Blagajac, M. (2025) Holistic analzsis of modern strength training In: Dašić, D. (ed) Sporticopedia SMB2025, Vol 3, No 1, 11-24

DOI: https://doi.org/10.58984/smbic250101011b
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HOLISTIC ANALYSIS OF MODERN STRENGTH TRAINING

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Abstract: The paper analyzes strength training as a complex process of managing adaptation across multiple organic subsystems. In contrast to the traditional view of muscles solely as force producers, the holistic approach treats them as the most important metabolic and endocrine organ. In parallel, the fundamental physiological and kinesiological characteristics of the main strength training systems are examined. The practice of applying strength training immediately after a football match is also analyzed. The central thesis of the paper is the transition from "copying" generic programs to truly "grasping" (understanding) the biochemical and physiological principles of adaptation, supported by the application of modern monitoring systems. Special emphasis is placed on the specifics of training children and adolescents through an analysis of the musculofascial and osteoarticular imbalance that occurs during growth.

Keywords: Strength training adaptation, holistic muscle function, physiological and kinesiological systems, training monitoring and load management, youth growth and musculoskeletal imbalance

Introduction

Muscles, together with the skeletal system, account for 60–65% of total body mass and represent the foundation of organismal health. The fact that approximately 80% of the centers in the cerebral cortex are motor centers clearly indicates the inseparable link between movement and cognition.

Strength development is associated either with the improvement of motor control processes governing muscle activity or with an increase in the number of myofibrils

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within muscle fibers. An increase in the number of myofibrils simultaneously leads to the expansion of the sarcoplasmic reticulum, which overall increases myofibrillar density within the fibers and, subsequently, the muscle cross-sectional area. Changes in cross-sectional area may also be related to an increase in mitochondrial mass, glycogen stores, and other organelles. However, in a trained athlete, myofibrils and mitochondria occupy more than 90% of the muscle cross-section; therefore, the primary factor of hypertrophy is the increase in the number of myofibrils and, consequently, strength gain (Blagajac, 2024).

The musculofascial system is the largest organ or organ system, and it is important to highlight its fundamental characteristics: elasticity, plasticity, the ability to contract and relax, force-generating capacity, the possibility of conscious control of muscle tension, various contraction modes, the capacity for regeneration into advanced age, the dynamics of catabolism (muscle protein half-life of approximately 30 days), and the ability to hypertrophy and atrophy. All these features characterize the musculofascial system. It is a dynamic, adaptive organ rather than merely a passive "generator and executor of movement."

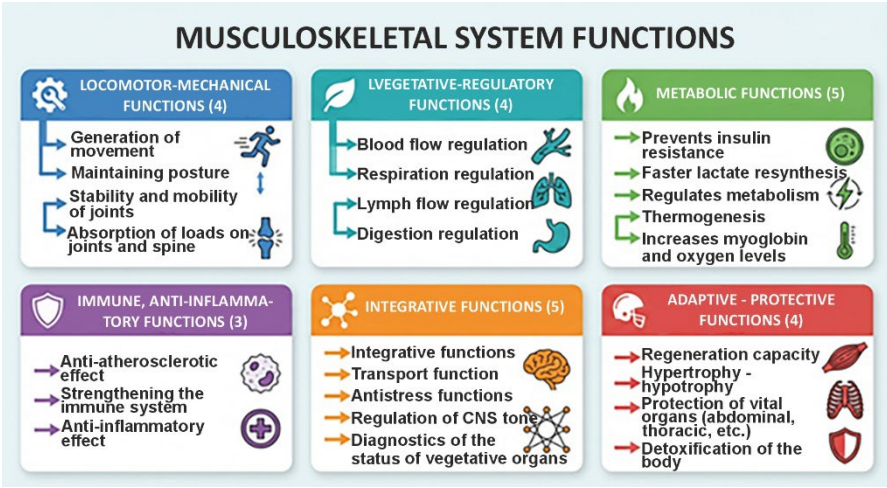
Contemporary research warns that uncritical emphasis on hypertrophy, combined with inadequate supplementation, leads to excessive mass that becomes a metabolic and biomechanical burden, increasing the risk to the cardiovascular system.

The functions of the muscular system are closely interconnected and interdependent, operating as an integrated functional whole that is also linked to the functions of other organs and systems of the body.

For the purpose of easier and more comprehensive analysis, the numerous functions of the muscular system can be conditionally grouped into six categories (Figure 1):

1. Locomotor – mechanical functions
2. Vegetative – regulatory functions
3. Metabolic functions
4. Immune and anti-inflammatory functions
5. Integrative functions
6. Adaptive – protective functions

Figure 1. Musculoskeletal system functions



Form motor abilities to adaptology

Traditional training theory defines “strength” as a motor ability. However, contemporary Adaptalogy argues that “strength” or “speed” do not exist in the human body as independent entities; rather, they are labels for the external manifestations of internal processes (Seluyanov, 1998; Issurin, 2016).

The holistic concept of strength training emphasizes that training does not “develop abilities” per se, but instead stimulates adaptive changes in three key systems:

1. The locomotor apparatus: muscles, fasciae, bones, and joints
2. The energy–metabolic system: energy supply and utilization
3. The control system: the central nervous system, peripheral nervous system, and the endocrine system

Chacteristics of the main strength training systems

In training practice, five strength training systems predominate, each with a specific energetic and physiological signature (Milanović, 2013; Schleip & Müller, 2013).

Powerlifting (System of Maximal Effort)

- Essence: Focused on the development of maximal voluntary muscle force through three fundamental lifts (squat, bench press, deadlift).
- Mechanism: Primarily stimulates neuromuscular adaptation (recruitment of a greater number of motor units and their synchronization). Very high loads are used

(90–100% 1RM) with a low number of repetitions (1–3) and long rest intervals to allow central nervous system recovery.
- Goal: Achievement of absolute force records, accompanied by high stress on the osteoarticular and tendon structures.

Bodybuilding (System of Maximal Hypertrophy)

- Essence: Aimed at altering body composition by increasing muscle size (hypertrophy) and symmetry.
- Mechanism: Employs moderate loads (70–85% 1RM) with higher repetition ranges (8–12) and short rest periods (60–90 s) to induce maximal metabolic stress and microtrauma of muscle fibers. Sarcoplasmic hypertrophy predominates.
- Goal: Aesthetic body modification; often results in increased mass that may become a biomechanical burden in sport games.

Traditional Strength Training (General System)

- Essence: Based on linear progression and general preparation of the muscular system without strict sport specificity.
- Mechanism: Combines basic gym exercises with the aim of increasing the general strength base. The focus is on the muscle as an isolated force generator, often neglecting the context of movement and stability under load.
- Goal: General strengthening of the organism; however, transfer to specific sport activities is often unpredictable and limited.

Functional Strength Training (Movement Integration System)

- Essence: Trains movement rather than isolated muscles. Strength is viewed through the efficiency of musculofascial chains.
- Mechanism: Utilizes multi-joint exercises across all planes of movement (rotational, stabilization, unilateral patterns). Emphasis is placed on proprioception, motor control, and force transmission from the trunk to the extremities.
- Goal: Maximal transfer to sport-specific technique, injury prevention, and movement economy.

Statodynamic Strength Training (Mitochondrial Transformation System)

- Essence: A specific method (according to Seluyanov) aimed at training muscles under conditions of local hypoxia without mechanical overload of the joints.
- Mechanism: Uses low loads (approximately 30% 1RM), slow execution within a shortened range of motion (constant tension for 30–45 s). Capillary compression restricts oxygen supply, thereby activating anabolic processes in slow oxidative muscle fibers.

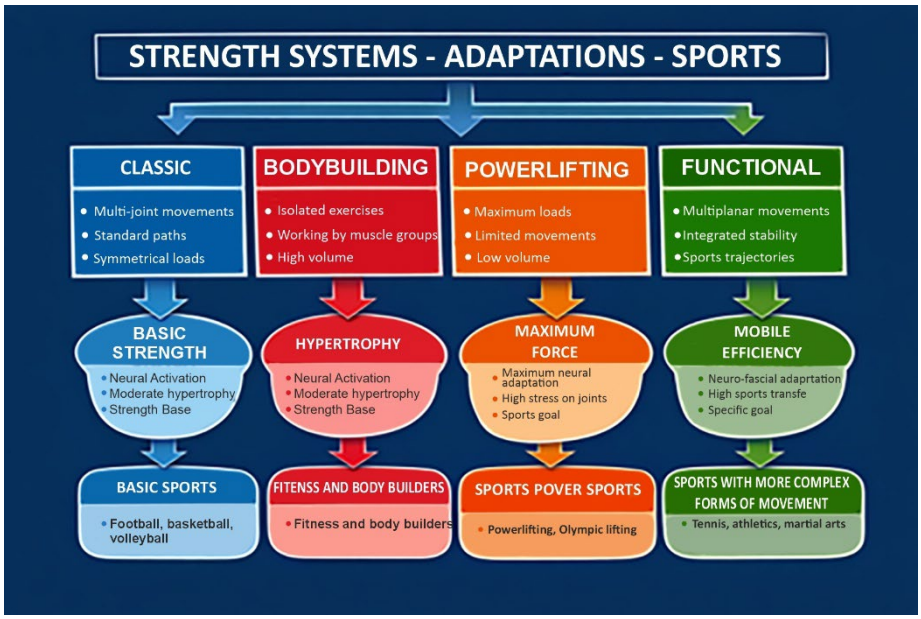
- Goal: Hypertrophy of slow-twitch fibers and their transformation into stronger and more fatigue-resistant fibers through mitochondrial network expansion, making this method particularly suitable for rehabilitation and elite endurance performance.

Comparative Overview of Strength Training Systems

A comparative overview highlights the distinct adaptive targets, energetic demands, and practical applications of each strength training system, underscoring the necessity of selecting methods in accordance with sport-specific demands and long-term adaptation goals.

System	Primary Goal	Dominant Adaptation	Transfer to Sport
Traditional	General strength	Neural + structural	Moderate
Bodybuilding	Aesthetics / muscle mass	Metabolic (sarcoplasmic)	Low
Powerlifting	Maximal force	Neural efficiency (motor unit recruitment)	Low–Moderate
Functional	Movement efficiency	Neurofascial integration	High
Statodynamic	Strength endurance	Mitochondrial transformation	High

Figure 2. Strength systems – adaptations - Sports

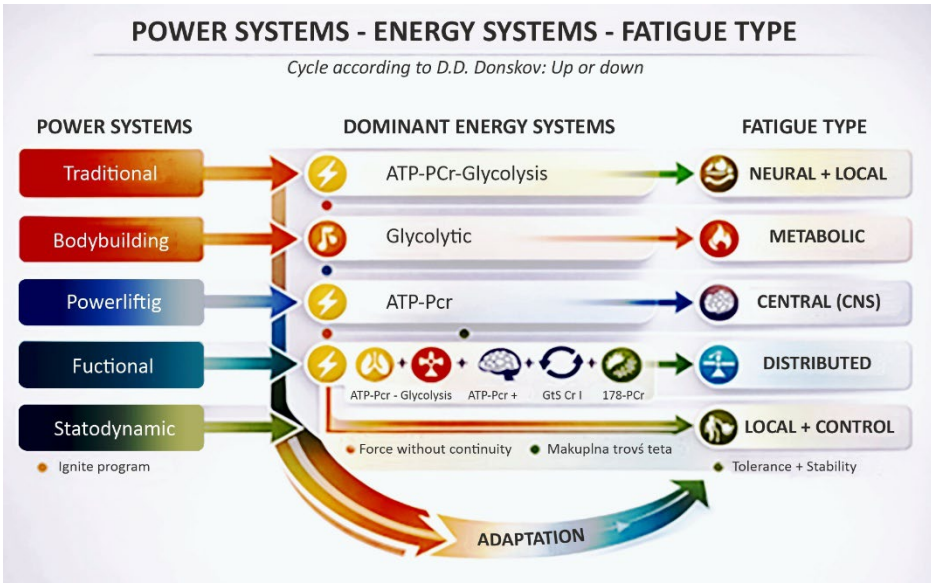


Energetic aspects of strength training

Strength training is simultaneously training of the body's energy systems. Understanding these processes is essential for preventing overload of the central nervous system (Blagajac, 2016).

- Traditional / Powerlifting: Primarily relies on the ATP–CP system. It induces significant central nervous system fatigue and requires prolonged recovery periods.
- Bodybuilding: Dominated by the glycolytic system. The focus is on metabolic stress, with minimal adaptation of the oxidative system.
- Functional training: Integrates all three energy systems (ATP–CP, glycolytic, and oxidative), resulting in the highest transfer to sport practice.
- Statodynamic training: Engages both the glycolytic and oxidative systems, increasing fatigue tolerance and improving metabolic control.

Figure 3. Power systems – energy systems – fatigue type



Strength training immidiately after a football matsh

Within the widespread practice of uncritical copying and application of other people's training methods—without understanding their physiological and kinesiological foun-

dations—the application of strength training immediately after a football match is also frequently observed.

The application of high-load strength training immediately after a match (within 1–2 hours) has no physiological justification and is counterproductive. Strength training performed immediately after a match may only be directed toward tonization and active recovery, and under no circumstances toward true strength development (Seluyanov, 2001).

Basic characteristics of the physiological state after a match:

- The athlete's organism is in a state of deep stress
- Glycogen stores in muscles and the liver are depleted
- Muscle fiber damage (microtrauma) caused by numerous eccentric contractions (decelerations, jumps, changes of direction, duels)
- Accumulation of metabolites in the blood and muscles (lactate, hydrogen ions) and activation of inflammatory processes
- Significantly elevated levels of stress hormones, especially cortisol
- Evident central nervous system (CNS) fatigue, manifested as reduced capacity for motor unit recruitment

Why strength training immediately after a match is harmful:

- It exacerbates muscle damage and intensifies inflammatory processes
- It disrupts glycogen resynthesis
- It increases stress hormone levels—chronically elevated cortisol creates a catabolic environment that inhibits recovery and increases the risk of overload
- It overloads the CNS, which requires relaxation after a match rather than additionaltress

After a match, active recovery through tonizing loads is required in order to improve circulation, accelerate the elimination of metabolites and stress hormones, reduce stiffness, and provide mental and emotional relaxation.

Therefore, after a football match—as after any competition—a systematic application of appropriate recovery systems (kinesiological, physiological, and psychological), programs, and protocols is required.

Kinesiological recovery programs may include:

- Very low external loads (30–50% 1RM)
- Low training volume (1–2 sets per exercise)
- Low intensity (no failure, no proximity to failure)
- Full range of motion with dynamic stretching through movement

Characteristics of strength development across age groups

In approaches to strength, a one-sided perspective is often adopted: strength is proclaimed as the foundation of all motor abilities, while neglecting the fact that strength never manifests independently in any sport. Instead, it always appears synergistically within a system and structure alongside other motor abilities. The relationship, interdependence, and relative contribution of each motor ability depend on the specific demands of the sport.

It is essential to emphasize that the foundation of all motor abilities is functional sport technique (movement), not one of its components—strength.

A particular kinesiological, physiological, and health-related issue is strength training in young athletes. Increasingly, strength training is promoted and offered to youth athletes (including via online platforms) independently of comprehensive training aimed at versatile, harmonious general physical, bodily, and functional development, and optimal preparation for healthy growth, education, profession, sport, and life in general (Verkhoshansky, 1980; Malacko & Rađo, 2004).

Development of the Musculofascial and Osteoarticular Systems

The development of the musculofascial and osteoarticular systems does not proceed evenly. These systems alternate in "leadership," sometimes diverging in tempo, and it is precisely from this mismatch that both great developmental potential and typical problems in strength training of children and adolescents arise. Strength training must therefore be viewed as a developmental process that respects age-specific characteristics.

AGE 7–10 YEARS – "Soft Body, Living Learning System"

During this period, the osteoarticular system is still in the modeling phase. Bones are elastic, epiphyseal (growth) plates are wide and sensitive, joints are relatively unstable but mobile, articular cartilage is thick, and the ligamentous apparatus is more lax.

The musculofascial system is poorly differentiated in terms of strength but extremely plastic in control. Fasciae are well hydrated, soft, and "slippery," allowing large ranges of motion but with limited force-generating capacity.

The dominant developmental dynamic at this age is not strengthening, but organization. Movement is learned, the nervous system "maps" the body, and muscles function primarily as stabilizers and guides rather than force generators. Numerous mismatches occur: a child can do a lot, but not for long; can learn quickly, but cannot tolerate mechanical load.

Primary goal: motor literacy and control of body and movement.

Training priorities:

- Development of coordination, balance, and spatial orientation
- Trunk stability and basic postural control
- Full joint mobility
- Development of basic endurance through play

Permitted forms of "strength" (indirect development only):

- Mastery of bodyweight (supports, mixed hangs, climbing)
- Jumps with controlled landings
- Carrying light objects while moving
- Pushing and pulling activities through play

These activities develop:

- Neuromuscular activation
- Basic muscle tone
- Joint stabilization

Prohibited or not recommended:

- Gym-based training with external loads
- Set-and-repetition training aimed at "strengthening"
- High-intensity static isometric holds
- Competitive approaches to strength training

Training structure:

- Duration: 45–60 minutes
- High variability
- Frequent task changes
- Minimal verbal pressure from the coach

Strength training must not be an independent goal at this age. Strength is not developed; instead, the foundation of neuromuscular control is built.

AGE 10–14 YEARS – Accelerated Bone Growth Relative to Muscles

This is the most critical developmental phase. The osteoarticular system enters accelerated longitudinal growth. Bones lengthen, lever arms change, joint axes shift, and centers of mass move. Epiphyseal plates remain active but are particularly vulnerable.

The musculofascial system lags behind skeletal growth. Muscles become relatively shortened, fasciae lose elasticity, and tendon attachments experience increased stress. Strength may increase, but coordination often temporarily declines.

Development is asymmetric and wave-like. Typical issues include overload of attachment sites, knee pain, heel pain, lumbar discomfort, and apparent declines in motor abilities.

Strength training may be included, but:

- With low to moderate loads
- Through full ranges of motion
- With emphasis on technique and control

The goal must not be maximal strength, but:

- Preservation of mobility
- Joint stabilization
- Correction of growth-related imbalances

Primary goal: stability and control during growth and development.

AGE 14–17 YEARS – Structural Closure and Entry into Strength

The osteoarticular system gradually completes longitudinal growth. Epiphyseal plates close, joints stabilize, and bone resistance increases.

The musculofascial system enters a phase of rapid capacity development. Muscle mass, fiber cross-sectional area, fascial stiffness, and force transmission improve. Tendons become stronger and more efficient in elastic energy storage.

Development shifts from adaptation to optimization: strength, speed, reactivity, and endurance can now be systematically developed.

Primary goal: planned development of strength and the strength–speed relationship.

Training priorities:

- Systematic development of maximal and explosive strength
- Strengthening of the tendon–fascial system
- Integration of strength into sport technique
- Injury prevention through stability

Permitted strength training:

- Training with external loads
- Progressive intensity increases
- Bilateral and unilateral exercises
- Development of strength, strength–speed, and reactivity

Necessary conditions:

- Technical maturity
- Stable mobility
- Proper dosing of volume and intensity
- Load periodization

Training structure:

- 2–4 strength sessions per week (sport-dependent)
- Clear distinction between developmental and maintenance phases
- Integration with technical–tactical training

At this age, strength is not a risk but a protective and developmental factor—provided it is properly planned and dosed.

Methodological conclusion

- Early, forced strength training does not accelerate long-term development; it often slows it down.
- Balanced development requires respecting the sequence: control → stability → capacity → performance.
- The gym is not the problem. The problem is the wrong age, the wrong goal, and the wrong methodology.

GENERAL METHODOLOGICAL FRAMEWORK FOR ALL AGE GROUPS

Training for young athletes must be aligned with:

- the degree of morphological development of the locomotor apparatus (musculofascial and osteoarticular systems),
- the functional maturity of the central and peripheral nervous systems,
- the capacities of metabolic–energetic systems,
- the adaptive potential of the endocrine system.

If any of these systems is pushed beyond its developmental capacities, overall physical development is compromised and the risk of injuries and functional imbalances increases.

Strength training must simultaneously:

- ensure that strength development follows the athlete's biological maturity,
- develop the locomotor apparatus (musculofascial and osteoarticular systems),
- stimulate the nervous system without overload,
- respect the age-related metabolic and endocrine limits,

- support long-term development rather than short-term outcomes.

Each age group has a primary training objective and secondary permissible effects. Errors occur when secondary effects are forced as primary goals.

Conclusion

Modern strength training must not be reduced to forcing "weight lifting." Strength training is a sophisticated system of adaptation that requires:

1. Understanding instead of copying: knowledge of biochemical and physiological foundations, with respect for individual characteristics and current ability level.
2. Continuous monitoring: tracking internal physiological responses (e.g., SmO_2, HR, BC) to applied training and competition loads.
3. A holistic approach: aligning strength development with growth phases and maintaining musculofascial balance.

Strength is a performance factor only when it is integrated into functional movement and supported by a healthy vascular system. Strength should not be isolated and trained as the foundation of all motor abilities, but treated as an integral part of a system (a network) of motor abilities that manifests differently across different sports activities and sport techniques.

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