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Assessment of physical (somatic) health of young men in the construction of health improving strength training

Vitalii Korotych*

Postgraduate Student
Vasyl Stefanyk Precarpathian National University
76018, 57 Shevchenko Str., Ivano-Frankivsk, Ukraine
https://orcid.org/0000-0002-1662-2141

Abstract. The systematic review aimed to determine the effect of strength training on physiological and morphological adaptive capacities in healthy young men. A search was conducted for randomised clinical trials containing information on the effect of resistance exercise on physical and functional changes in young men aged 18-45 years. As a result, 13 publications that met the search criteria were found, of which 9 studies were selected after excluding inappropriate ones. Most of the studies were assessed as good-quality research with a score of 7-9 on the PEDro scale. Long-term strength training has been shown to significantly improve strength, muscle volume and explosive abilities in trained individuals. Strength training 3 times a week can increase lean body mass and left ventricular mass index, with a decrease in body fat. Light training stimulates hypertrophy of the gastrocnemius muscle more than heavy training, which has a greater impact on the middle and lateral heads of the gastrocnemius muscle. The sequence of exercises does not affect the increase in maximum strength, but the effect on pectoral muscle hypertrophy may be better when performing multi-joint exercises after isolated exercises. The appearance of microRNAs does not show specificity in the early acute state of training, with changes in expression observed 8 hours after training. The duration of weightlifting training has a positive effect on anthropometric and physiological parameters, but not on biochemical parameters

Keywords: resistance exercise; systematic review; functional adaptation; muscle hypertrophy; sports medicine

INTRODUCTION

Lack of physical activity can have significant negative health consequences. Systematic exercise can improve health by contributing to the prevention of cardiovascular, musculoskeletal, and metabolic disorders [1]. Strength training (ST) is becoming increasingly popular among young men as a means of improving physical fitness and increasing muscle mass and strength [2]. However, many young men lack adequate information about safe and effective training methods. To properly prescribe and monitor ST, clinicians need to know the health effects of exercise to design optimal exercise programmes and reduce the risks of injury and complications. There are many studies describing the general effects of ST, but there is a lack of systematic reviews that evaluate specific changes in functional and physical status in men. This study will provide a comprehensive assessment of the impact of ST on somatic health, considering physiological and biochemical changes that occur in the body.

Muscle strength is defined as the ability to produce force against resistance [3]. The stress-recovery-adaptation model assumes that training stress causes the body to recover and adapt to the load, which is manifested in increased performance. This cycle of stress, recovery, and adaptation is the basis of an effective ST programme [2]. The regeneration of damaged tissues occurs through the transfer of daughter nuclei from satellite cells after they have multiplied and fused. Over time, bones also increase their mineral density to withstand increasing loads [4].

Resistance training helps to increase muscle strength and mass, improve balance, bone mineral density, walking speed, and the ability to climb stairs [5]. They reduce systolic blood pressure (SBP), back pain, and local and total fat mass, and increase intestinal transit time, which can reduce the risk of colon cancer in healthy men [6]. The mechanism of prevention of metabolic syndrome and type 2 diabetes mellitus is associated with a decrease in

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*Corresponding author

visceral fat and an increase in lean body mass, as well as the ability to insulin-independent glucose uptake, which is activated by muscle contraction [7]. ST is an effective method of counteracting sarcopenia, which is characterised by a decrease in muscle mass and strength. Scientific studies show that ST significantly improves grip strength and upper limb function in patients with sarcopenia [8]. Individually tailored and periodised ST programmes can slow the progression or development of sarcopenia by increasing muscle strength [9].

The effectiveness of different modes of training loads for the development of physical qualities in students was studied by I. Skibytskyi *et al.* [10] in an experiment during gymnastics classes. As determined, the greatest increase in muscle mass was observed at 80% of the maximum weight. For strength development, 90% of the maximum weight was the most effective, while 60-70% of the maximum weight was the best for strength endurance. The recommended training regimes include 3 sets with a 3-minute rest for strength development, 3 sets of 12 repetitions for muscle growth, and 3 sets with a 60-second rest for strength endurance.

The study of the relationship between the risk of low muscle mass and the frequency and duration of ST involved 126,339 people from Korea. The results of the study by J.H. Park *et al.* [11] showed that regular ST (3-4 days a week) reduces the risk of low muscle mass by 22% and performing more than 5 days a week – by 27%. The duration of training also matters training for 1-2 years reduces the risk by 19%, and for more than 2 years – by 41%. The greatest effect is achieved with training for more than 2 years.

M.H. Stone *et al.* [12] and H. Momma *et al.* [13] studied aspects of ST and their impact on health. It was found that STs confirm the existence of a strength-endurance continuum (S-EC), with two main aspects: high-load, low-repetition exercises (power stimulus) and high-volume, low-load exercises (HIEE stimulus). Dynamic matching of training principles improves the transfer of results to real-world performance. Studies have also shown that muscle-strengthening activity is associated with a 10-17% reduction in the risk of all-cause mortality, cancer, cardiovascular disease, metabolic disorders and lung cancer, while no association was found with the risk of colorectal, renal, bladder and pancreatic cancer.

The effect of a single high-intensity ST on memory was studied by T. Hashimoto *et al.* [14]. The training group demonstrated improved memory two days after the strength training session, particularly in cued recall and free recall. Free recall was associated with increased connectivity in the left posterior hippocampus. This suggests that short, intense ST can have a positive effect on memory and neural plasticity without requiring repeated training.

The study of the long-term impact of strength training on the physical health of young people, addressing individual differences, psychological aspects and optimal recovery methods, remains relevant. The study presents a systematic review of studies of the effect of ST on functional and physical changes in men aged 18-45 years.

MATERIALS AND METHODS

This systematic review was conducted following the PRISMA 2020 guidelines for systematic reviews and meta-analyses [15]. Relevant scientific publications were selected by searching PubMed, Google Scholar and Wiley Online Library databases. A combination of keywords in English was used, and a time filter was set to select publications published between 2019 and 2024. To ensure the accuracy and completeness of the search, logical operators AND/OR were used. The following combination of search queries was used for Google Scholar: ("young men" AND "strength training" AND "health" AND "research") OR ("healthy men" AND "physiological changes" AND "waist circumference" AND "volume"). The search phrases used in PubMed and Wiley Online Library were "young men" AND "strength training" AND "health" AND "research". The process of literature selection was carried out following the PRISMA flowchart, which allows us to systematise and visualise the stages of publication selection.

Study inclusion criteria were developed based on the PICOS model (population, intervention, comparison, outcomes, study design). The study included publications that analysed functional and physiological changes in healthy men aged 18-45 years under the influence of strength training of varying intensity. Studies where the population consisted of both men and women were included only if separate indicators for men were available. The intervention consisted of ST of different intensities: low, moderate and high. It also included a combination of strength exercises with other types of training. The somatic assessment of participants' health was carried out before and after the training period, and a comparison was made between groups with different intensities of exercise, and exercises for different muscle groups.

The results were assessed by comprehensive indicators of physical characteristics, anthropometry, muscle function and biochemical parameters related to strength training. Exclusion criteria included the presence of acute or chronic diseases of the cardiovascular, musculoskeletal or respiratory systems, and metabolic disorders that could affect exercise performance. Individuals with bad habits and those who used androgenic and anabolic steroids during the study were also excluded.

Only randomised controlled trials were included in the review. The risk of bias was assessed using the PEDro scale. Data from the selected studies were organised and entered a Microsoft Excel spreadsheet. The collected data elements included the author's name and year of publication, number of participants, their level of physical fitness at the beginning of the study, specifics of the STs performed, including duration, frequency and intensity, and combination with other training exercises. Methods for assessing physical activity, somatic condition, and genetic and biochemical parameters were also carefully documented. The data also included baseline measures of participants' condition at the beginning of the study or before the intervention, as well as the dynamic changes that occurred as a result of regular resistance exercise. A systematic search for relevant articles identified 9 publications. The search process is shown in Figure 1.

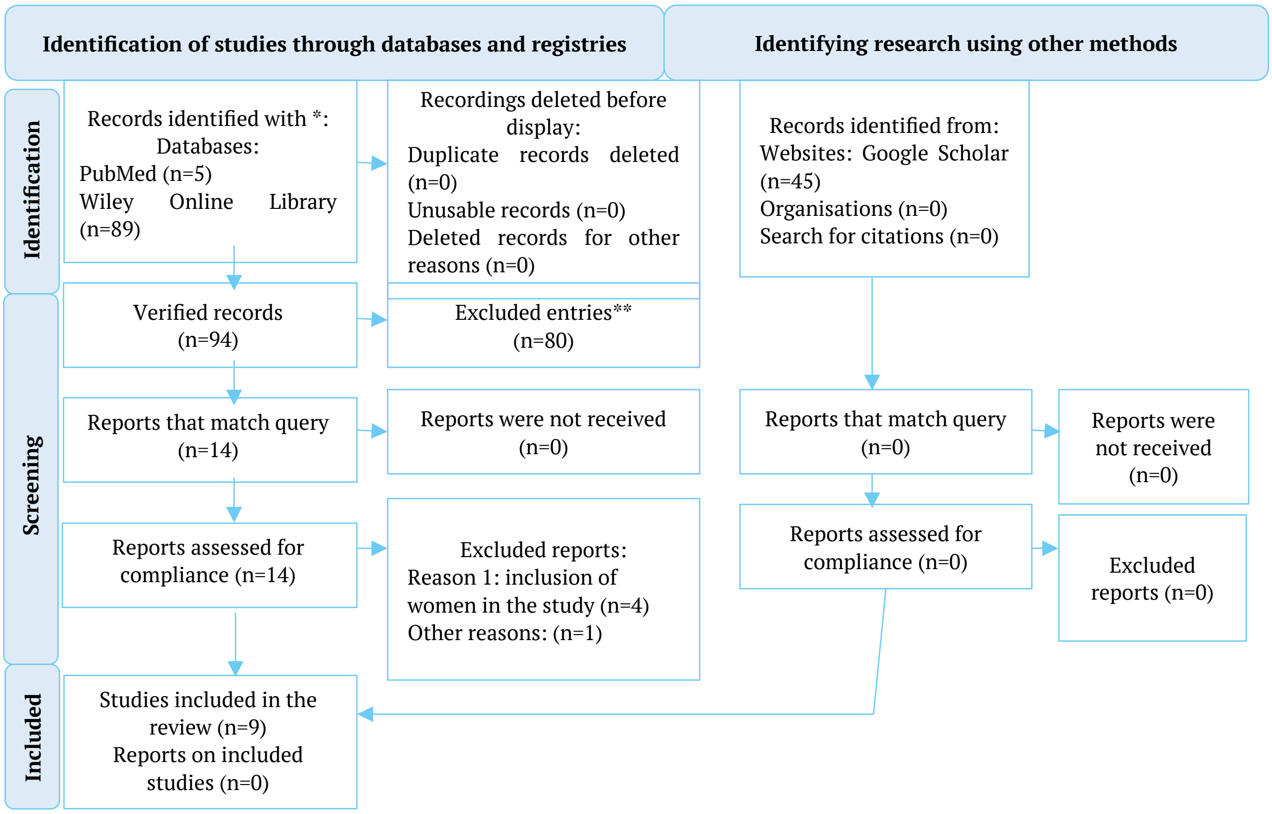

Figure 1. PRISMA flowchart for selecting literature that meets the inclusion criteria
Source: compiled by the author

RESULTS AND DISCUSSION

ST is based on progressive overload: a gradual increase in the load, which stimulates physiological adaptation. At the initial stage, this can be achieved by simply increasing the weight while keeping other training parameters unchanged [2]. Most studies scored between 7 and 9 on the PEDro scale (Table 1), which indicates a high quality of methodology, but there are limitations to objectivity due to the lack of blinding of participants and researchers. The main results of the included studies are presented in Table 2. The studies evaluated the effect of ST on the physiological parameters of men of different ages and fitness levels. Participants underwent various ST programmes that included exercises for the upper and lower extremities with varying intensity and volume. Muscle strength, endurance, muscle hypertrophy, changes in cardiac and vascular function, as well as cellular respiration and levels of inflammatory biomarkers were assessed. The pre-and post-intervention scores were compared to determine physiological changes, such as increased muscle mass, strength, improved cardiac function and endurance.

Table 1. Evaluation of the quality of studies of the effect of ST on the body of young men using the PEDro scale

Author's name and year	A. Grandperrin *et al.* [16]	B.J. Schoenfeld *et al.* [17]	T.G. Balshaw *et al.* [18]	B.J. Schoenfeld *et al.* [19]	E.A. Dawson *et al.* [20]	E.I. Lähteenmäki *et al.* [21]	L. Brandão *et al.* [22]	G.D. Telles *et al.* [23]	P. Deku *et al.* [24]
The selection criteria were defined as follows	1	1	1	1	1	1	1	1	1
Participants were randomly assigned to groups	1	1	1	1	1	1	1	1	0
The distribution was hidden	1	1	0	0	0	0	1	0	0

Table 1. Continued

Author's name and year	A. Grandperrin *et al.* [16]	B.J. Schoenfeld *et al.* [17]	T.G. Balshaw *et al.* [18]	B.J. Schoenfeld *et al.* [19]	E.A. Dawson *et al.* [20]	E.I. Lähteenmäki *et al.* [21]	L. Brandão *et al.* [22]	G.D. Telles *et al.* [23]	P. Deku *et al.* [24]
The groups were similar at baseline in terms of the most important prognostic indicators	1	1	1	1	1	1	1	1	1
All participants were anonymised	0	0	0	0	0	0	0	0	0
All therapists who conducted therapy were anonymised	0	0	0	0	0	0	0	0	0
All evaluators who measured at least one key outcome were anonymised	0	0	0	0	0	0	0	0	0
More than 85% of the participants achieved one outcome	1	1	1	1	1	1	1	1	1
All participants received treatment or control condition as defined	1	1	1	1	1	1	1	1	1
Results of intergroup statistical comparisons are reported for at least one key outcome	1	1	1	1	1	1	1	1	1
The study provides both point estimates and measures of variability for at least one key outcome	1	1	1	1	1	1	1	1	1
ST	8	8	7	7	9	7	8	7	6

Notes: ST – total score 0-10 points
Source: compiled by the author based on [25]

Table 2. Data from studies of power loads on the physiological characteristics of young men

Author, date	Sample	Impact/intervention	Assessment/ surveillance/ inspection	Metrics before the intervention	Physiological changes associated with ST (after the intervention)
A. Grandperrin *et al.* [16]	17 men aged 18-40 years. Exercise no more than 1 hour/per 3 years	CT 3 times/week for 16 weeks. 70% of 1-RM (leg press, squats, leg extension and flexion), trunk (butterfly, bench press, incline bench press, vertical pull-ups and horizontal rowing), arms and shoulders (triceps curl, rope pull, military press, barbell biceps curl, side/front raises, dumbbell biceps curl). 4 sets of 10 repetitions with a 90-second rest between sets	of the 16-item Global Physical Activity Questionnaire version 2, adapted (GPAQ-2) to collect data on sedentary behaviour and physical activity in three areas: commuting, work activities and leisure activities during a typical week. Anthropometry, blood pressure, and date. Cardiac output, body composition, function and morphology	1-RM bench press (kg) 67.9 ± 19.1; 1-RM squat (kg) 82.5 ± 20.9; fat-free body weight (kg) 36.9 ± 3.9; body fat mass (%) 23.0 ± 6.1; cardiac morphology and function: LVMi (gm^{-2}) 89.1 ± 9.6; wave E (cms^{-1})71.7 ± 16.8; wave A, (cms^{-1}) 35.2 ± 6.9; E′ mean (cms^{-1}) 10.49 ± 1.81; EF (%) 62.2 ± 4.4; GLS, % – 19.56 ± 1.76; LAVI (ml. m^{-2}) 23.9 ± 3.9; reservoir function LP(%) 30.5 ± 7	1-RM bench press (kg) 87.9 ± 17.5; 1-RM squat (kg) 118.7 ± 16.4; fat-free body weight (kg) 37.6 ± 3.9; body fat mass (%) 22.6 ± 5.7; cardiac morphology and function: LVMi (gm^{-2}) 109.2 ± 12.9; wave E (cms^{-1}) 77.6 ± 15.5; wave A (cms^{-1}) 29.5 ± 6.1; E′ mean, (cms^{-1}) 10.60 ± 1.37; EF (%) 63.9 ± 2.9; GLS (%) – 18.65 ± 1.39; LAVI ($ml.m^{-2}$) 25.3 ± 4.2; LV reservoir function (%) 30.8 ± 9.1
B.J. Schoenfeld *et al.* [17]	34 men aged 18-35 years, experience of ST (3/ week≥1 year. 3 groups: low volume of CT (1SET) (n = 11), moderate volume (3SET) (n = 12), high volume (5SET) (n = 11)	8 weeks, 3 r/week, (1SET) 1 set per exercise per training session, (3SET) – 3 sets per exercise per training session, (5SET) – five sets in the upper and lower extremities. 7 exercises per session for all muscle groups: bench press, military bench press, wide-grip lateral stretches, seated cable row, barbell back squat, simulator leg press, and unilateral leg extension in the simulator. 8-12 repetitions performed to the point of instantaneous concentric failure, 90 seconds of rest, and 120 seconds between exercises.	Anthropometry, muscle mass thickness (ultrasound). The endurance of the upper body muscles was assessed by bench pressing at 50% of 1-RM until the moment of maximum failure. Muscle hypertrophy was examined using B-mode ultrasound for elbow flexors and extensors, as well as for the middle and lateral thigh	Squats (1RM) (kg): 1SET: 104.5 ± 14.2, 3SET: 114.9 ± 26.1, 5SET: 106.6 ± 24.0. Bench press 1-RM (kg): 1SET: 94.1 ± 16.1, 3SET: 100.2 ± 20.6, 5SET: 91.1 ± 20.9. Bench press endurance (repetitions): 1SET: 21.3 ± 5.0. 3SET: 2.1 ± 5.6. 5SET: 23.6 ± 7.4. Muscle thickness (mm): biceps 1SET: 39.7 ± 4.7, 3SET: 42.2 ± 4.0, 5SET: 41.7 ± 4.6. Triceps (mm): 1SET: 47.4 ± 4.6, 3SET: 47.7 ± 6.1, 5SET: 47.2 ± 6.8. Rectus femoris muscle (mm): 1SET: 54.2 ± 5.3, 3SET: 52.2 ± 5.0, 5SET: 54.9 ± 5.4. Lateral broad muscle bone (mm): 1SET: 57.9 ± 6.8, 3SET: 56.4 ± 5.6, 5SET: 57.9 ± 6.4	Squats (1RM): 1SET: 123.4 ± 12.9, 3SET: 126.6 ± 25.0, 5SET: 122.2 ± 19.0. Bench press 1-RM: 1SET: 102.6 ± 15.5, .3SET: 108.6 ± 20.6. 5SET: 100.7 ± 22.3. Bench press endurance: 1SET: 23.0 ± 4.2, 3SET: 24.9 ± 5.2, 5 SET: 25.3 ± 8.0. Biceps muscle thickness: 1SET: 40.7 ± 4.7.3SET: 43.6 ± 4.1. 5SET: 44.6 ± 4.7. triceps: 1SET: 48.2 ± 4.7, 3SET: 49.4 ± 6.2, 5SET: 50.2 ± 6.6. rectus femoris muscle after: 1SET: 55.3 ± 5.8, 3SET: 54.6 ± 5.8, 5SET: 57.3 ± 5.8. The lateral broad muscle bone after: 1SET: 59.0 ± 6.7, 3SET: 58.8 ± 5.7, 5SET: 62.6 ± 5.8

Table 2. Continued

Author, date	Sample	Impact/intervention	Assessment/ surveillance/ inspection	Metrics before the intervention	Physiological changes associated with ST (after the intervention)
T.G. Belshaw *et al.* [18]	n = 63.2 groups: UNTs (n = 49) had not engaged in lower body ST for >18 months in total. Physical activity level according to MOFA: 2326 ± 1337 IU min/week. LT-MST group (n = 14): performed systematic heavy quadriceps ST for ⩾3 years. Physical activity level: 5568 ± 1457 IU min/week	Long-term maximal ST (LT-MST) several knee extensions exercises 3 times a week (squats, lunges, step up and leg press). Participants underwent an introductory session, which included unilateral isometric voluntary maximal and explosive contractions, as well as evoked contractions on an isometric dynamometer for knee extension/ flexion. Neuromuscular measurement sessions with the dominant leg. LT-MST group performed knee extension exercises 3 times per week	CSA of the quadriceps (QACSA $_{MAX}$); quadriceps by MRI). Maximal voluntary torque (MVT), Electromyography (EMG) from quadriceps (QEMG), hamstring muscles (HEMG)	For UNT: MVT knee extension (nm): 245 ± 45; QEMG (cm²): 90 ± 12	For LT-MST MVT, knee extension: 407 ± 63; QEMG: 138 ± 14; LT-MST showed significantly higher maximal strength and CSA values of +66% and +54%, respectively. The absolute explosive power was also higher in LT-MST (+41% to +64%). The relative explosive power was lower in LT-MST (by 11% to 16%). LT-MST showed slower contractile properties, which did not depend on differences in the activation of the neuromuscular system
B.J. Schoenfeld *et al.* [19]	26 untrained men. Average metrics Height: 175.7 cm; weight: 77.3 kg; adipose tissue: 20.5%; age: 22.5 years	LT (20-30 repetitions) and WT (6-10) for the calf muscles. Sitting and standing shin raises 2/ week 8 weeks, 4 sets, 90s rest between sets, 3 min between exercises	Muscle thickness (ultrasound) and muscle strength (dynamometer)	WT: soleus (mm) 18.8 ± 4.4; medial calf muscle (mm) 18.3 ± 3.2; lateral calf muscle (mm) 15.9 ± 2.6; isometric plantar flexion (N·m) 154 ± 48. LT: soleus (mm) 18.2 ± 4.3; medial calf muscle 17.7 ± 3.0; lateral calf muscle 15.6 ± 2.8; isometric plantar flexion 153 ± 47	VT: soleus 20.1 ± 4.6; medial calf muscle 19.7 ± 3.1; lateral calf muscle 17.9 ± 2.5; isometric plantar flexion 170 ± 41. LT: soleus 19.7 ± 4.6; medial calf muscle; lateral calf muscle 17.9 ± 3.2; isometric plantar flexion 168 ± 41. Hypertrophy of the psoas muscle: LT: 10 ± 10% more; WT: 7 ± 8% more. Hypertrophy of the calf muscles: LT: 15 ± 30% more; VT: 20 ± 25% more

Table 2. Continued

Author, date	Sample	Impact/intervention	Assessment/ surveillance/ inspection	Metrics before the intervention	Physiological changes associated with ST (after the intervention)
E.A. Dawson *et al.* [20]	35 healthy young men	Two programmes of 4 weeks: ST and endurance training (END). ST 3 times a week on a leg extension machine. 4 sets of 10 repetitions of 80% of 1-RM for each leg, 2 min break between sets. END was performed on a cycle ergometer and 30 minutes of cycling with a maximum heart rate of 70% in the first 3 sessions. In sessions 4-6, 5 intervals of 1 min at 90% of the maximum heart rate, followed by 5 min at 70% of the maximum heart rate. Sessions 7-9 30 minutes cycling at 80% of the maximum heart rate. Sessions 10 and 11 included 5 intervals of 1 min each with an intensity of 90% of the maximum heart rate and 5 min with a load of 80% of the maximum heart rate	Anthropometric measurements, CPET testing, brachial artery vascular function assessment (ultrasound), peak VO_2, RER, genotype PCR, power output for END	For CT: 1-RM (kg) 56 ± 14; total load (kg) 5,874 ± 1,456; peak VO_2 (ml·min^{-1kg-1}) 47.5 ± 11.0 For END: Output power (W) 113 ± 23; maximum CPET: VO_2 peak, (ml·min^{-1} kg^{-1}) 46.5 ± 9.4	For CT: 1-RM (kg) 67 ± 13; total load (kg) 7,208 ± 1,563; peak VO_2, (ml·min^{-1} kg^{-1}) 46.4 ± 104. For END: Output power (W) 123 ± 25; maximum CPET: Peak VO_2, (ml·min^{-1} kg^{-1}) 49.6 ± 10.4 Total load increased by 23% (7,208 ± 1,563 kg), a 1-RM increase from week 1 to 4. 1-RM, one maximum repetition: 67 ± 13. Peak VO_2 ml·min -1 kg -1: 46.4 ± 10.4. Output power (END) 123 ± 25. ik VO_2, ml·min-1·kg-1: 49.6 ± 10.4
E.I. Lähteenmäki *et al.* [21]	12 trained healthy men	Isokinetic bench press on the Smith isokinetic machine with 5 sets of 10 repetitions of maximum load with a rest of 2 minutes. Subjects performed (1) concentric (C) only, (2) eccentric (E) only, or (3) combined eccentric-concentric (E+C) contraction exercises in random order on the Smith isokinetic machine for 3 to 5 s with 15 s rest between trials	The levels of leukocytes, interleukin 6*(IL-6)*, C-reactive protein (CRP), creatine kinase (CK), venous blood lactate and maximal voluntary isometric strength were measured at the same time points. Cellular respiration of intact VSMCs was measured using a high-resolution respirometer	Maximum isometric force (N) = 1.084 ± 4.1; PBMC cellular respiration: Regular breathing (μmol O_2/ min/ml): 2.5 ± 0.2; Free routine activity: Before training: 1.0 ± 0.1; ET-capacity (μmol O_2/min/ ml): 3.0 ± 0.2; Lactic acid (10 mmol L-(+)-lactic acid): pH = 7.4	Maximal isometric force = 1.084 ± 4.1; 1 min after E+C: reduced to 950 ± 5.0; 24 h after E+C: restored to 1.050 ± 4.8. Regular breathing: 5 minutes after E+C: reduced to 1.8 ± 0.3; 24 h after E+C: restored to 2.4 ± 0.2; free routine activity: 5 minutes after E+C: reduced to 0.7 ± 0.1; 24 h after E+C: restored to 0.9 ± 0.1. ET-capacity: 5 minutes after E+C: reduced to 2.3 ± 0.3. 24 hours after E+C: restored to 2.9 ± 0.2.

Table 2. Continued

Author, date	Sample	Impact/intervention	Assessment/ surveillance/ inspection	Metrics before the intervention	Physiological changes associated with ST (after the intervention)
E.I. Lähteenmäki *et al.* [21]					Lactate (20 mmol L-lactate sodium): insignificant effect on cellular respiration. Lactic acid (10 mmol L-(+)-lactic acid): 5 min after exercise: pH decreases to 7.2. 24 hours after exercise: pH restored to 7.3
L. Brandão *et al.* [22]	43 young men	CT 10 weeks 2 r/week group 1: bench press with bench triceps press (MJ+SJ, n = 12); group 2: bench triceps press plus bench press (SJ+MJ, n = 10); group 3: bench triceps press (SJ, n = 11) group 4: bench press (MJ, n = 10). 8 repetitions of 50% 1RM, 2 min rest, 3 repetitions of 70% 1RM and single repetitions of heavier weights until failure	CSA of the cross-sectional area of the pectoralis major muscle (PMM) and the triceps brachii of the shoulder (MRI)	1-RM for bench press (kg) MJ: 72.3 ± 19.3; SJ: 77.6 ± 21.1; MJ+SJ: 75.2 ± 23.5; SJ+MJ: 76.6 ± 11.5; elbow extension (kg): MJ: 36.6 ± 9.5; SJ: 42.9 ± 12.6; MJ+SJ: 37.2 ± 14.0; SJ+MJ: 39.8 ± 6.6. CSA (cm^2) for VGM: MJ: 413 ± 3.7; SJ: 40.5 ± 8.9; MJ+SJ: 39.1 ± 9.4; SJ+MJ: 41.0 ± 4.2; for TM: MJ: 36.6 ± 9.5; SJ: 42.9 ± 12.6; MJ+SJ: 37.2 ± 14.0; SJ+MJ: 39.8 ± 6.6	1-RM for bench press increased by (%) MJ 27.1 ± 17.7; MJ+SJ: 23.6 ± 144; SJ+MJ: 22.3 ± 15.4; for SJ: 9.9 ± 10.9 (there was no significant difference); for triceps press, it increased by (%): MJ: 36.6 ± 9.5; SJ: 23.2 ± 14.0; MJ+SJ: 35.3 ± 26.3; SJ+MJ: 26.3 ± 17.2; for MJ 26.3 ± 17.2 (no significant difference). CSA increased by (%) for PMM: MJ: 9.1 ± 5.6; SJ: 40.5 ± 8.9; MJ+SJ+MJ: 5.6 ± 5.1; for SJ, the metric was 0.8 ± 1.9; for TM: SJ: 9.5 ± 4.8; MJ+SJ: 11.5 ± 5.1; SJ+MJ: 10.4 ± 6.1; for MJ metric was 4.8 ± 4.2
G.D. Telles *et al.* [23]	Nine untrained young men	2 sets of 10 repetitions of ST, 2 sets of leg press and leg extension HIIE – 12 sets of 1-minute sprints with a 1-minute rest. SE (HIIE after ST) separated by 1 week	Skeletal muscle biopsy before training, during training (0 h), after 4 and 8 hours, followed by RNA quantification	Expression of *miR-1-3p*, *miR-133a-3p*, *miR-133b*, *miR-181a-3p*, *miR-486* 8 hours after training was higher than before exercise. Expression was lower after HIIE compared to CT and SE	

Table 2. Continued

Author, date	Sample	Impact/intervention	Assessment/ surveillance/ inspection	Metrics before the intervention	Physiological changes associated with ST (after the intervention)
P. Deku *et al.* [24]	66 weightlifters	The majority (61.3%) trained for 120 minutes per session, 46.7% trained 5 days a week, and 41.3% had been training for about 1-5 years	BREWTQ questionnaire, anthropometry, physiological (SBP, DBP, heart rate), biochemical studies (total cholesterol, triglycerides, total protein, creatinine, urea, LDL, HDL)	A positive association was found between DBP and arm circumference (r = +0.331, P = 0.022). Differences in the mean values of CC (P = 0.013) and AC (P = 0.010). Maximal oxygen consumption was positively correlated with HDL, total cholesterol, total protein and globulin levels, with the strongest correlation with cholesterol levels. BP was positively correlated with BMI, hip circumference, CC, creatinine and LDL-C levels, with the most pronounced relationship being with creatinine levels. Positive correlation between SBP and total cholesterol, CC, arm circumference, creatinine and HDL. HR had a positive correlation with all anthropometric and biochemical parameters, except for total cholesterol, LDL, cholesterol, urea, total protein and globulins, which had a negative correlation	

Notes: 1-RM – one repetition with maximum weight; DBP – diastolic blood pressure; LVMi – left ventricular mass index; EF – emission fraction; LP – left atrium; LAVI – left atrial volume index; CSA – cross-sectional area; LT – light training; WT – hard workout; UNT – untrained; LT-MST – Long-Term Maximal Strength Training; MOFA – international physical activity questionnaire; ME – metabolic equivalent; CPET – maximum cardiopulmonary exercise capacity; RER – respiratory exchange rate; peak VO2 – oxygen uptake; PCR – polymerase chain reaction; PBMC – peripheral blood mononuclear cells; VGM – pectoralis major muscle; TM – triceps brachii muscle; HIIE – high-intensity interval training; CT – cardio training; SBP – mean arterial pressure; BMI – body mass index; HDL – high-density lipoprotein; LDL – low-density lipoprotein; CC – chest circumference
Source: compiled by the author

The ST program led to improvements in muscle strength, and body composition, and contributed to morphological remodelling of the heart (enlargement of the LV, RV) in a study by A. Grandperrin *et al.* [16].

B.J. Schoenfeld *et al.* [17] demonstrated that a significant increase in muscle strength can be achieved in individuals who engage in ST with only three 13-minute sessions per week. The results of such training are similar to those achieved with significantly more time spent on medium-load training (8-12 repetitions per set). This is relevant for those with time constraints, allowing for efficient strength gains that can contribute to a greater commitment to physical activity among the population. The increase in muscle hypertrophy is dose-dependent, with greater gains being achieved with higher training volumes. To maximise muscle growth, it is recommended to spend more time training every week. However, the amount of training does not affect the endurance of the upper body muscles.

T.G. Belshaw *et al.* [18] also confirmed that prolonged maximal ST significantly improves strength, muscle volume and explosive muscle capacity in trained individuals compared to untrained individuals. B.J. Schoenfeld *et al.* [19] determined that a light training programme induced greater hypertrophy of the gastrocnemius muscle compared to a heavy training programme, while heavy training promoted greater hypertrophy of the middle and lateral heads of the gastrocnemius muscle.

ST and END have a positive effect on men's physiological parameters. E.A. Dawson *et al.* [20] determined that peak VO_2 increased significantly after endurance training, and brachial artery vascular function increased after both types of training. Both training plans led to a significant improvement in endothelium-dependent vasodilation of the brachial artery, but the overall adaptation to peak VO_2 was more significant after END. Eccentric exercises without concentric exercises have a significant impact on PBMC respiration. Combined eccentric-concentric exercise caused the greatest muscle fatigue, reducing PBMC respiration and lactate levels, while eccentric exercise alone had the least effect. The effect of anaerobic metabolism did not change PBMC respiration in the study by E.I. Lähteenmäki *et al.* [21].

The sequence of exercises does not affect the increase in 1-RM in bench press and bench triceps extension. L. Brandão *et al.* [22] argued that performing these exercises in any sequence is effective for achieving maximum strength. There was a moderate decrease in CSA increase in the pectoralis major when an isolated triceps exercise was performed before a multi-joint exercise. It may be worth performing exercises where the pectoral muscles are the main agonist muscles first in the sequence if the goal is to maximise hypertrophy of this muscle complex. Performing a combination of exercises that vary in length-tension ratio is preferable for maximising the development of all three triceps heads.

The microRNA responses in the study by G.D. Telles *et al.* [23] were specific, in the early acute state during different types of skeletal muscle training, no specificity was observed for *miR-1-3p, miR-133a-3p, miR-133b, miR-378aa-5p*, as well as for the expression of *miR-181a-3p* and *miR-486* between ST, HIIE or CT in untrained individuals. This indicates that changes in expression occurred mainly approximately 8 hours after training. ST had a more pronounced effect on the expression of *miR-23a-3p* and *miR-206* compared to *HIIE*. This is relevant for the formation of the molecular basis of adaptive responses for each type of exercise. P. Deku *et al.* [24] determined that the duration of weightlifting training had a positive effect on anthropometric and physiological parameters, but not on biochemical parameters (glomerular filtration rate and total protein). Increasing the duration of training was associated with an increase in breast and arm volumes ($P < 0.05$). There was a significant increase in DBP with training duration ($P = 0.038$).

A systematic review by B.S. Currier *et al.* [26] included 192 studies evaluating the effects of various resistance training protocols on muscle strength and hypertrophy. The highest effects for both indicators were observed in protocols with high load and training frequency. The overall risk of bias in the studies was moderate, suggesting that the results should be interpreted with caution. The main conclusion is that high load and frequency of training provide the greatest gains in strength and hypertrophy, highlighting the importance of intensity in ST programmes.

In this review, most studies used different levels of volume and intensity in the number of sets (1, 3, 5) and repetitions (10-30). After analysing 2083 articles comparing the responses to training with different volumes to induce muscle hypertrophy, E. Baz-Valle *et al.* [27] determined that for the quadriceps and biceps brachii there were no significant differences between moderate and high-volume training, but high volume training was better at stimulating muscle mass gain in the triceps brachii. The optimal volume for muscle hypertrophy in young, trained men was 12-20 sets per week.

STs, as an acute stressor, affect the sympathetic and parasympathetic nervous systems, as well as the hypothalamic-pituitary-adrenal axis (HPA axis). During intense training or competition, the HPA axis is activated to mobilise the body's resources [28]. The hypothalamus signals the pituitary gland to produce adrenocorticotropic hormone (ACTH), which stimulates the adrenal glands to produce cortisol. Cortisol regulates metabolism, anti-inflammatory processes, and recovery. After exercise, cortisol levels usually decrease, allowing the body to recover and adapt. Regular training can lead to HPA-axis adaptation, where the body becomes less sensitive to stress or recovers faster after exercise [29, 30]. The HPA axis is activated when endurance exercise reaches high and prolonged intensity [31].

During muscle contractions, skeletal muscles increase oxygen consumption, which leads to the formation of oxygen-dependent free radicals that can cause tissue damage [32]. Accordingly, at the cellular level, muscles adapt through the activation of endogenous antioxidant enzymes and stress proteins (HSPs), which protect against oxidative stress during subsequent exercise [33]. The maximum hypertrophic effect of muscles can be achieved by performing multiple sets, which increases *p70S6* kinase phosphorylation and muscle protein synthesis (MPS), as opposed to exercises with a single set [17].

Before starting intense physical activity, the patient must undergo a medical examination, with a complete history, examination and necessary tests. Contraindications to strength training include valvular heart disease, ventricular hypertrophy, dangerous arrhythmias, and malignant hypertension. Patients with obesity, bronchial asthma, diabetes, and haemoglobinopathies should undergo a stress test before exercise, including measurement of heart rate, blood pressure, and electrocardiogram [6].

STs may have a positive effect on traditional cardiovascular risk factors such as blood pressure, glucose, lipids, body composition, and systemic inflammation [34-36]. Evidence for these effects is mostly based on randomised controlled trials of medium duration (2-6 months); data from studies longer than 6 months are limited. Most studies used moderate to high intensity exercise programmes (40-80% of maximal effort) 2-3 times per week [37-39].

STs contribute to an increase in muscle strength and power due to neuromuscular adaptation, an increase in muscle cross-sectional area (CSA) and changes in connective tissue stiffness. The initial rapid increase in strength during exercise mastery gradually slows down with muscle development [40]. According to some studies, both high and low loads can effectively activate muscle protein synthesis and hypertrophy, and blood flow restriction at low loads can also promote hypertrophy [41]. To achieve optimal hypertrophy, a combination of mechanical stress and metabolic stress must be ensured. Achieving optimal neuromuscular adaptation or increasing CSA is possible with different variations in the intensity and volume of training programmes [42]. Individuals seeking to optimise muscle hypertrophy are advised to implement a hypertrophic-oriented ST programme, which includes 3 to 6 sets with 6 to 12 repetitions of the programme [43]. The rest interval between sets should be 60 seconds. The intensity of the effort is from 60 to 80% of one repetition of the maximum. It is also important to increase the volume of the current load to 12-28 sets [44]. The American College of Sports Medicine (ACSM) advises untrained individuals to perform 1-3 sets of each exercise, with the number of repetitions in the range of 8-12, using a load of 70-85% of the maximum effort per repetition. For people with training experience, it is recommended to perform 3-6 sets with the number of repetitions from 1 to 12, using a weight in the range of 70-100% of 1RM. Normally, loads in the range of one 1RM to 10RM with the number of repetitions from 4 to 12 are used.

The results of studies reflect the different effects of ST on the physiological characteristics of young men. In most studies, there was an increase in *1-RM* in exercises such as bench presses and squats. Increases in muscle mass were evident in both large muscle groups (thighs, pectorals) and smaller muscle groups (biceps, triceps). This suggests that regular strength training contributes to significant improvements in muscle strength and hypertrophy. W. Kassiano *et al.* [45] demonstrated that the choice of different exercises can affect muscle hypertrophy and strength gains. Systematic variation in the training programme enhances regional hypertrophic adaptation and maximisation of dynamic strength, whereas increased or chaotic variation can negatively affect muscle mass gain. Excessive stimulus or frequent exercise rotation can interfere with muscle adaptation.

CONCLUSIONS

The systematic search identified 9 relevant publications. Most studies showed high methodological quality (7-9 points on the PEDro scale). The review showed that different strength training regimens have a positive effect on physical and physiological parameters in healthy young men. Frequent strength training significantly improves 1-RM, lean body mass, and morphological and functional parameters of the heart. A higher volume of training (5 sets) may be more effective in improving strength performance and muscle hypertrophy compared to lower volumes (1 or 3 sets). This is confirmed by the significant increase in 1-RM and muscle thickness in the high-volume groups.

The effect of ST on physiological parameters such as muscle thickness, hypertrophy and cardiovascular function was positive, with an increase in lean body mass and a decrease in fat mass. Training also improved biochemical parameters such as leukocyte activity and levels of key metabolic markers. Combination training, which includes both concentric and eccentric exercises, has shown significant potential for improving muscle performance and functional performance. High-intensity training with a variety of exercise types can provide more pronounced results than traditional approaches.

The study was limited by the small number of participants, short intervention period, and lack of blinding of participants and researchers, which may affect the objectivity of the results. Increasing the level of control over the random allocation of participants and concealing the allocation would help to ensure greater accuracy of the results.

Given the results, it is recommended that a comprehensive approach to strength training, including a high volume of exercises and different types of loads, be applied to achieve maximum physiological benefits. Further research, development and testing of individually adapted training programmes based on the physiological and metabolic characteristics of the participants and their long-term health effects is also recommended.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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Оцінка фізичного (соматичного) здоров'я чоловіків молодого віку при побудові оздоровчого тренування силової спрямованості

Віталій Коротич
Аспірант
Прикарпатський національний університет імені Василя Стефаника
76018, вул. Шевченка, 57, м. Івано-Франківськ, Україна
https://orcid.org/0000-0002-1662-2141

Анотація. Метою цього систематичного огляду було визначення впливу силових вправ на фізіологічні та морфологічні адаптаційні можливості у здорових молодих чоловіків. Було здійснено пошук рандомізованих клінічних досліджень, що містять інформацію про вплив вправ з опором на фізичні та функціональні зміни у молодих чоловіків 18-45 років. Було знайдено 13 публікацій, що підходять критеріям пошуку, з яких відібрано 9 досліджень після виключення невідповідних. Більшість статей були оцінені, як дослідження хорошої якості з оцінкою 7-9 балів за шкалою PEDro. Було виявлено, що тривале силове тренування значно покращує силу, м'язовий об'єм та вибухові здібності у тренованих осіб. Силові тренування 3 рази на тиждень здатні збільшити безжирову масу тіла та індекс маси лівого шлуночка, зі зменшенням маси жиру. Легкі тренування стимулюють гіпертрофію камбалоподібного м'яза більше ніж важкі, які більше впливають на середню та латеральну головки литкового м'яза. Черговість вправ не впливає на підвищення максимальної сили, але вплив на гіпертрофію грудних м'язів може бути кращим при виконанні багатосуглобових вправ після ізольованих. Поява мікроРНК не показує специфічності у ранньому гострому стані тренувань, зміни в експресії спостерігаються через 8 годин після тренування. Тривалість тренувань з підняття ваги позитивно впливає на антропометричні та фізіологічні показники, але не на біохімічні

Ключові слова: вправи з опором; систематичний огляд; функціональна адаптація; гіпертрофія м'язів; спортивна медицина