and thermography could be attributed to the fact that changes in reflex muscle contraction can be reflected in an objective force production indicator, which is precisely what dynamometry assesses.

The variability in the accuracy of deltoid muscle testing across different expertise levels in the normotonic, hypertonic, and hypotonic states, underscores the complex interplay between clinical experience and the reliability of neuromuscular tests. Studies have highlighted the concurrent validity of neuromuscular tests, showing its effectiveness in measuring muscle strength when compared to objective tools like dynamometers, with significant reliability observed between these methods and neuromuscular tests, especially in discerning muscle weakness [30]. This indicates the importance of clinician expertise in performing accurate assessments [34]. An increase in accurate clinical judgment across different levels can be observed, demonstrating the impact of training and education [35]. In this line, the Rectus Femoris test also showed notable differences in accuracy and error rates across the three levels of expertise in identifying normotonic, hypertonic, and hypotonic states. This variance underscores the nuanced role of experience in muscular diagnostics and the critical need for precise testing methodologies. Previous authors emphasized the subjectivity of manual muscle testing and the necessity for objective assessment methods to ensure the reproducibility and validity of test outcomes [36]. Other authors suggested that while experience enhances diagnostic precision, objective measures and standardized protocols are essential for improving the reliability of muscle testing outcomes [37,38]. The data from this study reveal that Level III subjects exhibit exceptionally high sensitivity and accuracy, underscoring the profound impact of training and expertise. This level of proficiency enables their clinical judgment and sensitivity to rival that of a dynamometer, highlighting the pivotal role of advanced training in enhancing diagnostic capabilities. These insights collectively stress the necessity for comprehensive training and objective testing to enhance muscle testing accuracy in clinical settings [39].

Building on the insights from the dynamometer, the differences observed across various levels of expertise in the neuromuscular tests for both the Middle Deltoids and Rectus Femoris (in normotonic, hypotonic, and hypertonic conditions) also highlighted the critical influence of experience on clinical testing outcomes. This data underscores a significant enhancement in the diagnostic precision as expertise levels increase, particularly in complex assessments of muscle conditions. The progression from Level I to Level III practitioners not only illustrates a marked improvement in accuracy but also reflects the indispensable role of comprehensive training and proficiency development in neuromuscular diagnostics. Such findings align with the broader discourse on the necessity for standardized testing protocols and the integration of objective measurement tools in clinical settings to augment the reliability and validity of muscle function assessments [23,30]. The elevation in testing performance with higher expertise levels resonates with the concept that advanced training and experience equip practitioners with a refined understanding of muscle function, enhancing their ability to conduct precise evaluations. This is particularly evident in the sharp accuracy exhibited by Level III practitioners, whose outcomes parallel the objectivity of a dynamometer, highlighting the potential of high-level expertise in bridging the gap between subjective clinical judgment and objective diagnostic tools [40]. This is in line with previous research that found significant differences in force profiles generated by testers with varying levels of experience, indicating that expertise influences the application of force during testing [36].

4.1. Limitations and future research lines

This study presents several limitations. First and foremost, the reliance on manual muscle testing and dynamometry, despite their established utility, introduces a degree of subjectivity and potential for variability between testers. This could affect the reproducibility of results across different settings or practitioners. Additionally, the study's sample size, though adequate for preliminary insights, may not fully capture the breadth of variability in clinical judgment and muscular response among a wider population of professionals with varying levels of expertise. Furthermore, the study primarily focuses on specific muscle groups, which may limit the generalizability of the findings to other muscles or complex clinical scenarios encountered in practice.

Addressing these limitations opens several avenues for future research. Expanding the study to include a larger and more diverse cohort of practitioners and patients could enhance the robustness and generalizability of the findings. Future studies could also benefit from incorporating a wider array of muscles and clinical conditions to assess the applicability of the results across the full spectrum of neuromuscular assessment. Moreover, the development and integration of more objective, technology-based assessment tools alongside traditional methods could help mitigate the subjectivity inherent in manual muscle testing and dynamometry, offering a more nuanced and comprehensive understanding of muscle function and pathology. Additionally, longitudinal studies examining the evolution of clinical judgment and diagnostic accuracy over time, with continuous professional development, could provide valuable insights into the trajectory of expertise acquisition in neuromuscular diagnostics. Lastly, exploring the interplay between clinical judgment, diagnostic tools, and patient outcomes could further elucidate the practical implications of these findings in optimizing patient care strategies in clinical and sports medicine settings. These directions not only aim to refine the current understanding of neuromuscular assessment but also to enhance the accuracy, reliability, and clinical relevance of muscle testing in healthcare practice.

4.2. Practical applications

This study's practical implications encompass several areas of clinical practice, rehabilitation, and sports medicine, emphasizing enhanced training programs for practitioners to improve diagnostic accuracy and clinical judgment. It advocates for the adoption of standardized neuromuscular assessment protocols, incorporating objective tools like dynamometers to complement traditional methods, thereby reducing subjectivity, especially in formation stage. These insights facilitate the development of personalized care strategies, enabling healthcare providers to tailor treatments effectively. Professional associations and health authorities might use this evidence to update clinical practice guidelines, ensuring they reflect the latest in diagnostic efficacy and the role of practitioner expertise.

5. Conclusion

The findings revealed that while traditional methods like thermography and electromyography provide valuable insights, digital dynamometry stands out for its sensitivity in detecting muscle condition changes in neuromuscular test. Moreover, the data underscored the pivotal role of advanced training and expertise in enhancing the precision and accuracy of neuromuscular diagnostics, since there were significant differences in objective parameters and clinical judgment between participants of different levels of expertise in the different muscular conditions in Middle deltoid and Rectus femoris neuromuscular tests analyzed, presenting higher expertise participant clinical judgment like objective validated instrument.

CRediT authorship contribution statement

Jorge Rey-Mota: Conceptualization. **Guillermo Escribano-Colmena:** Writing – original draft, Formal analysis, Conceptualization. **Jesús Fernández-Lucas:** Writing – original draft, Software. **Jose A. Parraca:** Validation, Methodology, Data curation. **Vicente Javier Clemente-Suárez:** Writing – review & editing, Visualization, Project administration, Conceptualization.

Declaration of competing interest

Guillermo Escribano-Colmena and Jorge Rey-Mota are affiliated with ®NeuroReEvolution.

Data availability

Data will be made available on request.

References

[1] R. Correa-de-Araujo, M.O. Harris-Love, I. Miljkovic, M.S. Fragala, B.W. Anthony, T. M. Manini, The need for standardized assessment of muscle quality in skeletal muscle function deficit and other aging-related muscle dysfunctions: a symposium report, Front. Physiol. 8 (2017), https://doi.org/10.3389/fphys.2017.00087.

[2] J.F.T. Aguilera, J. Gil-Cabrera, V.J. Clemente-Suárez, Determining the psychophysiological responses of military aircrew when exposed to acute disorientation stimuli, BMJ Mil. Health 168 (2) (2022) 112–116.

[3] P. Belinchón-deMiguel, D.J. Ramos-Campo, V.J. Clemente-Suárez, Exploring the evolutionary disparities: a case study on the psychophysiological response to recreating the Hunter–Gatherer lifestyle through physical activity and caloric restriction, Appl. Sci. 13 (20) (2023) 11140.

[4] A. Bellido-Esteban, P. Ruisoto, J.F. Tornero-Aguilera, V.J. Clemente-Suárez, Modification in psychophysiological stress parameters of soldiers after an integral operative training prior to a real mission, Sustainability 14 (5) (2022) 2792.

[5] V.J. Clemente-Suárez, S. Villafaina, T. García-Calvo, J.P. Fuentes-García, Impact of HIIT sessions with and without cognitive load on cortical arousal, accuracy and perceived exertion in amateur tennis players, Healthcare 10 (5) (2022) 767.

[6] J. Díaz-García, V.J. Clemente-Suárez, J.P. Fuentes-García, S. Villafaina, Combining HIIT plus cognitive task increased mental fatigue but not physical workload in tennis players, Appl. Sci. 13 (12) (2023) 7046.

[7] S.E. Baker, E.E. Painter, B.C. Morgan, A.L. Kaus, E.J. Petersen, C.S. Allen, G. D. Deyle, G.M. Jensen, Systematic clinical reasoning in physical therapy (SCRIPT): tool for the purposeful practice of clinical reasoning in orthopedic manual physical therapy, Phys. Ther. 97 (1) (2017) 61–70, https://doi.org/10.2522/ptj.20150482.

[8] H. Bengacemi, K. Abed-Meraim, O. Buttelli, A. Ouldali, A. Mesloub, A new detection method for EMG activity monitoring, Med. Biol. Eng. Comput. 58 (2) (2020) 319–334, https://doi.org/10.1007/s11517-019-02048-0.

[9] R.C. Tait, J.T. Chibnall, K. House, J. Biehl, Medical judgments across the range of reported pain severity: clinician and lay perspectives, Pain Med. 17 (7) (2016) 1269–1281, https://doi.org/10.1093/pm/pnv076.

[10] A. Rajkomar, G. Dhaliwal, Improving diagnostic reasoning to improve patient safety, Perm. J. 15 (3) (2011) 68–73, https://doi.org/10.7812/TPP/11-098.

[11] N.J. Jarque-Bou, J.L. Sancho-Bru, M. Vergara, A systematic review of EMG applications for the characterization of forearm and hand muscle activity during activities of daily living: results, challenges, and open issues, Sensors 21 (9) (2021) 3035, https://doi.org/10.3390/s21093035.

[12] R. Pilkar, K. Momeni, A. Ramanujam, M. Ravi, E. Garbarini, G.F. Forrest, Use of surface EMG in clinical rehabilitation of individuals with SCI: barriers and future considerations, Front. Neurol. 11 (2020), https://doi.org/10.3389/fneur.2020.578559.

[13] W.H. Schmitt, S.C. Cuthbert, Common errors and clinical guidelines for manual muscle testing: "the arm test" and other inaccurate procedures, Chiropr. Osteopat. 16 (1) (2008) 16, https://doi.org/10.1186/1746-1340-16-16.

[14] J.E. Esteves, C. Spence, Developing competence in diagnostic palpation: perspectives from neuroscience and education, Int. J. Osteop. Med. 17 (1) (2014) 52–60, https://doi.org/10.1016/j.ijosm.2013.07.001.

[15] C. Gonçalves, J.A. Parraca, J. Bravo, A. Abreu, J. Pais, A. Raimundo, V.J. Clemente-Suárez, Influence of two exercise programs on heart rate variability, body temperature, central nervous system fatigue, and cortical arousal after a heart attack, Int. J. Environ. Res. Public Health 20 (1) (2022) 199.

[16] L. zhang, H. Guo, Z. Li, Application of medical infrared thermal imaging in the diagnosis of human internal focus, Infrared Phys. Technol. 101 (2019) 127–132, https://doi.org/10.1016/j.infrared.2019.06.013.

[17] Jasti, N., Bista, S. & Bhargav, H. (2019). *Medical applications of infrared thermography: a narrative review*. https://www.researchgate.net/publication/335518059.

[18] K. Ammer, The Glamorgan Protocol for recording and evaluation of thermal images of the human body, Thermol. Int. 18 (4) (2008) 125–144.

[19] M. Chudecka, A. Lubkowska, Thermal imaging of body surface temperature distribution in women with anorexia nervosa, Eur. Eating Disord. Rev. 24 (1) (2016) 57–61, https://doi.org/10.1002/erv.2388.

[20] C. Hildebrandt, C. Raschner, K. Ammer, An overview of recent application of medical infrared thermography in sports medicine in Austria, Sensors 10 (5) (2010) 4700–4715, https://doi.org/10.3390/s100504700.

[21] A. Lubkowska, W. Pluta, Infrared thermography as a non-invasive tool in musculoskeletal disease rehabilitation—the control variables in applicability—a systematic review, Appl. Sci. 12 (9) (2022) 4302, https://doi.org/10.3390/app12094302.

[22] D. Kesztyüs, S. Brucher, C. Wilson, T. Kesztyüs, Use of infrared thermography in medical diagnosis, screening, and disease monitoring: a scoping review, Medicina (B Aires) 59 (12) (2023) 2139, https://doi.org/10.3390/medicina59122139.

[23] R. McGrath, G.R. Tomkinson, B.C. Clark, P.M. Cawthon, M. Cesari, S. Al Snih, K. J. Hackney, Assessing additional characteristics of muscle function with digital handgrip dynamometry and accelerometry: framework for a novel handgrip strength protocol, J. Am. Med. Dir. Assoc. 22 (11) (2021) 2313–2318.

[24] J. Pinto-Ramos, T. Moreira, F. Costa, H. Tavares, J. Cabral, C. Costa-Santos, B. Sousa-Pinto, Handheld dynamometer reliability to measure knee extension strength in rehabilitation patients—a cross-sectional study, PLoS ONE 17 (5) (2022) e0268254.

[25] T. Stark, B. Walker, J.K. Phillips, R. Fejer, R. Beck, Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review, PM&R 3 (5) (2011) 472–479.

[26] B. Martínez-Pascual, A. Ramírez-Adrados, S. Fernández-Martínez, C. Gonzalez-de-Ramos, V.E. Fernández-Elías, V.J. Clemente-Suárez, Autonomic stress response of physiotherapy student in the different scenarios of an objective structured clinical examination, BMC Med. Educ. 22 (1) (2022) 811.

[27] J.-C. Guyard, Manuel Pratique De Kinésiologie, Le Souffle d'Or, 1998.

[28] A. Molina-Molina, E.J. Ruiz-Malagón, F. Carrillo-Pérez, L.E. Roche-Seruendo, M. Damas, O. Banos, F. García-Pinillos, Validation of mDurance, a wearable surface electromyography system for muscle activity assessment, Front. Physiol. 11 (2020), https://doi.org/10.3389/fphys.2020.606287.

[29] E.F.J. Ring, K. Ammer, Infrared thermal imaging in medicine, Physiol. Meas. 33 (3) (2012) R33.

[30] C. Karagiannopoulos, S. Griech, B. Leggin, Reliability and validity of the ActivForce Digital Dynamometer in assessing shoulder muscle force across different user experience levels, Int. J. Sports Phys. Ther. 17 (4) (2022) 669.

[31] J.L. Ramirez-GarciaLuna, R. Bartlett, J.E. Arriaga-Caballero, R.D.J. Fraser, G. Saiko, Infrared thermography in wound care, surgery, and sports medicine: a review, Front. Physiol. 13 (2022), https://doi.org/10.3389/fphys.2022.838528.
[32] M.B.I. Reaz, M.S. Hussain, F. Mohd-Yasin, Techniques of EMG signal analysis: detection, processing, classification and applications, Biol. Proced. Online 8 (1) (2006) 11–35, https://doi.org/10.1251/bpo115.
[33] S. Aitkens, J. Lord, E. Bernauer, W.M. Fowler, J.S. Lieberman, P. Berck, Relationship of manual muscle testing to objective strength measurements, Muscle Nerve 12 (3) (1989) 173–177, https://doi.org/10.1002/mus.880120302.
[34] A. Markaki, S. Malhotra, R. Billings, L. Theus, Training needs assessment: tool utilization and global impact, BMC Med. Educ. 21 (1) (2021) 310, https://doi.org/10.1186/s12909-021-02748-y.
[35] S.O. Baboolal, V.S. Singaram, Specialist training: workplace-based assessments impact on teaching, learning and feedback to support competency-based postgraduate programs, BMC Med. Educ. 23 (1) (2023) 941, https://doi.org/10.1186/s12909-023-04922-w.
[36] F. Bittmann, S. Dech, M. Aehle, L. Schaefer, Manual muscle testing—force profiles and their reproducibility, Diagnostics 10 (12) (2020) 996, https://doi.org/10.3390/diagnostics10120996.
[37] S. Mallett, S. Halligan, M. Thompson, G.S. Collins, D.G. Altman, Interpreting diagnostic accuracy studies for patient care, BMJ 345 (jul02 1) (2012), https://doi.org/10.1136/bmj.e3999 e3999–e3999.
[38] B. Shinkins, M. Thompson, S. Mallett, R. Perera, Diagnostic accuracy studies: how to report and analyse inconclusive test results, BMJ 346 (may16 2) (2013), https://doi.org/10.1136/bmj.f2778 f2778–f2778.
[39] S.C. Cuthbert, G.J. Goodheart Jr., On the reliability and validity of manual muscle testing: a literature review, Chiropr. Osteopat. 15 (1) (2007) 4.
[40] R.W. Bohannon, Muscle strength: clinical and prognostic value of hand-grip dynamometry, Curr. Opin. Clin. Nutr. Metab. Care 18 (5) (2015) 465–470.