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Review

Biomechanical principles in bodybuilding: Implications for performance, safety, and workforce well-being

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Abstract: Effective resistance training depends not only on exercise selection and training load but also on the mechanical quality of movement. In bodybuilding, appropriate movement execution may improve muscular adaptation while limiting unnecessary stress on joints and connective tissues. For fitness professionals, biomechanical competence may also have practical relevance for occupational health, professional development, and the delivery of safer exercise services. This systematic review synthesizes evidence on the biomechanical factors that influence bodybuilding-related training outcomes and injury prevention. It also explores how this knowledge may inform professional competence and staff development within fitness organizations. Nineteen peer-reviewed publications were systematically reviewed. Evidence was examined in relation to joint positioning, movement mechanics, muscle activation, load distribution, exercise technique, strength development, and injury-related outcomes. Studies were assessed according to their methodological relevance and contribution to applied resistance-training biomechanics. The reviewed evidence suggests that exercise configuration, joint positioning, and loading strategies influence muscle activation, strength, and other performance-related outcomes. However, biomechanical improvements should not be interpreted as direct evidence of reduced injury incidence unless injury outcomes were specifically measured. In professional fitness settings, such knowledge may strengthen instructional practice, technical decision-making, and the management of physically demanding work activities. Biomechanically informed training offers a practical basis for improving exercise quality and reducing preventable physical stress in bodybuilding. Its application to staff education, occupational well-being, and service quality remains a potential implication, as direct employee outcomes were not assessed. Further longitudinal research is required to evaluate these relationships over time.

Keywords: Employee development; fitness professionals; human capital; injury prevention; occupational health; professional competence; service quality; training effectiveness.

1. Introduction

Bodybuilding is a form of resistance training primarily aimed at developing muscular size, proportion, symmetry, and definition for aesthetic and competitive purposes. Contemporary bodybuilding practice combines carefully planned training, nutrition, recovery, and body-composition management, particularly during phases such as muscle gain, fat reduction, and pre-competition preparation (Alarcón-Rivera et al., 2025). Although these elements remain central to the sport, increasing attention has been directed toward the mechanical quality of

exercise execution and its influence on performance and injury prevention. This perspective is especially relevant in professional fitness environments, where trainers and coaches are responsible not only for achieving physical outcomes but also for delivering exercise instruction safely and competently.

In such settings, biomechanical knowledge can be understood not only as technical expertise but also as a form of professional human capital that supports the quality, consistency, and safety of service delivery. Developing this competence requires more than individual experience; it may also depend on organizational investment in staff education, continuing professional development, and structured technical training.

Human movement results from the coordinated interaction of anatomical structures that generate, transmit, and control force (Lopes et al., 2025). Biomechanics provides a framework for understanding how posture, joint position, force application, and movement strategy influence performance and injury exposure. Technological developments have expanded the possibilities for movement assessment through portable and increasingly accessible monitoring systems (Giustino & Patti, 2025), while applied biomechanical principles have also supported safer loading strategies and exercise techniques in resistance training and rehabilitation (Lake et al., 2014). For fitness professionals, the practical value of this knowledge lies in the ability to translate biomechanical information into safer instruction, more appropriate exercise modification, and more consistent technical decision-making.

Kinetic and kinematic analyses provide additional insight into how movement characteristics relate to health and physical functioning. Variables such as exercise intensity, duration, frequency, age, health status, and physical capacity may influence movement outcomes and therefore need to be considered when exercise is prescribed or evaluated (Forte & Teixeira, 2023). More recent work has emphasized the value of combining biomechanical and mathematical approaches when assessing sports performance (Bendo et al., 2025). Biomechanical assessment has likewise become increasingly relevant to injury prevention and rehabilitation because individualized movement analysis may assist in identifying potentially harmful patterns before they become persistent problems (Zhang, 2025). Advances in applied sports biomechanics have strengthened the capacity to evaluate movement, support rehabilitation, and identify modifications that may reduce injury exposure while maintaining performance demands (Penichet-Tomas, 2024).

These considerations are particularly important for younger individuals entering resistance-training environments. When appropriate supervision and technically sound movement instruction are provided, resistance training can be performed safely by young athletes and may contribute to injury prevention (Faigenbaum & Myer, 2010). Performance improvement similarly depends on more than increasing external load; technical refinement and an understanding of the mechanical factors underlying movement are also important components of effective training. Biomechanical analysis can therefore provide useful information for interpreting sport-specific movement and identifying opportunities for technical improvement (Aditya et al., 2025). In fitness organizations, this knowledge represents a relevant dimension of professional competence because trainers and coaches must convert technical information into safe, understandable, and individualized exercise instruction. From a human resource perspective, the capacity to recognize movement limitations, adjust exercise technique, and communicate corrective feedback can therefore be regarded as part of the technical skill base that organizations need to develop and maintain among their staff.

Bodybuilding differs from strength-focused disciplines because its primary

objective is often muscular hypertrophy rather than maximal force production. Training practices therefore tend to emphasize strategies that increase the stimulus applied to targeted muscle groups while managing fatigue and recovery. Bodybuilders commonly manipulate loading patterns and training variables throughout different phases of preparation to support hypertrophic development (Alves et al., 2020). Advanced resistance-training methods may also be used to increase training stimulus, manage monotony, and overcome performance plateaus, although the evidence supporting particular combinations of volume, intensity, and frequency remains variable (Krzysztofik et al., 2019). Changes in muscle size and physical performance are closely related to training-induced adaptations, including increases in muscular cross-sectional area and other structural changes (Kabir et al., 2025).

Exercise selection is another important consideration in bodybuilding. Both multi-joint and single-joint exercises can contribute to muscular development, although they differ in movement complexity, muscular involvement, and training purpose. Evidence suggests that both approaches can produce improvements in muscular strength and hypertrophy when appropriately programmed (Gentil et al., 2015). At the same time, growing interest in effective body-composition strategies reflects the broader demand for exercise approaches capable of increasing lean tissue while reducing fat mass (Zalillah et al., 2025).

The emphasis on physique development also introduces psychological and social considerations. Body-image dissatisfaction may arise when personal perceptions of physical appearance differ from socially valued aesthetic standards, particularly during adolescence (Rocu-Gómez et al., 2025). Relationships between physical activity, biological development, nutritional status, and body satisfaction have also been observed among adolescents, illustrating the complexity of body-image experiences during this stage of life (Paes et al., 2025). These concerns may extend into emerging adulthood, when individuals are simultaneously developing personal identities, lifestyle habits, and educational or occupational pathways (Jerez-López et al., 2025). Physical performance is also influenced by body composition, making the balance between muscular development and fat mass relevant in several sporting contexts (García-Chaves, 2025).

Resistance-training effectiveness depends partly on how key programming variables are manipulated. Range of motion, repetition technique, contraction characteristics, and movement tempo can influence the stimulus imposed on skeletal muscle. In particular, training through longer muscle lengths has received attention as a potentially relevant factor in hypertrophy-oriented exercise prescription (Androulakis Korakakis et al., 2024). Professional supervision may further influence training outcomes by helping individuals apply these variables more consistently and appropriately. Evidence from resistance-trained men suggests that professional guidance may be relevant to improvements in body composition and training progression (Vargas Molina et al., 2025). For fitness organizations, this reinforces the importance of developing employees who can combine biomechanical knowledge with individualized exercise prescription, client assessment, and technically appropriate supervision. Poorly controlled movement, inappropriate loading, and excessive mechanical stress may contribute to musculoskeletal problems over time. Although bodybuilding has a relatively low reported injury rate compared with several other sports, muscle strains, tendinopathies, and cartilage-related problems remain relevant concerns (Franca & Harcet, 2024). This makes exercise selection, load management, and technical execution important not only for performance but also for the long-term sustainability of training.

Different resistance-training models may provide useful options for

individualized exercise prescription. Functional and traditional training approaches share several methodological characteristics, although their effectiveness may vary according to individual goals and participant needs (Beck et al., 2025). Strength and functional conditioning programs may also contribute to both physical and psychological well-being, particularly when training is structured to promote adherence and functional capacity (David et al., 2025). In organizational settings, these findings support the value of evidence-informed staff development, since trainers must be able to adapt exercise prescription to individual needs rather than apply standardized routines indiscriminately. Such adaptability can be viewed as a professional capability that contributes to both service quality and the effective use of human capital within fitness organizations.

The quality of supervision is particularly important when training involves technically demanding or heavily loaded movements. Weight-training injuries can involve the shoulder, knee, wrist, muscles, tendons, and other musculoskeletal structures, with injury patterns influenced by training exposure and load (Bukhary et al., 2023). Reviews of weightlifting and powerlifting have similarly identified the lower back, shoulder, and knee as commonly affected anatomical regions, although overall injury incidence may remain comparable with that of other non-contact sports (Aasa et al., 2017). More recent evidence confirms that both acute injuries and training-related pain remain relevant considerations in strength sports (Tung et al., 2024). For employees who repeatedly demonstrate, supervise, and correct loaded movements, injury-prevention knowledge also has an occupational dimension, as poor load management may affect not only clients but also the long-term physical capacity of the fitness workforce.

Injury-prevention interventions may modify movement mechanics in ways that reduce potentially harmful loading. Programs targeting landing mechanics, for example, have demonstrated changes in knee and hip movement characteristics associated with lower injury risk (Lopes et al., 2018). Resistance-training interventions can also improve strength, functional performance, joint torque, and biomechanical characteristics of skeletal muscle (Liu et al., 2024). More broadly, muscular strength is strongly associated with athletic performance, force production, and reduced vulnerability to injury (Suchomel et al., 2016). Developing appropriate physical and technical abilities is therefore particularly important during youth athletic development (Mema et al., 2025). Training methods such as plyometric exercise may further contribute to physical fitness, muscular power, and sport-related performance when appropriately programmed (Putro et al., 2025).

Taken together, the literature indicates that biomechanical knowledge has relevance not only to exercise performance but also to the way resistance training is taught, supervised, and managed. For fitness professionals, the ability to understand joint mechanics, control loading, recognize inefficient movement, and adapt exercise techniques may be considered part of professional competence. In this context, biomechanical education may contribute to employee development, safer working practices, and higher-quality fitness services.

Despite the growing body of research on resistance training and sports biomechanics, the evidence remains fragmented across different populations, exercise modalities, and methodological approaches. Relatively few reviews have brought these findings together specifically within the context of bodybuilding. There is also limited research addressing bodybuilding practice in Southeastern Europe, including Albania, where gym participation and fitness services have expanded while structured biomechanical education and standardized injury-prevention practices remain insufficiently documented.

Accordingly, the primary purpose of this systematic review is to synthesize current evidence on biomechanical principles relevant to bodybuilding, with

particular attention to joint mechanics, movement patterns, muscle activation, loading strategies, performance, and injury prevention. The review also examines how biomechanically informed practice may support safer and more effective training. As a secondary interpretive objective, the review considers biomechanical competence as a component of professional human capital and examines its implications for employee development, continuing professional development, occupational safety, and workforce well-being within fitness organizations. This framing positions technical biomechanical knowledge not only as an exercise-related capability but also as an organizational resource that may influence professional standards and service quality.

2. Materials and methods

2.1 Study Design

This systematic review was conducted in accordance with the PRISMA 2020 reporting guidelines to promote transparency and methodological consistency (Page et al., 2021). The review was designed to identify, evaluate, and synthesize evidence on biomechanical principles relevant to bodybuilding and resistance training, with particular attention to movement technique, joint mechanics, muscle activation, training load, performance, and injury prevention. The primary focus of the review was biomechanical and performance-related evidence. A secondary interpretive objective was to consider how these findings may inform professional competence, employee training and development, occupational safety, and well-being among fitness professionals. This organizational perspective was applied during interpretation rather than used as a separate criterion for study selection. Within this interpretive framework, biomechanical competence was considered in relation to professional capability, human capital development, continuing professional development, and occupational safety in fitness settings.

2.2 Research Questions

The review was guided by the following primary research questions:

1.What biomechanical factors are most relevant to muscle activation and exercise execution in bodybuilding and resistance training?

2.How do biomechanical principles contribute to injury prevention and the reduction of unnecessary mechanical stress?

What evidence-based recommendations can be derived for improving training effectiveness, movement quality, and safety?

In addition to these primary questions, the review considered the broader implications of biomechanical knowledge for professional competence, human capital development, continuing professional development, occupational safety, and workforce well-being in fitness organizations.

2.3 Search Strategy and Data Sources

The literature search was conducted between January 1 and July 31, 2026, targeting English-language, peer-reviewed publications published between January 2010 and July 2025. Five electronic sources were consulted: PubMed, Scopus, Web of Science, SPORTDiscus, and Google Scholar. Google Scholar served as the primary source for the manual identification of relevant publications, while the remaining databases were consulted to identify additional studies and cross-check relevant literature.

The search focused on combinations of terms related to biomechanics, bodybuilding, resistance training, muscle activation, exercise performance, and injury-related outcomes. Google Scholar results were screened sequentially for relevance to the review objectives, with screening continued until subsequent results no longer demonstrated a meaningful relationship to the research topic. No predetermined numerical cut-off was applied. Search terms were

combined flexibly according to the topic under investigation, rather than applying all thematic categories simultaneously. Publications addressing broader training-related factors were initially considered for

contextual relevance; however, their inclusion in the final synthesis was subject to the predefined eligibility criteria and their contribution to the review questions.

According to the available selection records, 76 full-text publications were assessed against the eligibility criteria, of which 19 were retained in the final qualitative synthesis following eligibility reassessment. Because the included publications differed in methodological design and outcome measures, findings were synthesized narratively.

The literature search primarily addressed biomechanical and resistance-training evidence. Human resource management and workforce well-being were considered secondary interpretive dimensions rather than separately searched evidence domains. Complete database-specific search histories and the exact number of Google Scholar results screened were not retained and therefore could not be retrospectively verified. This limitation is acknowledged when interpreting the reproducibility of the literature search. Available details of the literature search strategy, data sources, and screening procedures are summarized in Appendix A (**Tables A1 and A2**).

2.4 Inclusion Criteria

Studies were eligible for inclusion when they examined bodybuilding, powerlifting, weight training, or structured resistance-training populations and reported outcomes relevant to biomechanics, exercise performance, or injury prevention. Eligible biomechanical and training variables included joint mechanics, muscle activation, electromyographic activity, repetition tempo, range of motion, training volume, load distribution, hypertrophy, strength-related measures, one-repetition maximum, torque, and other measurable indicators of physical performance. Primary studies were eligible when participants were aged 12 years or older. Systematic reviews covering mixed age groups were considered eligible when they provided identifiable findings relevant to the target population and the review objectives. Accordingly, the inclusion of Beck et al. (2025), which synthesized studies involving participants across a broad age range, was considered at the review level rather than as a single primary investigation.

Studies involving coaches or exercise professionals were also eligible when their findings were directly relevant to training practice. Because the review aimed to provide a broad synthesis of the available evidence, several study designs were considered, including randomized controlled trials, cohort studies, cross-sectional studies, mixed-method studies, systematic reviews, and narrative reviews. Publications were required to fall within the 2010–2025 period and to provide findings relevant to performance, injury, body composition, training practice, or biomechanical outcomes. Studies were not required to report human resource outcomes directly, as organizational implications were examined during the interpretive stage of the review. **Figure 1** summarizes the annual distribution of the 76 full-text publications assessed for eligibility.

2.5 Exclusion Criteria

Studies were excluded when they did not address resistance-based exercise, strength-related disciplines, or relevant biomechanical or physiological outcomes. Research focused primarily on sports or activities without a meaningful connection to resistance training was not retained. Primary studies involving participants younger than 12 years were excluded. Reviews covering mixed age groups were excluded when findings relevant to the eligible population could not be meaningfully identified or distinguished. The 15 full-text publications

excluded on the basis of age were assessed according to these eligibility criteria.

Editorials, opinion pieces, and commentaries without substantive research evidence were excluded. Studies were not excluded on the basis of missing HRM-specific outcomes, since workforce and organizational implications were considered only during interpretation of the included evidence.

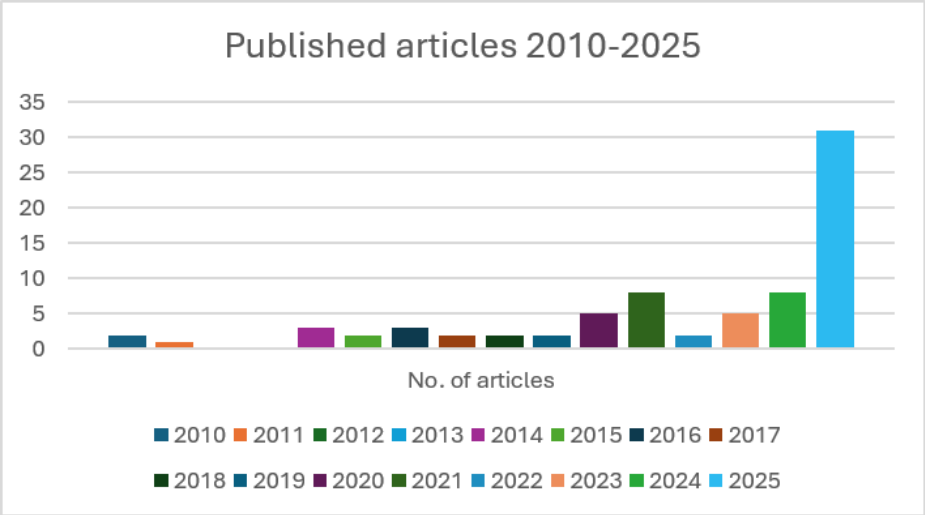


Figure 1. Annual Distribution of Full-Text Publications Assessed for Eligibility (2010–2025).

2.6 Study Context

The included studies were conducted across a range of settings, including sports science laboratories, university research environments, and gym-based training facilities. Common assessment tools included electromyography, force platforms, motion-analysis systems, strength testing, anthropometric assessment, and other measures of human movement and physical performance. Gym-based and applied training studies were particularly informative because they reflected environments in which coaches, trainers, and other fitness professionals routinely supervise exercise and provide technical instruction. These settings were also relevant to the workforce perspective of the review because they reflect the occupational environments in which biomechanical competence is translated into daily professional practice. Regional relevance to Albania and Southeastern Europe was considered when interpreting the findings; however, geographical location was not used as a preferential selection criterion. This distinction was important to avoid introducing regional selection bias into the systematic review process.

2.7 Data Extraction and Narrative Synthesis

All three authors participated in the screening, eligibility assessment, and data extraction processes. The 76 full-text publications were evaluated against the predefined eligibility criteria, resulting in 23 initially included publications, of which 19 were retained following eligibility reassessment.

Data were extracted from the 19 publications retained in the final qualitative synthesis. The extracted information included author and publication year, study design, sample characteristics, participant age and training background, biomechanical or physiological variables, intervention or assessment methods, and the main findings related to performance and injury prevention. Findings were organized according to recurring themes, including muscle activation and joint mechanics, injury-prevention strategies, performance optimization, sticking-point mechanics, muscle-fiber adaptation, exercise selection, and psycho-emotional or instructional factors. Because the included studies differed substantially in design, participants, interventions, outcome measures, and reporting approaches, statistical

pooling was not considered appropriate. The evidence was therefore synthesized narratively. Where available, statistical indicators reported by the original studies, including p-values, confidence intervals, and effect estimates, were considered when interpreting individual findings. As a secondary interpretive stage, findings related to coaching, supervision, instructional quality, professional guidance, injury prevention, psychological factors, and training practice were examined in relation to professional competence, human capital development, continuing professional development, occupational safety, service quality, and sustainable professional practice within fitness organizations.

Primary studies and review-based publications were treated as distinct types of evidence in the narrative synthesis. Primary investigations were used to describe directly measured outcomes, while systematic and narrative reviews provided broader summaries and context. The possibility of overlapping underlying studies was considered when interpreting these sources; however, a complete study-by-study overlap assessment across all included reviews could not be verified retrospectively. Consequently, review-level findings were not regarded as independent corroboration of primary-study results, and conclusions were interpreted cautiously rather than strengthened on the basis of publication counts alone.

2.8 Methodological Quality Appraisal

Given the diversity of study designs included in the review, methodological quality was considered through a structured narrative appraisal rather than through a single scoring instrument applied uniformly to all studies. Attention was given to the clarity of study design, participant description, appropriateness of biomechanical or performance measures, transparency of procedures, relevance of reported outcomes, and consistency between methods and conclusions. This approach was chosen because the review included heterogeneous evidence types, including experimental, observational, mixed-method, and review-based studies, for which a single quality-assessment scale would not provide an equivalent assessment across all designs. Methodological limitations identified during appraisal were considered when interpreting the overall evidence. No formal review protocol was prepared or prospectively registered. This is acknowledged as a methodological limitation of the review.

3. Results

The findings of this systematic review were organized according to the principal biomechanical themes identified across the included literature. The synthesis focused primarily on exercise mechanics, muscle activation, injury prevention, and training performance. Where supported by the reviewed evidence, additional attention was given to coaching, supervision, professional competence, and other factors relevant to the safe delivery of fitness services.

3.1 Study Selection

The literature search initially identified 382 records. After 228 duplicates were removed, 154 records remained for title and abstract screening. Of these, 78 were excluded as insufficiently relevant, leaving 76 full-text publications for eligibility assessment. During the original assessment, 53 publications were excluded because of insufficient biomechanical reporting ($n = 24$), an ineligible participant age range ($n = 15$), or lack of peer-reviewed publication status ($n = 14$), resulting in 23 initially included publications. Following a further eligibility reassessment prompted by peer review, four publications primarily addressing psychological, behavioral, or nutritional outcomes were reclassified as contextual literature rather than systematically included evidence. Consequently, 19 publications were retained in the final qualitative synthesis. The original selection process and subsequent eligibility reassessment are documented in

Figure 2.

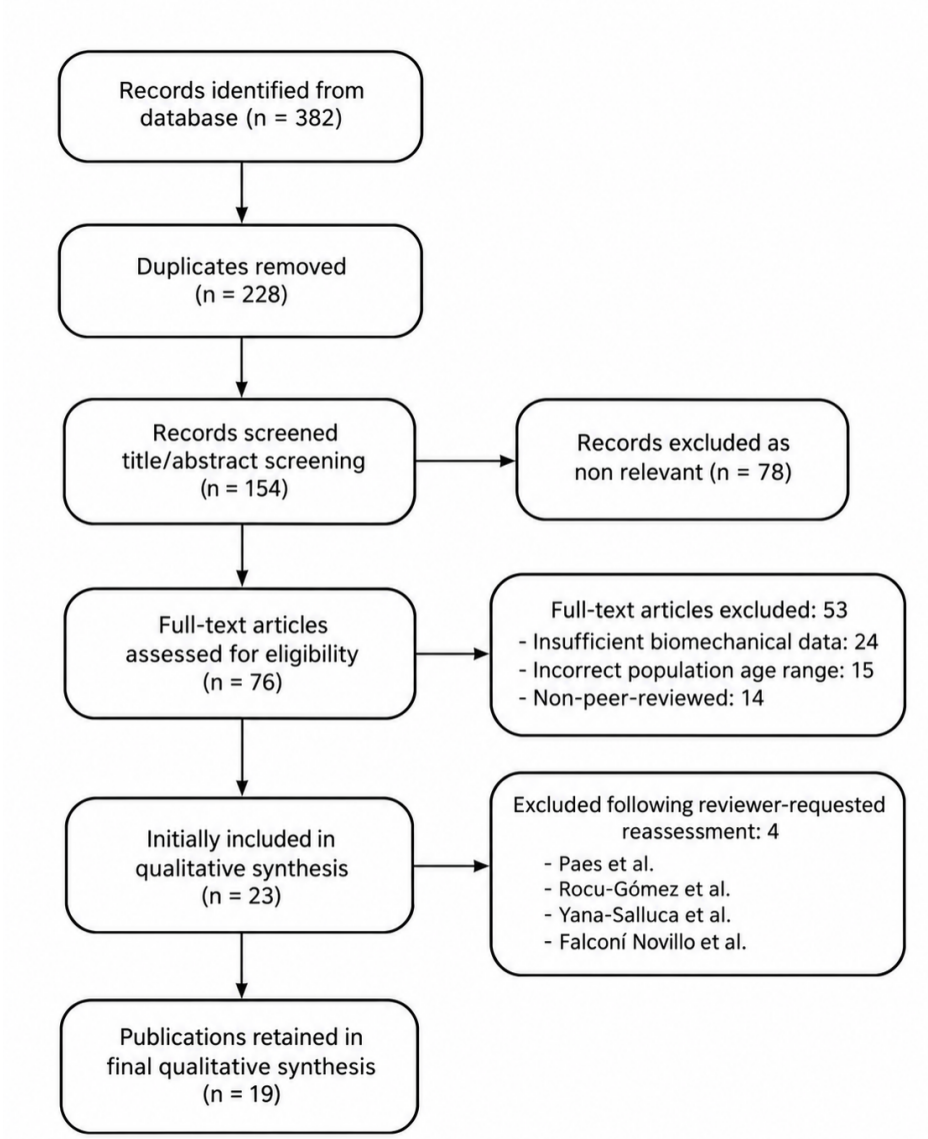


Figure 2. PRISMA Flow Diagram for Study Selection.

3.2 Characteristics of the Included Studies

The 19 retained publications represented a broad range of methodological approaches, including randomized and non-randomized studies, cohort and cross-sectional investigations, mixed-method research, systematic reviews, and narrative reviews. Considerable variation was observed in sample size, participant characteristics, age, training status, and research setting. The studies examined several biomechanical and performance-related variables, including muscle activation, joint mechanics, force production, range of motion, repetition tempo, electromyographic activity, training load, body composition, strength, and injury occurrence. Some publications also examined coaching, supervision, motivation, psychological factors, or professional guidance. These findings provided a basis for considering selected practical implications for fitness professionals and organizational training environments. The main characteristics and findings of the included studies are summarized in **Table 1**.

Table 1. Descriptive Characteristics of Included Studies.

Study (author, year),	Study design	Sample size	Participant demographics	Biomechanical variables analyzed & technical skills	Key outcome/conclusions
Aasa et al., 2017	Systematic review	9 articles	12-16 years weightlifters & powerlifter:	Injury incidence/hour	Injury risk is like other non-contact sports but lower than contact sports.
Aidar et al., 2021	Randomized counterbalanced cross-over study (static & dynamic strength tests)	12 subjects	Paralympic Powerlifting	The max. Isometric Force (MIF) with peak torque measurement (PT), the rate of force development (RFD), the fatigue index (FI), the time in the max. isometric force	Elastic bands don't reduce strength but increase fatigue and time to max isometric strength vs. fixed resistance.
Alarcón-Rivera et al., 2025	Observational cross-sectional study	26 competitive bodybuilders	> 18 years	body composition, fat mass (FM), skeletal muscle mass (SMM) & their relationship.	Poor sleep links to higher body fat; good sleep to more muscle, highlighting sleep's role in body composition.
Alves et al., 2020	A Narrative Review (including Resistance training)	14 articles	Competitive bodybuilding	Muscle hypertrophy, & changes in body composition	Bodybuilders use heavier loads, fewer reps, and longer rests off-season than pre-contest.
Androulakis et al., 2024*	A Narrative Review	42 articles	exercise professionals, physique sport athletes, &coaches.	maximizing muscle hypertrophy, exercise-specific kinematics, contraction type, repetition tempo, and range of motion (ROM)	Eccentric and concentric tempos vary if total rep time is 2–8 seconds.
Beck et al., 2025	Systematic review of Controlled trial	15 articles, 612 participants (425 women and 187 men).)	9.6 - 71 years	Traditional training protocols, functional training protocols	Knowing functional vs. traditional training aids in creating adaptable, evidence-based programs.
Bukhary et al., 2023	A descriptive cross-sectional, questionnaire-based study	393 participants, where all attendant weightlifters	18-29 years	Weightlifting injuries in the last 6 months include shoulder, knee, wrist pain/inflammation, body torsion issues, ligament and muscle tears, and stripped-off injuries.	Weightlifters commonly experience musculoskeletal injuries linked to the weight lifted, with no significant connection to gender, age, or BMI.
David et al., 2025*	Motivation Questionnaire for Sports Activity (QMAD) & Survey on Motivations for the Absence of Sports Activity (IMAAD)	189 participants	18 - 58 year	Gender, Educational qualification, Residential Environment, Box Affiliation, Experience, Practice Level	Motivation to participate in strength and functional training was influenced by personal, social, and environmental factors. The study primarily assessed practitioners' perceptions and participation-related motivations rather than objectively measured comparative physical performance.
Franca & Harcet, (2024).	A brief review	30 articles	Competitors bodybuilders	muscle hypertrophy, injuries happen in the squat, deadlift & bench press, incidence of injuries; muscle strain, tendinitis & cartilage wear	Preventive measures include medical check-ups, athlete education, competition safety, proper training/load, and equipment inspections.
Gentil et al., 2015	Cohort	29 young men without prior resistance training experience	> 18 years	Muscle Thickness, Peak Torque	MJ and SJ exercises are equally effective for promoting increases in upper body muscle strength &size
Grgic et al., 2018	A systematic review & meta-analysis	22 studies	Young and middle-aged/older adults	muscular strength outcomes with different RT frequencies, training volume, exercise selection for 1 RM	Higher training frequency was associated with greater strength gains overall; however, the effect was not statistically significant when training volume was equated ($p = 0.421$).

Continued table:

Study (author, year),	Study design	Sample size	Participant demographics	Biomechanical variables analyzed & technical skills	Key outcome/conclusions
Krzysztofik et al., 2019	A Systematic Review	30 articles	trained athletes	Muscle hypertrophy: changes in cross-sectional area, thickness, strength (1RM tests); mechanical tension, metabolic stress, muscle damage; training volume measured by reps.	Insufficient evidence limits guidelines for volume, intensity, and frequency of RT techniques, but well-trained athletes can incorporate advanced methods to break plateaus and prevent monotony.
Liu et al., 2024	RCT	40 participants	18-30 years	body composition, physical fitness components, 1RM, isokinetic muscle functions, &biomechanical properties (muscle frequency, stiffness)	Resistance training improved strength, function, and joint torque in the PSG group.
Paoli et al, 2017	Cohort	36 amateurs	23-33 years	Body Composition, Max. strength (with 1 RM), Aerobic Power (VO_2max)	RT with MJ exercises improves strength & VO_2max more than SJ, with no body composition differences.
Rukstela et al., 2023*	Cohort	33 Bodybuilding coaches	male and female bodybuilders	protein/kg bodyweight, Meal frequency/day, Intensity of Cardiovascular Exercise ((LISS; MISS & HIIT); cardiovascular exercise duration (min)/week, supplements: Creatine, caffeine, omega 3, bergamot, hormonal factors	Findings reveal coaching decision patterns in bodybuilding and highlight gaps needing further research.
Saeterbakken et al., 2021	A within-subjects crossover experimental design	28 men recreational, resistance-trained, & power lifters	$>$ 18 years	6-RM, lifting time, EMG activity between the 3 grip widths (narrow, medium & wide)	Grip width influences 6-RM loads and muscle activity, notably between wide and narrow grips.
Tung et al., 2024	Systematic review	17 articles	weightlifting & powerlifting	period prevalence of injuries during competitions, incidence injuries (hours of training)	Weightlifting showed competition injuries; powerlifting had low incidence but high training-impairing pain.
Vargas Molina et al., 2025*	Non-randomized longitudinal study.	17 young men	aged 18-35) with $\geq$ 3 years of training experience	Assessment of 1RM. Body composition,	Long-term trained individuals show little FFM gain after 15 months unsupervised; expert guidance is crucial for progress.
Zheng et al., 2025	A systematic review & meta-analysis (with RCT studies)	19 articles with 28,176 subjects	Young athletes with sports experience	Exercise duration (min), frequences (times/week), program length (weeks)	Training interventions effectively reduce athletes' knee injury risk.

*Note: * Publications with relevance to applied fitness practice. Androulakis Korakakis et al. (2024) inform exercise programming; David et al. (2025) address practitioners' perceptions and motivations; Rukstela et al. (2023) examine bodybuilding coaching practices; and Vargas Molina et al. (2025) address training supervision. The asterisk indicates practical relevance, not necessarily direct evidence of employee development, occupational outcomes, or service quality.Note: RCT = randomized controlled trial; EMG = electromyography; 1RM = one-repetition maximum. Study characteristics and findings are summarized as reported in the original publications.*

3.3 Data Extraction and Main Outcome Domains

Data extracted from the included studies covered study design, sample characteristics, participant demographics, training background, biomechanical variables, and principal outcomes. Attention was given to joint position, movement technique, muscle activation, force production, repetition characteristics, strength development, hypertrophy, and injury-related outcomes. Statistical measures such as p-values, confidence intervals, and effect estimates were considered during interpretation. Because outcome reporting differed substantially between studies, the evidence was grouped according to recurring

themes rather than pooled statistically. A secondary interpretive layer was used for findings related to coaching quality, professional supervision, training guidance, psychological factors, and exercise instruction. These findings were considered in relation to professional development, occupational practice, and service quality within fitness environments.

3.4 Methodological Appraisal

The methodological characteristics of the 19 retained publications varied substantially across experimental, observational, and review-based designs. Experimental studies provided information on strength, muscle activation, and performance-related outcomes, whereas observational investigations primarily contributed evidence on training practices, injury patterns, and participant characteristics. Review-based publications offered broader summaries of existing research, although differences in their methodological approaches and potential overlap with primary evidence required cautious interpretation.

Methodological appraisal focused on study design, participant characteristics, appropriateness of outcome measures, procedural transparency, and consistency between reported findings and conclusions. Particular attention was given to small sample sizes, observational designs, heterogeneous populations, and limitations in outcome measurement. These considerations informed the narrative synthesis by restricting conclusions to the outcomes assessed, avoiding unsupported causal interpretations, and distinguishing biomechanical indicators from directly measured injury outcomes.

3.5 Narrative Synthesis

The substantial heterogeneity of participants, study designs, training protocols, biomechanical measures, and reported outcomes did not support meaningful quantitative pooling. Findings were therefore synthesized narratively according to the principal themes that emerged across the literature. These themes included muscle activation and joint mechanics, injury-prevention strategies, performance optimization, sticking-point mechanics, muscle-fiber adaptation, exercise selection, and psycho-emotional and instructional factors.

The thematic Results presented below are based exclusively on the 19 publications retained in the final qualitative synthesis following eligibility reassessment. Four publications addressing broader psychological, behavioral, or nutritional outcomes were reclassified as contextual literature because their findings did not sufficiently address the predefined biomechanical and structured resistance-training eligibility criteria. These publications, together with other contextual sources, are discussed separately in the Introduction or Discussion and were not treated as systematically included evidence.

3.6 Muscle Activation and Joint Mechanics

Among the 19 retained publications, Saeterbakken et al. (2021) examined the influence of grip width on muscle activation and loading capacity during bench-press exercise. Aidar et al. (2021) investigated elastic resistance in Paralympic powerlifting, reporting differences in force production and fatigue-related responses. These findings indicate that exercise configuration and resistance conditions influence measurable neuromuscular outcomes, although they do not directly establish reductions in injury incidence.

3.7 Injury-Prevention Strategies

The included publications provide evidence on injury occurrence and injury-related outcomes in resistance-training and strength-sport populations. Aasa et al. (2017) reviewed injury incidence in weightlifting and powerlifting, while Bukhary et al. (2023) reported musculoskeletal injuries affecting regions such as the shoulder, knee, and wrist among weight-training participants. Tung et

al. (2024) examined injury occurrence and training-related pain in strength sports. Zheng et al. (2025) synthesized evidence on exercise-based interventions targeting knee-injury risk in athletic populations. Although these findings emphasize the importance of injury-related outcomes in training practice, differences in populations, interventions, and study designs limit direct conclusions about injury prevention specifically in bodybuilding. Importantly, Aasa et al. (2017), Bukhary et al. (2023), and Tung et al. (2024) primarily reported injury occurrence, prevalence, or related symptoms, whereas Zheng et al. (2025) synthesized intervention evidence concerning knee-injury prevention in broader athletic populations. These outcomes should not be treated as equivalent to changes in muscle activation, strength, or movement mechanics.

3.8 Performance Optimization Through Biomechanics

The included publications provide evidence on the relationship between resistance-training variables and physical performance. Gentil et al. (2015) examined single-joint and multi-joint exercises, reporting improvements in muscular strength and size. Paoli et al. (2017) compared exercise approaches and reported advantages of multi-joint training for strength and aerobic performance, without corresponding differences in body composition. Grgic et al. (2018) reviewed resistance-training frequency and strength outcomes, indicating that the apparent benefits of higher training frequency should be interpreted in relation to total training volume, as differences were not statistically significant when volume was equated. Collectively, these findings emphasize the importance of exercise selection, training volume, and individualized programming when interpreting resistance-training performance.

3.9 Load-Related Mechanics and Muscular Adaptation

The included publications addressed mechanical loading, resistance conditions, and training-related muscular adaptations. Aidar et al. (2021) investigated the effects of elastic resistance on maximal isometric force production and fatigue-related responses in Paralympic powerlifting. Krzysztofik et al. (2019) reviewed advanced resistance-training methods and identified limitations in the available evidence concerning the optimal combination of training volume, intensity, and frequency. Androulakis Korakakis et al. (2024) discussed repetition tempo, contraction characteristics, and range of motion in relation to hypertrophy-oriented training. Together, these findings highlight the importance of distinguishing acute neuromuscular responses from longer-term training adaptations, while recognizing that the evidence derives from different study designs and populations.

3.10 Isolation and Multi-Joint Exercises

The included studies examined the effects of single-joint and multi-joint exercises on resistance-training outcomes. Gentil et al. (2015) reported that both exercise approaches contributed to improvements in upper-body muscular strength and size. Paoli et al. (2017) found that multi-joint exercise training produced greater improvements in maximal strength and aerobic capacity than single-joint training, without significant differences in body composition. Together, these findings suggest that exercise selection should be guided by specific training objectives rather than the assumption that one exercise category is universally superior.

3.11 Psycho-Emotional, Instructional, and Professional Context

Among the included publications, David et al. (2025) examined motivation and participation-related perceptions in exercise settings, while Rukstela et al. (2023) investigated coaching practices and preparation strategies in bodybuilding. These studies provide evidence concerning behavioral and professional aspects of training rather than direct measurements of biomechanical outcomes.

Their findings are therefore considered separately from the biomechanical and performance-related evidence, with potential implications for professional competence and fitness-service delivery discussed in Section 4.

4. Discussion

This systematic review shows that biomechanical competence is relevant not only to exercise performance and injury prevention but also to the professional practice of coaches and fitness trainers. Across the reviewed literature, movement technique, joint mechanics, load management, and individualized exercise prescription emerged as recurring determinants of training quality and physical safety (Saeterbakken et al., 2021; Drigny et al., 2025; Zheng et al., 2025; Grgic et al., 2018). Rather than restating each finding separately, the discussion focuses on how such technical knowledge may function as a professional capability within fitness organizations and how it may relate to staff development, occupational safety, service quality, and workforce well-being.

Additional biomechanical literature provides useful context for interpreting these findings. Research on exercise technique and joint positioning has highlighted their relevance to muscle recruitment and mechanical loading (Cao & Li, 2025). Studies examining shoulder mechanics have further emphasized the importance of scapular control, joint positioning, and movement coordination for shoulder function (Ludewig & Braman, 2011; Jaggi & Lambert, 2010). Although these publications were not included in the final systematic synthesis, they provide relevant contextual perspectives on movement quality and joint mechanics. Additional biomechanical research provides context for interpreting injury-related findings. Straub and Powers (2024) discussed movement mechanics and loading considerations relevant to demanding resistance exercises, while Forte and Teixeira (2023) examined the broader relationship between exercise biomechanics, physical demands, and health-related movement outcomes. These publications were used to contextualize the findings rather than as part of the 19 systematically included studies. Their contribution supports a cautious interpretation of biomechanical indicators, which should not be equated with demonstrated reductions in injury incidence.

Additional performance-related literature provides a broader context for interpreting these findings. Davies et al. (2015) examined the role of plyometric exercise in physical performance development, while Suchomel et al. (2016) discussed the contribution of muscular strength to athletic performance and force-production capacity. La Scala Teixeira et al. (2019) further considered exercise progression and the integration of different training demands. These publications were used to support the contextual interpretation of resistance-training performance rather than as independent evidence within the final set of 19 included studies.

Additional literature provides context for interpreting load-related mechanics and muscular adaptation. Kompf and Arandjelović (2016) examined the biomechanical characteristics of sticking points during resistance exercise, while Gene-Morales et al. (2020) investigated mechanical and performance-related responses to elastic resistance. Research on muscular adaptation has further addressed the relationships among hypertrophy, strength development, training load, and physiological responses (Travis et al., 2020; Schoenfeld et al., 2021; Roberts et al., 2023; Reggiani & Schiaffino, 2020). Broader ethical considerations concerning artificial approaches to muscular adaptation have also been discussed (Brzeziańska et al., 2014). These publications provide complementary scientific context but are not treated as independent evidence within the 19 studies included in the systematic synthesis.

Further contextual evidence suggests that repetition tempo may influence

muscular loading and resistance-training adaptations, depending on the characteristics of the exercise protocol (Wilk et al., 2021). Although this publication was not included in the final qualitative synthesis, it provides complementary information relevant to individualized exercise prescription.

Additional contextual research highlights the importance of interpersonal and psychological factors in coaching and professional practice. Rong (2024) examined coaching behavior and its relevance to athletic development, while Liu et al. (2025) discussed the relationship between leadership and coach–athlete interactions. Den Hartigh et al. (2022) further considered resilience as a multidimensional process influenced by individual and environmental factors. These publications provide complementary perspectives on professional competence and athlete support but were not part of the 19 publications included in the systematic synthesis.

This interpretation is particularly relevant to professional fitness settings. Coaches and personal trainers routinely make decisions about exercise selection, load progression, movement correction, and training frequency. Their ability to interpret biomechanical information may therefore influence not only athlete or client performance but also the safety and consistency of exercise delivery. From a workforce perspective, biomechanical competence can be viewed as a technical capability that contributes to professional practice and may reduce avoidable physical risk in settings where employees repeatedly supervise and demonstrate demanding movements. Technological developments have further expanded the practical applications of biomechanics. Contemporary approaches increasingly incorporate motion analysis, force measurement, wearable systems, and computational tools to improve the understanding of human movement and sports performance (Dhahbi, 2025). The broader development of biomechanical analysis in physical activity and sport similarly reflects growing interest in translating laboratory-based methods into applied environments (Forte, 2025). Evidence from sport-specific biomechanical analysis also illustrates how movement assessment can identify technical characteristics that may be relevant to performance optimization and injury prevention (Monterrosa Quintero et al., 2025). These developments have implications for fitness organizations as well as for athletes. The availability of increasingly accessible assessment technologies may create opportunities for trainers to use evidence-informed feedback, but technological access alone is unlikely to improve practice. Employees must also possess the knowledge required to interpret movement data and translate it into appropriate training decisions. Consequently, professional development in fitness organizations may need to include both technical biomechanics education and practical instruction in the use of movement-analysis technologies. From a human resource perspective, this competence can be treated as a form of specialized human capital because it reflects knowledge and practical judgment that employees apply directly in service delivery. Its development should therefore not rely solely on individual experience, but can be supported through structured staff education, mentoring, and continuing professional development within fitness organizations.

Neuromuscular training provides another example of the interaction between movement quality and performance development. Such training can improve several components of physical fitness, including balance, agility, muscular power, speed, and movement control (Akbar et al., 2022). These adaptations are relevant because efficient movement depends not only on force production but also on coordination and the ability to control forces across joints and segments. At the shoulder, the functional contribution of individual muscles to glenohumeral movement and stability changes according to task demands and external loading (Assila et al., 2021). This reinforces the importance of considering joint-specific

mechanics when exercises are prescribed or modified. Broader physiological characteristics, including body composition and physical condition, may also influence performance demands across different sports populations (Popova et al., 2025). Although such populations are not directly equivalent to bodybuilders, these findings illustrate the wider relationship between physical characteristics and the mechanical demands placed on the body during training and competition. For fitness professionals, this variability highlights the need to interpret biomechanical information in relation to individual characteristics rather than relying on uniform training solutions. The ability to make such adjustments represents a practical professional competency that can be strengthened through staff education and continuing professional development.

Force production during resistance exercise is similarly influenced by movement conditions. Squat performance, for example, can vary according to mechanical demands and stability conditions, affecting the way force is generated during different phases of the movement (Vázquez-Guerrero et al., 2016). Force–velocity analysis provides an additional framework for identifying loading conditions that may be appropriate for different performance objectives (Tauda et al., 2025). These findings support individualized rather than uniform exercise prescription, particularly when training goals differ between hypertrophy, maximal strength, muscular endurance, and power development. The need for individualization is also evident in youth training. Free-weight resistance training can be used effectively in young athletes when technical competency, supervision, and appropriate progression are considered (McQuilliam et al., 2020). This is especially relevant to the present review because technical instruction is partly dependent on coaching quality. Coaching behavior can influence athlete performance through the way training, feedback, technical preparation, and goal setting are organized (Ullah et al., 2021). Strength training itself may enhance performance in endurance athletes by improving factors such as neuromuscular efficiency, muscular power, and exercise economy (Beattie et al., 2014). Resistance exercise may also support functional independence and physical capacity in older populations when appropriately structured (Galdames Maliqueo et al., 2025). Together, these findings highlight the broad responsibility of fitness professionals. Effective instruction requires more than knowledge of bodybuilding routines; it requires the capacity to adapt training to age, experience, physical capacity, and individual goals. Biomechanical education may therefore form part of a wider professional competency framework that includes assessment, communication, exercise prescription, and risk management. For fitness organizations, this breadth of responsibility suggests that trainer competence should be developed as a multidimensional capability rather than as technical exercise knowledge alone. Structured continuing professional development can help employees maintain skills in individualized programming, communication, supervision, and risk-aware decision-making across different client populations.

The application of biomechanics in educational and training settings nevertheless faces practical barriers. Limited access to equipment, variation in instructor expertise, and resistance to new teaching approaches can restrict the implementation of biomechanically informed practice (Ji & Wang, 2025). These barriers are directly relevant to human resource management because employee competence depends partly on organizational opportunities for learning, mentoring, technological access, and continuing professional development. Fitness organizations that invest in structured education may therefore be better positioned to translate biomechanical evidence into consistent professional practice. Muscle adaptation also requires careful interpretation. Resistance training can influence muscle-fiber characteristics, but adaptations depend on

the interaction of training history, intensity, volume, recovery, and individual biological factors (Plotkin et al., 2021). This reinforces the need to avoid overly simplified training prescriptions. Similarly, the mechanisms underlying sticking points during resistance exercise demonstrate that performance limitations can emerge from complex interactions between biomechanics, muscle force, and joint position (Kompf & Arandjelović, 2016). Understanding these mechanisms may help practitioners modify technique or loading strategies while avoiding inappropriate increases in training stress. For fitness professionals, this complexity reinforces the need for technical judgment rather than reliance on standardized or routine-based exercise prescriptions. Organizations can support this judgment through continuing education and practice-oriented training that helps staff interpret loading demands in relation to individual needs and recovery capacity. Nutrition and supplementation represent additional elements of bodybuilding practice, although they fall outside the primary biomechanical focus of this review. Functional foods and sports supplements have been discussed in relation to physical performance and recovery (Falconí Novillo et al., 2025). At the same time, psychological and behavioral factors also influence participation in physical activity. Body appreciation and motivation are associated with healthier attitudes toward exercise and related behaviors among university students (Yana-Salluca et al., 2025). These findings support a broader interpretation of performance and well-being in which physical, psychological, and behavioral factors interact rather than operate independently. This broader perspective is also relevant to the development of the fitness sector itself. Research examining current fitness-sector trends highlights the continuing growth and diversification of fitness participation and services (Andrade Sánchez et al., 2025). As the sector expands, professional standards become increasingly important because coaches and trainers may provide guidance that extends beyond exercise technique to nutrition, supplementation, recovery, and other aspects of bodybuilding preparation.

Bodybuilding coaches may provide guidance extending beyond exercise programming, including recovery and nutrition-related decisions (Rukstela et al., 2023). This broader role highlights the need for clearly defined competency boundaries, appropriate referral practices, and continuing education. Such measures represent potential organizational approaches to supporting responsible coaching and consistent service delivery rather than outcomes directly established by the included studies. Psychological factors provide another important dimension. Mindfulness, attentional control, emotional regulation, and related psychological skills may contribute to athletic performance and coping with competitive demands (Sukmana et al., 2025). These considerations complement the biomechanical focus of the present review because sustainable performance depends not only on physical technique but also on the ability to manage psychological and training-related stress. The use of performance-enhancing substances adds further complexity to bodybuilding environments. Such substances remain relevant to discussions of bodybuilding performance and health because their use may introduce physiological risks that cannot be addressed through biomechanical optimization alone (Mantri et al., 2023). Accordingly, the promotion of safe professional practice requires an interdisciplinary approach in which biomechanics is integrated with appropriate knowledge of health, recovery, psychology, and ethical decision-making. For fitness organizations, this broader competency profile suggests that technical expertise should be complemented by communication skills, psychological awareness, ethical judgment, and an understanding of when referral to other qualified professionals is appropriate. Supporting these competencies through staff development and continuing professional education may help strengthen responsible practice and reduce

uncertainty when trainers encounter issues that extend beyond exercise technique alone.

Future research in Albania and Southeastern Europe could examine how biomechanical education is incorporated into fitness-professional training, exercise supervision, and occupational safety practices. Region-specific studies would help establish whether additional professional-development resources, competency standards, or organizational support are needed. These questions remain priorities for investigation rather than conclusions established by the present review.

Taken together, the workforce implications of this review can be organized around three interconnected areas: professional capability, occupational safety, and service quality. Biomechanical knowledge contributes to professional capability by supporting technically informed decision-making; it contributes to occupational safety by guiding movement, loading, and exercise-demonstration practices; and it contributes to service quality by helping trainers provide individualized and defensible exercise guidance. For fitness organizations, the practical implication is that biomechanical competence should be developed, updated, and supported as part of a broader workforce-development strategy rather than treated solely as knowledge acquired during initial professional preparation.

At the same time, these conclusions should be interpreted cautiously. Most of the studies included in this review were designed to investigate biomechanics, physical performance, injury, or training outcomes rather than human resource variables. Therefore, relationships involving employee performance, occupational well-being, service quality, or organizational effectiveness cannot be considered direct causal findings of the reviewed literature. Accordingly, the HR and organizational implications discussed in this review should be understood as theoretically informed and practice-oriented extensions of the biomechanical and professional-practice evidence, rather than as direct causal effects demonstrated by the included studies.

4.1 Study Impact

This review extends the practical interpretation of bodybuilding biomechanics beyond athlete performance alone. Its findings suggest that biomechanical knowledge may contribute to the technical preparation of coaches, personal trainers, and other fitness professionals who are responsible for supervising resistance exercise. Within fitness organizations, this knowledge may support employee development, safer exercise instruction, professional confidence, and more consistent service standards. This perspective extends the relevance of biomechanics beyond individual expertise by linking trainer competence with professional standards, occupational safety, and consistent service delivery. The study may be particularly relevant to Albania and Southeastern Europe, where empirical research on bodybuilding practice and structured professional education remains limited. Rather than proposing region-specific biomechanical conclusions, the review highlights the need for locally appropriate training standards, professional-development opportunities, and injury-prevention frameworks that reflect the realities of emerging fitness markets.

4.2 Limitations

Several limitations should be considered when interpreting the findings. First, the included studies were heterogeneous in design, participant characteristics, training experience, intervention duration, and outcome measurement. This variation limited direct comparison and prevented meaningful quantitative pooling.

Second, the evidence base included both primary studies and review-based publications, which differ in methodological purpose and level of evidence. The findings should therefore be interpreted as a broad narrative synthesis rather

than as a single pooled estimate of biomechanical effectiveness. An additional eligibility reassessment during peer review resulted in the reclassification of four publications as contextual literature. This refinement improved alignment with the review objectives but also highlights the importance of interpreting the original study-selection process and the final included evidence transparently.

Third, many studies were cross-sectional or relatively short in duration, limiting conclusions about the long-term effects of biomechanically informed training on performance, injury prevention, and professional practice. Differences in assessment tools, including electromyography, force measurement, strength testing, and observational methods, may also contribute to variability across findings.

Finally, most included studies did not directly assess employee outcomes such as job performance, job satisfaction, occupational well-being, or organizational effectiveness. Accordingly, the workforce and HR implications discussed in this review should be interpreted as theoretically informed and practice-oriented extensions of the biomechanical evidence rather than as directly demonstrated HRM effects.

4.3 Future Research Directions

Future research should use more standardized and longitudinal designs to determine whether biomechanically informed training produces durable improvements in exercise performance and injury prevention. Greater attention should also be given to individual variability, including differences associated with age, training history, exercise experience, movement characteristics, and recovery capacity. Emerging technologies such as wearable sensors, motion-analysis systems, force-measurement devices, and real-time feedback platforms warrant further investigation in applied gym environments. Future studies should assess not only their technical accuracy but also whether fitness professionals can use these tools effectively in routine practice. Future studies should directly examine whether structured biomechanical education and continuing professional development improve trainer competence, occupational safety, employee well-being, service quality, and professional performance. Greater attention should also be given to organizational factors such as mentoring, training resources, technological support, and professional standards that may influence how biomechanical knowledge is applied in practice.

5. Conclusion

This systematic review suggests that exercise technique, joint positioning, and loading strategies are relevant to muscle activation, strength, and performance-related outcomes in resistance training. However, the evidence for injury occurrence, injury-related symptoms, and intervention-based injury prevention derives from different study designs and populations; improvements in biomechanical indicators alone do not establish a reduction in injury incidence.

Beyond their direct relevance to athletes, these principles also have practical value for fitness professionals. Biomechanical competence may strengthen the ability of coaches and personal trainers to assess movement, provide appropriate technical feedback, and supervise resistance training more safely. Within fitness organizations, incorporating biomechanical education into staff training and continuing professional development represents a potential application rather than an established intervention for improving employee occupational safety, service quality, or workforce well-being.

The available evidence nevertheless remains heterogeneous, and most studies were not designed to measure human resource outcomes directly. Further research should determine whether structured biomechanical education, continuing professional development, and organizational support translate into measurable

improvements in employee performance, occupational health and safety, and sustainable professional practice. Greater attention to applied research in Albania and Southeastern Europe would also help clarify how these principles can be implemented within developing fitness-sector environments.

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Appendix A. Retrospective Documentation of the Literature Search and Study Selection

Table A1. Retrospective summary of literature-search procedures

Data source	Search role and available details	Information not retained
Google Scholar	Primary manual search using combinations of biomechanics, bodybuilding, resistance training, muscle activation, exercise performance, and injury-related outcomes. Records were screened sequentially by relevance, without a preset numeric cutoff.	Exact queries, result counts, number screened, and stopping boundary.
PubMed	Supplementary literature identification and cross-checking.	Exact search dates, query strings, field tags, search limits, and source-specific record counts.
Scopus	Supplementary literature identification and cross-checking.	Exact search dates, query strings, search fields, search limits, and source-specific record counts.
Web of Science	Supplementary literature identification and cross-checking.	Exact search dates, query strings, search fields, search limits, and source-specific record counts.
SPORTDiscus	Supplementary literature identification and cross-checking.	Exact search dates, query strings, search fields, search limits, and source-specific record counts.

Note: Searches were conducted between January and July 2026 and covered publications from January 2010 to July 2025. This table summarizes the authors' retained account and does not reconstruct exact database search histories.

Table A2. Reconciliation of study-selection counts

Selection stage	n	Explanation
Records identified	382	Reported total; source-specific counts could not be retrospectively verified.
Duplicates removed	228	Originally reported.
Records screened	154	382 − 228.
Records excluded during screening	78	Originally reported.
Full texts assessed	76	154 − 78.
Full texts excluded at the original screening stage	53	Reasons listed below.
Insufficient biomechanical reporting	24	Original exclusion reason.
Ineligible participant age	15	Original exclusion reason.
Not peer reviewed	14	Original exclusion reason.
Additional exclusions following reassessment	4	Previously included publications removed following reviewer-requested reassessment.
Final included publications	19	76 − 53 − 4.

Note: The four publications excluded following reassessment had previously been included and were additional to the 53 original full-text exclusions.