

# Enhancing Strength Assessment: A Comprehensive Analysis of Velocity-Based and Isometric Methods for 1RM Estimation

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**Abstract.** This study explores safer and more efficient alternatives to traditional one-repetition maximum (1RM) testing, particularly for the elderly or individuals with medical conditions. It focuses on velocity-based methods, specifically the load-velocity (L-V) relationship, and isometric approaches, like the isometric midthigh pull (IMTP), which correlate strongly with maximal strength while reducing fatigue and injury risk. A bibliometric analysis using VOSviewer software was conducted on articles from 2015 to 2025 to map trends, identify key researchers, and highlight gaps. The results show a growing interest in 1RM estimation since 2017. L-V methods relate lifting velocity to maximal strength, while isometric tests offer fatigue-free alternatives. However, variability in technique and individual response remains a challenge. The study underscores the need to standardize these methods for broader applicability. Future research should enhance accuracy, especially for untrained and clinical populations. Overall, alternative 1RM estimation methods show promise but require refinement and validation.

**Keywords:** one-repetition maximum (1rm), load-velocity relationship (l-v), isometric midthigh pull (imtp), strength estimation methods, bibliometric analysis.

## 1 Introduction

The one-repetition maximum (1RM) test has long been considered the gold standard for assessing maximal strength in various fields, including fitness and rehabilitation. However, despite being regarded as the most accurate method, direct 1RM testing has significant drawbacks, especially in terms of injury risk and impracticality for certain populations, such as the elderly or individuals with specific medical conditions [1, 2]. To address these issues, alternative approaches have been developed to estimate 1RM in a safer and more efficient manner, without sacrificing accuracy. One such approach gaining traction is the load-velocity relationship (L-V), which relies on the velocity of movement during submaximal lifts to predict

maximal strength [3-5]. Recent studies have shown that propulsive velocity during submaximal lifts is strongly correlated with the ability to lift maximal loads. By utilizing the relationship between load and velocity, this method offers a safer alternative that allows for 1RM prediction without requiring maximal effort, which could lead to fatigue and increased injury risk [6, 7]. While this technique shows great potential, challenges remain in terms of prediction accuracy, particularly due to individual variability in lifting technique and responses to training [4, 8].

Age also plays a critical role in the effectiveness of 1RM testing. Significant declines in muscle strength occur naturally with age, with a more pronounced decrease after the age of 50 [9, 10]. This age-related decline renders traditional 1RM testing less practical and more risky for older individuals. Therefore, safer alternatives, such as submaximal velocity-based methods or isometric testing, are increasingly being considered. The isometric midhigh pull (IMTP), for example, has shown a strong correlation with 1RM in exercises like the deadlift and squat, offering a safer way to estimate maximal strength without inducing fatigue or risking injury [11, 12].

In addition, advancements in wearable technologies, such as exoskeletons equipped with surface electromyography (sEMG) sensors, have opened new possibilities for estimating muscle strength. These devices provide real-time data on muscle activity during training, allowing for non-invasive and more accurate 1RM predictions [5, 13]. Although promising, the application of these technologies is still limited by concerns about data validity and consistency across different populations, necessitating further research to establish standardized protocols [1, 5]. Along with the development of new methodologies, research on 1RM estimation continues to highlight variability in methods and their applications. Velocity-based methods, such as velocity-feedback in bench press training, and approaches based on minimum velocity threshold (MVT) have demonstrated high accuracy in predicting 1RM, although results can vary across different age groups [14, 15]. These approaches present significant opportunities for further development in the field, enabling more efficient and safer 1RM estimation, particularly in fitness or clinical rehabilitation settings.

In light of these advancements, this article aims to explore and analyze various methodologies for estimating 1RM. The primary focus will be on velocity-based and isometric approaches, examining their strengths, limitations, and how they can be optimized for use in a variety of settings, from fitness training to clinical rehabilitation.

## **2 Methods**

### **2.1 Search**

The literature search was conducted on June 15, 2025, using the Scopus database via Harzing's Publish or Perish software (Windows GUI Edition, version 8.18.5090.9296). The primary objective of this search was to identify relevant articles concerning the estimation of 1RM strength using technological approaches. The search was specifically limited to the period between 2015 and 2025 without bias toward any particular journal or geographical region, ensuring comprehensiveness and representativeness of the retrieved literature.

The Boolean search logic comprised two main components: the first included terms related directly to the estimation or measurement of 1RM strength, and the second encompassed technological terms associated with strength evaluation. The detailed Boolean search expression used is as follows, (Estimated OR Estimation OR "1RM") AND ("Strength Assessment" OR "Strength Evaluation" OR "Strength Testing") AND ("Healthy Non-Athlete" OR "Healthy General Population"). This Boolean expression was entered into the keyword search box within the Publish or Perish software, and the publication year range was explicitly set from 2015 to 2025. Subsequently, the resulting articles were saved in CSV format to facilitate subsequent data management and analysis.

## 2.2 Article Selection

Articles included (Table 1) in this study are peer-reviewed original research articles published in English-language academic journals. Eligible articles must present original data obtained through quantitative, qualitative, or mixed-method approaches. The primary focus of selected studies must explicitly address strength assessment in physically active, non-athlete participants. Studies involving athletes or participants with degenerative conditions or specific injuries that may significantly influence strength assessment outcomes are excluded. Participants in eligible studies may include any gender and all age groups, provided they meet the aforementioned conditions. Initial article screening is based on titles and abstracts; articles demonstrating clear adherence to these criteria through their titles and abstracts are eligible for inclusion, even when full-text access is not available. Conversely, articles with unclear compliance based on their titles or abstracts are excluded from further analysis.

**Table 1.** Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
Empirical articles presenting original data (qualitative or quantitative)	Articles derived from literature reviews or theoretical articles
Articles written in English	Articles written in languages other than English
Published in academic journal sources	Published in non-academic sources, such as magazines, reports, notes, meetings, or conferences
Discussion focused on strength assessment	Discussion focused on nutrition/supplementation, general training programs, or other topics not directly related to muscular strength assessment
Study population consists of humans in the context of sports or physical health	Study population consists of athletes or individuals with specific conditions, such as degenerative diseases or injuries

## 2.3 Data Extraction

The data utilized in this research were extracted from the Scopus database in the form of Comma-Separated Values (CSV) files. These CSV files were subsequently opened and managed using Microsoft Excel to ensure data integrity prior to further analysis. Following the preparation of the CSV files, the data were imported into VOSviewer software version 1.6.20, a specialized bibliometric analysis tool used for conducting co-authorship network analysis and keyword co-occurrence analysis. Utilizing VOSviewer enabled an effective and clear

visualization of the bibliometric data. In addition to VOSviewer, supplementary visualizations were generated using the Data Analyst tool, an Artificial Intelligence (AI)-based feature available within the ChatGPT platform. This AI-driven tool facilitated efficient and deep exploration of complex and extensive data patterns through advanced visual representations.

## 2.4 Bibliometric Analysis

Bibliometric analysis in this study refers to a quantitative approach employed to systematically evaluate research variables and map as well as categorize scientific knowledge [16, 17]. This method facilitates the structured and comprehensive exploration of scientific publication patterns, emerging research trends, collaborative networks among authors, and principal concepts within a specific discipline according to Table 2. Specifically, this analysis includes calculating the number of articles published per year and classifying them according to the type of review employed in previous literature. Additionally, it identifies the most productive journals and authors within the studied field.

Furthermore, knowledge mapping is conducted using principal techniques such as co-authorship analysis, which aims to explore collaborative relationships among authors based on their jointly authored documents. Additionally, co-occurrence analysis is utilized to investigate the frequency with which certain keywords appear together within scientific documents. The combination of these techniques provides a clear visualization of interrelations among scientific elements, highlights the focus areas of research, and helps identify prevailing trends within the specific scientific discipline [17, 18].

**Table 2.** Bibliometric Analysis Techniques and Parameters Applied in VOSviewer.

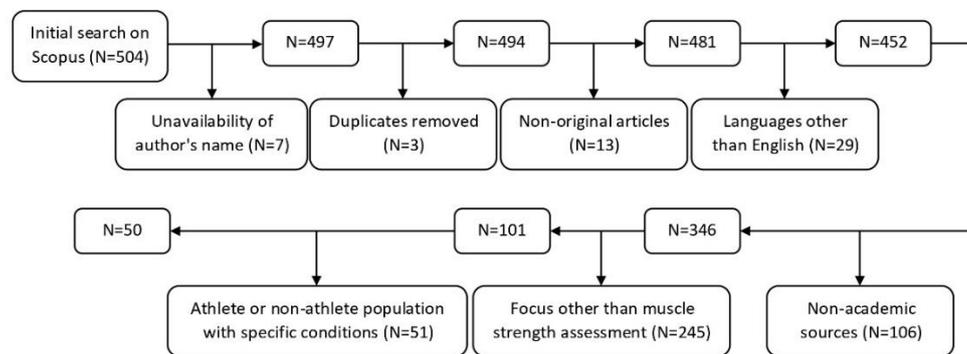
Technique	Unit of Analysis	Limitations (Min. Thresholds)	Type of Visualization
Co-authorship	Authors	a. Min. number of documents of an author = 1.	Overlay
		b. Only authors linked to at least one other author.	
Co-occurrence	Keywords	a. Min. number of occurrences of a keyword = 2.	Network
		b. Only keywords linked to at least one other keyword.	
		c. Thesaurus terms applied to a few of keywords such as resistance training, strength training, and resistance exercise as well as strength testing and strength assessment.	

## 3 Results

### 3.1 Selected Articles

The flow diagram in the document illustrates a systematic process of screening scholarly articles retrieved from an initial Scopus search totaling 504 records. The selection procedure (Figure 1)

is conducted in multiple stages by excluding articles based on specific exclusion criteria, including the unavailability of the author's name (7 articles), duplicate records (3 articles), non-original publications (13 articles), non-English language (29 articles), and non-academic sources (106 articles). From the remaining 452 articles, further screening was performed to ensure alignment with the research focus on muscle strength assessment. As a result, 245 articles were excluded due to an irrelevant focus, and another 51 articles were removed for involving athlete or non-athlete populations with specific conditions. Ultimately, only 50 articles met all inclusion and relevance criteria for further analysis. This diagram reflects a methodological and selective approach to literature review, aimed at ensuring the validity and appropriateness of sources in academic research.



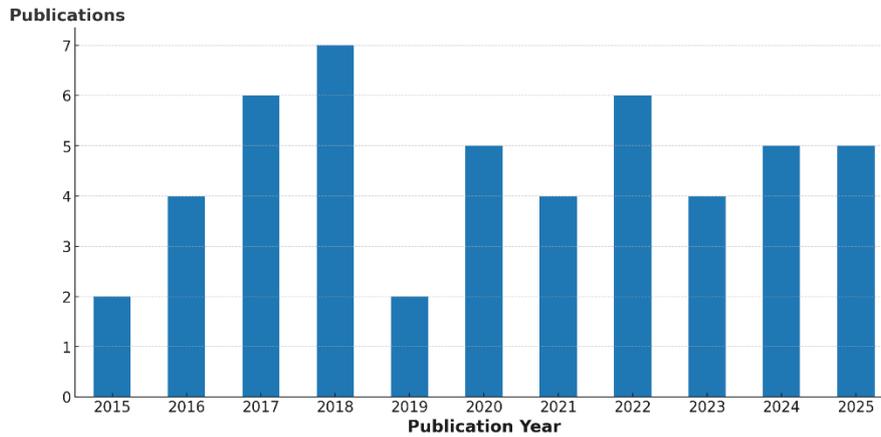
**Fig. 1.** Article Selection Process Flowchart.

### 3.2 Article Distribution

Figure 2 illustrates the annual trend in the number of publications from 2015 to 2025, highlighting fluctuations in scholarly output over the observed period. The early years (2015–2016) exhibited modest activity with only two and four publications, respectively. A marked increase followed in 2017 and 2018, culminating in a peak of seven publications in 2018. However, this upward trend was disrupted in 2019, which saw a sharp decline back to two publications. From 2020 onwards, the volume of publications recovered and stabilized, ranging between four and six publications annually through 2025. This pattern suggests a growing and sustained academic interest in the subject area after 2020, indicating both resilience and continued relevance within the field.

A total of 35 journals and 50 documents have contributed to publications related to strength assessment in healthy non-athletic populations, with several journals showing significant contributions in this field. Based on Table 3, *Journal of Strength and Conditioning* leads with 12 documents (24%) and a total of 467 citations, making it a key source for discussions on muscle strength and strength training programs for non-athletic populations. *Journal of Applied Physiology*, despite having only one document, has garnered 288 citations, reflecting its significant influence in the study of the physiological mechanisms underlying strength assessment. Additionally, *European Journal of Applied Physiology* with two documents (95

citations) and *Journal of Human Kinetics* with three documents (75 citations) also contribute to research related to the physiological and biomechanical aspects of strength assessment.



**Fig. 2.** A Decade Publication Distribution.

Other journals that have contributed to this area of research include *Journals of Gerontology Series A Biological Sciences and Medical Sciences* with one document (62 citations), *Experimental Gerontology* with one document (57 citations), and *Sports Biomechanics* with one document (36 citations). These journals generally focus on strength assessment in the context of aging and biomechanics in healthy populations. The distribution of contributions across these journals highlights the diversity of topics covered in strength assessment research for non-athletic populations, with a focus on physiology, biomechanics, and other factors influencing strength in the context of health.

**Table 3.** Number of Documents and Citations by Source.

Source	Documents	Citations
Journal of Strength and Conditioning	12	467
Journal of Applied Physiology	1	288
Journal of the American Medical Directors Association	1	113
European Journal of Applied Physiology	2	95
Journal of Human Kinetics	3	75
Journals of Gerontology Series A Biological Sciences and Medical Sciences	1	62
Experimental Gerontology	1	57
Clinical Interventions in Aging	1	39
Sports Biomechanics	1	36
Temperature	1	29
Peerj	1	25
Sports	2	22
Frontiers in Physiology	1	20
BMC Sports Science Medicine and Rehabilitation	1	18
Behavioral Sciences	1	17
Journal of Sports Sciences	1	15
Isokinetics and Exercise Science	1	15

A total of 288 authors have contributed to the literature, with 50 articles published. Among these authors (Table 4), Garcia-Ramos, Amador stands out as the most prolific, with six published papers, followed by Tufano, James J., who has published three articles, garnering 149 and 73 citations, respectively. Other authors, such as Banyard, Harry G., Calvani, Riccardo, and Landi, Francesco, each contributed two documents, with a total of 170 citations, indicating that, despite the limited number of articles, their academic impact remains substantial. The high citation count reflects the recognition of the quality of their research within the scientific community.

Furthermore, while some authors have fewer publications, such as Pareja-Blanco, Fernando, who has only one article with three citations, their contributions remain important. These works may address more specific topics, yet they still provide relevant insights within the broader scope of the field. Authors like Banyard, Harry G. and Marzetti, Emanuele, despite publishing only two articles each, have received higher citation counts, demonstrating the significant quality and relevance of their research in the academic community.

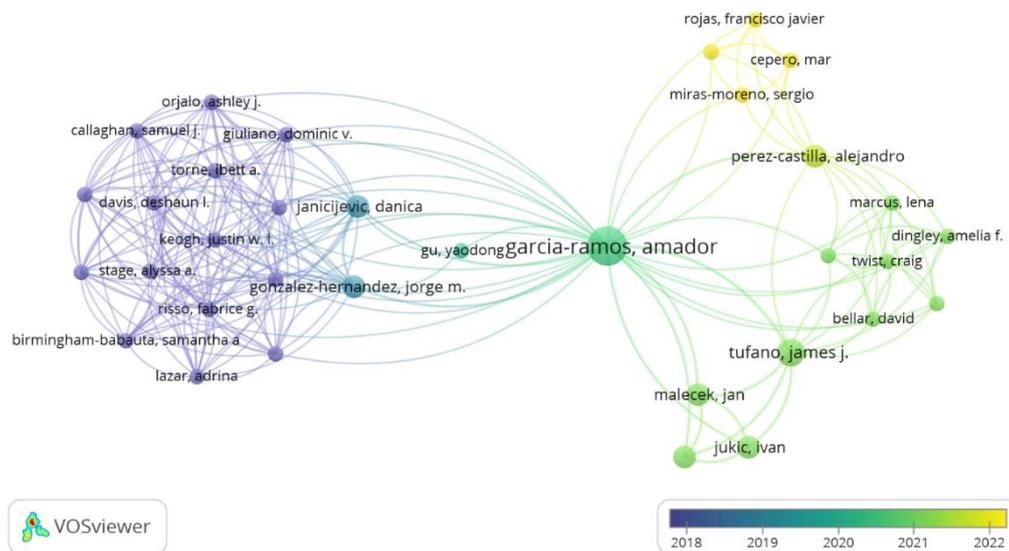
Overall, this distribution highlights the diversity within the field, with some authors contributing more frequently and others focusing on specific topics, yet still making a meaningful impact. This variety reflects differences in research approaches, both in terms of the depth and scope of the topics explored, ultimately enriching scientific knowledge in the field.

**Table 4.** Number of Documents and Citations by Author.

Author	Documents	Citations
Garcia-Ramos, Amador	6	149
Tufano, James J.	3	73
Banyard, Harry G.	2	239
Calvani, Riccardo	2	170
Landi, Francesco	2	170
Marzetti, Emanuele	2	170
Tosato, Matteo	2	170
Jukic, Ivan	2	56
Malecek, Jan	2	56
Omcirk, Dan	2	56
Perez-Castilla, Alejandro	2	53
Gonzalez-Hernandez, Jorge M.	2	40
Janicijevic, Danica	2	40
de Souza Fonseca, Fabiano	2	11
Gantois, Petrus	2	11
Nakamura, Fabio Yuzo	2	11
Pareja-Blanco, Fernando	2	3

### 3.3 Bibliometric Results

This analysis (Figure 3) illustrates the collaborative relationships among authors in the field, visualized into four clusters based on the period of publication and the intensity of collaboration. Each node in the diagram represents an author, with the size of the node reflecting the number of publications authored by that individual. The color of the nodes indicates the average publication year, with yellow representing more recent contributions, and other colors representing publications from earlier periods.



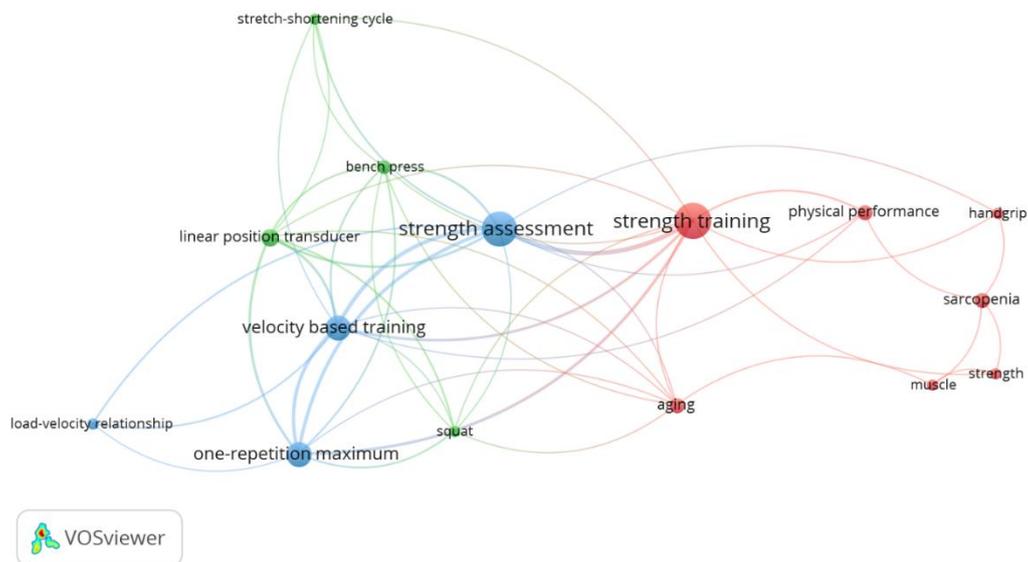
**Fig. 3.** Overlay Co-authorship Analysis Using VOSviewer.

The first cluster, represented in purple, covers the period from 2018 to 2019, showcasing the highest intensity of collaboration among authors. In this cluster, authors such as Orjalo, Ashley J., Keogh, Justin W. L., Lazar, Adrina, and others display the most extensive and frequent collaborative networks, marking the foundational period for deeper exploration of topics in this field. During this period, collaborations among authors began to form a solid base for subsequent research. The second cluster, represented in blue and covering the period from 2019 to 2020, includes authors like Gonzalez-Hernandez, Jorge M., Gu, Yaodong, and Janicijevic, Danica, who became more active in their collaborations. This cluster reflects a shift toward more specific research and the development of new methodologies in performance analysis.

Moving forward, the third cluster, represented in green and covering the period from 2020 to 2021, reflects a significant shift in author collaboration towards more intensive and interdisciplinary work. Within this cluster, Garcia-Ramos, Amador stands out as a highly influential author, with the largest node indicating his dominant contribution during this period. His collaboration with authors such as Jukic, Ivan, Marcus, Lena, and others further enriched the discussions and development of the field, with a more comprehensive and applied focus on performance analysis. Garcia-Ramos, Amador's central position in this network highlights the significant role his work played in advancing a more holistic understanding of the subject matter. The fourth cluster, represented in yellow and covering the period from 2021 to 2022, highlights the collaboration of authors such as Perez-Castilla, Alejandro, Miras-Moreno, Sergio, Cepero, Mar, and Rojas, Francisco Javier, who emerged more prominently in the latter years of the analysis. This cluster introduces fresh perspectives and methodologies, contributing to the integration of new technologies and analytical approaches in the study of soccer performance.

Overall, Garcia-Ramos, Amador emerges as a highly influential figure in this network, as evidenced by the size of his node in the green cluster. His substantial contributions during the 2020-2021 period played a pivotal role in shaping the direction of research in performance analysis, further establishing his prominent position in the field.

Figure 4 presents a network of keywords based on their co-occurrence frequency across the analyzed literature. The network is divided into three distinct clusters, each representing a unique thematic focus. The blue cluster centers on the relationship between load-velocity, 1RM, velocity-based training, and strength assessment. This cluster emphasizes the evaluation of strength and power performance, particularly through measures such as 1RM and velocity. 1RM, a key concept in this cluster, refers to the maximum weight an individual can lift for a single repetition of a given exercise. It is considered the gold standard for assessing maximal strength and is essential for tailoring training programs aimed at improving strength. The load-velocity relationship further supports the measurement of strength, as it predicts strength capabilities based on the velocity of the lift. Additionally, velocity-based training has gained popularity for allowing real-time adjustments to training loads, optimizing strength development while minimizing the risk of injury. Together, these elements create a comprehensive framework for strength assessment that is critical for both athletic performance and clinical applications.



**Fig. 4.** Network Co-occurrence Analysis Using VOSviewer.

The green cluster focuses on the stretch-shortening cycle, bench press, linear position transducer, and squat. Research in this area explores the biomechanical and physiological processes involved in exercises that require rapid muscle stretch and contraction. Keywords such as "bench press" and "squat" highlight the central role of these exercises in strength training, while the linear position transducer plays a critical role in measuring the mechanics of movement, enhancing the precision of strength training assessments.

The red cluster addresses the broader implications of strength training for health, particularly in aging populations. Keywords like aging, sarcopenia, muscle, and handgrip are prominent in this cluster, highlighting how strength training can mitigate age-related muscle loss (sarcopenia), improve physical performance, and measure strength through metrics such as handgrip strength.

This cluster underscores the importance of strength training not only in optimizing athletic performance but also in promoting health and functional independence in older adults.

The analysis also reveals that keywords from different clusters are interrelated, further illustrating the interconnectedness of these research themes. Strength training and strength assessment are central across all three clusters, underscoring their significance in understanding both performance optimization and health outcomes. This co-occurrence analysis provides valuable insights into the key themes and potential research gaps in the field, offering opportunities for further exploration and interdisciplinary collaboration.

## **4 Discussion**

### **4.1 Research Trends and Methodological Issues**

Recent developments in the field of strength assessment have led to the exploration of more efficient and non-invasive methods for estimating 1RM strength, particularly for non-athletic and clinical populations. Traditional 1RM tests, while considered the gold standard for evaluating maximal strength, require participants to lift maximal loads, which poses risks of injury and may not be feasible for certain groups, such as older adults or those with health conditions [3, 19]. As a result, the focus of strength assessment research has shifted toward alternative approaches that are both safe and efficient, such as velocity-based training (VBT), isometric strength testing, and hand-held dynamometry (HHD) [2, 20].

One key area of concern in strength assessment is the decline in muscle strength and mass with aging, particularly after the age of 50. Studies have shown that this decline follows a non-linear trajectory, with more rapid decreases in strength and muscle mass observed beyond this age, especially among men [9, 10]. This age-related decline underscores the importance of developing age-specific reference curves for 1RM, as these populations often have reduced physical capabilities and may not be able to safely perform traditional 1RM tests. As such, methods like IMTP and HHD have gained attention for their ability to provide reliable 1RM estimates without the physical strain of maximal lifting [11, 12].

A growing body of research has demonstrated the utility of the L-V relationship for estimating 1RM, especially in exercises such as the squat and bench press. This method relies on measuring the velocity at which a person lifts a submaximal load and then correlates that velocity with the corresponding 1RM value [19]. Studies have found that the L-V relationship can accurately predict 1RM across various exercises, making it a promising alternative to traditional maximal testing [7, 21]. However, this approach is not without challenges. Variability in individual responses to the load-velocity profile, particularly among untrained or less experienced individuals, has led to concerns about the reliability of this method for certain populations [6, 8]. This variability is compounded by external factors such as fatigue, which can influence the velocity and, therefore, the 1RM prediction accuracy [1].

The integration of subjective measures, such as the rating of perceived exertion (RPE), alongside objective velocity feedback has emerged as a potential solution to enhance the accuracy of 1RM estimations. Research has shown that combining these subjective measures with velocity-based methods improves both the reliability and accuracy of strength testing, particularly in

populations with varying levels of training experience [22, 23]. This hybrid approach allows for more individualized predictions and could prove particularly useful in settings where access to advanced equipment is limited.

Technological advancements have also introduced wearable devices and exoskeletons as potential tools for estimating muscle strength. These technologies utilize sensors, such as sEMG, to monitor muscle activity during resistance exercises and predict 1RM based on movement patterns and muscle activation [13]. Such innovations offer the potential to revolutionize strength assessment by providing non-invasive, real-time data that can be used to estimate strength in a variety of settings, from clinical environments to fitness training. However, further research is necessary to validate these technologies and ensure their accuracy and reliability across different populations [5].

Additionally, the role of muscle endurance in predicting 1RM has garnered increased attention. Several studies have demonstrated that muscle endurance, particularly in older adults, plays a critical role in determining functional strength and should be considered alongside traditional 1RM testing [5, 24]. Isokinetic testing and other endurance-based measures have been shown to provide valuable insights into an individual's overall strength capacity and can complement traditional strength assessments, particularly for populations where maximal lifting may not be safe or appropriate.

In conclusion, while alternative methods for estimating 1RM, such as velocity-based approaches and isometric strength tests, have shown promise, there remain significant challenges in standardizing these methods for broader application. Future research should focus on refining these techniques to account for individual variability, ensuring their applicability across a range of populations. Additionally, the integration of emerging technologies, such as wearable devices and feedback systems, could further enhance the precision and accessibility of 1RM estimations, making them safer and more effective for a wider range of individuals.

#### **4.2 Leading Authors and Journals**

Prominent authors in the field of strength assessment, such as Jukic, Ivan, Garcia-Ramos, Amador, and Perez-Castilla, Alejandro, have made significant contributions to the development of more efficient and safer 1RM estimation methodologies. Jukic specifically investigates the linear relationship between velocity and load in strength testing, demonstrating that this relationship is highly effective for predicting 1RM, particularly in major lifts like the deadlift and back squat. This velocity-based approach allows for quicker and safer strength measurements without requiring maximal testing, which carries a higher risk of injury or excessive fatigue. Meanwhile, Garcia-Ramos and Perez-Castilla focus on personalizing 1RM estimation models by using individualized minimum velocity threshold (MVT) values. This approach provides more accurate predictions by accounting for individual variability, especially in populations such as older adults or beginners who may be unable to perform traditional 1RM tests due to physical limitations or injury risk.

Key journals that focus on strength research, such as *Journal of Strength and Conditioning*, *Journal of Human Kinetics*, and *PeerJ*, play a central role in disseminating these studies. *Journal of Strength and Conditioning* publishes numerous articles that examine strength training techniques and the application of load-velocity relationships for 1RM estimation, highlighting

the use of movement velocity across various primary exercises to predict 1RM more efficiently. *Journal of Human Kinetics* contributes to the field by exploring strength measurement techniques, such as the use of HHD for isometric strength testing, offering a practical and safer alternative for individuals at higher risk of injury. *PeerJ*, on the other hand, publishes studies that develop submaximal velocity-based methods, providing a practical and efficient solution for 1RM estimation, especially for individuals with time constraints or specific physical conditions.

Overall, these authors and related journals highlight the growing importance of velocity-based approaches for 1RM estimation, which are increasingly accepted as safer and more efficient alternatives to traditional maximal testing. By utilizing these techniques, strength assessments can be performed with high accuracy without compromising the safety of the participants, making a significant impact on the development of training programs that are both more precise and accessible to a wide range of populations.

#### **4.3 Dominant Topics, Research Gaps and Conceptual Challenges**

The estimation of 1RM strength in healthy, non-athlete populations has gained increasing attention in the realm of exercise science and clinical rehabilitation. Traditional 1RM testing, while recognized for its accuracy, involves maximal exertion, which may not be feasible or safe for various individuals, particularly those with clinical conditions or advanced age [2, 3]. As a result, alternative approaches for estimating 1RM have emerged, with a particular focus on methods that minimize physical strain while maintaining or enhancing the predictive accuracy of strength assessments [4, 19]. Among these, VBT has shown considerable promise, leveraging the load-velocity relationship to predict maximal strength without requiring maximal effort [5, 25].

The load-velocity relationship has been a dominant area of research, demonstrating that the velocity of a lift is strongly correlated with the load lifted, thereby offering an accurate method for predicting 1RM [1, 26]. This approach is particularly advantageous for populations that may face limitations with traditional maximal strength testing, such as elderly individuals or those recovering from injury [12, 20]. In these contexts, the ability to predict 1RM using velocity-based methods without requiring a maximal effort test enhances both safety and accessibility. Several studies have emphasized the potential of individualized load-velocity profiles, where the use of tailored velocity thresholds can optimize training and improve 1RM predictions [5, 19].

HHD have also emerged as a viable tool for estimating 1RM, particularly in clinical and rehabilitation settings. These devices, which measure isometric strength, offer a less physically demanding alternative to traditional testing methods. Research has demonstrated that HHD measurements, such as those for biceps or quadriceps strength, correlate strongly with actual 1RM values, suggesting their utility in predicting strength without requiring maximal effort [2, 27]. The advantage of HHDs lies in their simplicity and portability, making them particularly valuable for settings where more sophisticated equipment is unavailable [28]. Despite these benefits, challenges remain in ensuring that HHD-based measurements are consistent across different users and devices, particularly given the potential for operator variability [29, 30].

While alternative 1RM estimation methods have advanced, several research gaps remain. One of the primary challenges is the lack of standardized protocols for velocity-based methods, which results in discrepancies between studies and exercises [7, 8]. Variations in the velocity thresholds, as well as differences in exercise types (e.g., squat vs. bench press), can affect the reliability and generalizability of 1RM predictions. Therefore, there is a pressing need for standardized guidelines that can ensure the consistency of these methods across different research contexts and populations [5]. Furthermore, while velocity-based methods have shown considerable promise, the individual variability in strength responses—such as the influence of fatigue, prior training history, and specific health conditions—remains a significant source of error [6, 31]. This underscores the importance of developing personalized models that can account for these factors and improve the accuracy of predictions [20, 25].

Additionally, the integration of isometric testing, particularly the IMTP, into the 1RM estimation process has garnered significant attention due to its non-fatiguing nature and strong correlations with maximal strength [11]. Isometric tests have been shown to be reliable predictors of 1RM, especially in clinical populations where high-intensity maximal tests may pose injury risks [12]. However, more research is needed to establish the effectiveness and reliability of these methods across various exercises and populations. Standardization of isometric protocols is critical to ensure that they can be widely applied and provide consistent results [5]. Furthermore, the use of isometric testing alongside other methods, such as velocity-based feedback, could offer a more comprehensive and individualized approach to 1RM estimation, but further validation is required [14].

Conceptual challenges in 1RM estimation remain substantial, particularly in reconciling the different methods available for strength assessment. The variability in individual responses to strength training and maximal effort testing makes it difficult to establish a universal approach to 1RM estimation [9, 32]. This has led to a growing interest in developing individualized models that take into account personal factors such as age, training history, and current physical condition [3, 25]. Moreover, the shift towards newer methods such as velocity-based training and isometric testing requires a change in the established mindset of strength coaches and practitioners, who have long relied on traditional 1RM testing. Therefore, addressing the conceptual challenges in the integration of newer methods with existing practices is essential for advancing the field [1, 33].

In summary, while significant progress has been made in developing alternative 1RM estimation methods, numerous challenges remain. Standardization of velocity-based methods, improved personalization of 1RM models, and further validation of isometric testing will be key to enhancing the accuracy and applicability of these methods for a broader range of populations. Addressing these gaps will enable more accurate and individualized strength assessments, thereby improving training outcomes and reducing injury risks for non-athletes and clinical populations.

#### **4.4 Limitations**

Although alternative approaches for estimating 1RM, such as velocity-based and isometric methods, provide safer and more efficient solutions compared to traditional 1RM testing, several significant limitations remain. Direct 1RM testing, while considered the gold standard, poses a

risk of injury, particularly for healthy non-athletic individuals, older adults, or those with certain physical conditions. In contrast, velocity-based methods, such as the load-velocity relationship, have demonstrated potential in improving the efficiency of 1RM estimation. However, the high variability in results between individuals remains a major challenge, especially in populations that are untrained or when external factors such as fatigue and individual experience influence the accuracy of measurements. Additionally, reliance on variations in training techniques contributes to the inaccuracy of maximal strength predictions.

Furthermore, the use of HHD to measure isometric strength as an alternative to 1RM testing shows promising potential. However, the accuracy of these measurements is still affected by device positioning and the operator's experience, limiting the consistency of results. This highlights the importance of standardizing the use of such devices to ensure the validity of the obtained results. Although isometric methods, such as the IMTP, have proven reliable in several studies, their application remains limited, and the lack of further research to validate these techniques for 1RM testing in diverse populations presents an obstacle. Therefore, while many new approaches offer great potential, further research is required to address these limitations, ensuring their broader application and enhancing the effectiveness of these methods across various settings.

## 5 Conclusion

This study critically evaluates alternative methods for estimating one-repetition maximum (1RM) strength, with a focus on VBT, isometric testing, and wearable technologies. Traditional 1RM testing, while regarded as the gold standard, carries inherent risks of injury, especially in non-athletic and clinical populations, such as the elderly or individuals with specific medical conditions. The load-velocity relationship (L-V) method has emerged as a promising alternative, correlating lifting velocity with maximal strength to predict 1RM. While it offers several advantages, challenges remain due to individual variability in lifting techniques and training responses, which necessitate further research to enhance its accuracy and reliability for diverse populations.

Additionally, isometric methods like the midhigh pull (IMTP) and hand-held dynamometry (HHD) offer valuable non-fatiguing alternatives for 1RM estimation, particularly in clinical and rehabilitation settings. These approaches are especially beneficial for individuals who cannot safely perform maximal effort tests. Advancements in wearable technologies, such as surface electromyography (sEMG) and motion sensors, further enhance the precision of strength assessments by providing real-time, non-invasive data. However, standardization of these methods, along with validation across varied populations, is essential for their broader application. Future research should focus on refining these techniques to ensure their applicability and reliability in both fitness and clinical environments.

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