American College of Sports Medicine Position Stand. Resistance Training Prescription for Muscle Function, Hypertrophy, and Physical Performance in Healthy Adults: An Overview of Reviews

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SUMMARY

CURRIER, B. S., A. C. D'SOUZA, M. A. F. SINGH, C. V. LOWISZ, E. S. RAWSON, B. J. SCHOENFELD, A. E. SMITH-RYAN, J. P. STEEN, G. A. THOMAS, N. T. TRIPLETT, T. A. WASHINGTON, T. J. WERNER, and S. M. PHILLIPS. American College of Sports Medicine Position Stand. Resistance Training Prescription for Muscle Function, Hypertrophy, and Physical Performance in Healthy Adults: An Overview of Reviews. *Med. Sci. Sports Exerc.*, Vol. 58, No. 4, pp. 851-872, 2026. **Purpose:** The aim of this overview of reviews was to determine the impact of resistance training (RT) prescription on muscle function and hypertrophy, utilizing evidence synthesis methods. It updates the American College of Sports Medicine 2009 Position Stand, "Progression models in resistance training for healthy adults." **Data sources:** Ovid MEDLINE(R) ALL, Ovid Emcare, Ovid Embase, Cochrane Database of Systematic Reviews, EBSCOhost SPORTDiscus, and Web of Science Core Collection current to October 2024. **Eligibility criteria:** Eligible systematic reviews synthesized randomized trials of healthy adults (≥18 yr) who completed RT (≥6 wk; range: 6–52 wk), compared with a group that completed no exercise or an alternative RT program, and reported the change in muscle function, size, or physical performance. **Results:** We synthesized data from 137 systematic reviews (>30,000 participants). Compared with no exercise (control), RT significantly improved muscle strength, size (hypertrophy), power, endurance, contraction velocity, gait speed, balance, and multiple physical function outcomes. Few RT prescription (RTx) variables affected primary adaptations. However, voluntary strength was enhanced by lifting heavier loads (≥80% one-repetition maximum), through a complete range of motion, for 2–3 sets, at the beginning of training sessions, and ≥2 sessions/wk. Muscle hypertrophy was enhanced by higher volumes (≥10 sets/wk) and eccentric overload. Power was enhanced by moderate loads (30%–70% one-repetition maximum), low-to-moderate volume (≤24 repetitions·sets), Olympic-style weightlifting, and power RT (fast concentric phase). Power RT enhanced physical function. Training to momentary muscle fatigue, equipment type, exercise complexity, set structure, time under tension, blood flow restriction, and periodization did not consistently impact training outcomes. **Conclusions:** Healthy adults should perform progressive RT, with variable prescription consistent with our findings, to improve muscle function, size, and physical performance. Muscle strength, hypertrophy, power, and certain components of physical function can be enhanced by manipulating the RT variables highlighted. **Key Words:** HYPERTROPHY, PHYSICAL FUNCTION, RESISTANCE TRAINING, SKELETAL MUSCLE, STRENGTH

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Exercise is crucial for health throughout the human lifespan, and muscle strength and function are essential components of fitness. Resistance training (RT), also known as strength or weight training, is a specialized method of physical conditioning in which muscles are exercised by contracting against external resistance, such as free weights, machines, resistance bands, water, or body weight, through isometric, isotonic, or isokinetic actions, progressively increasing force output to improve muscular strength, power, endurance, and overall health and sports performance. The benefits of RT are being increasingly appreciated as health-promoting behavior (1,2), but were perhaps first documented to be beneficial beyond personal strength development by Captain Thomas DeLorme, who recognized the benefits of RT in wounded soldiers (3). Beyond the hallmark improvements in skeletal muscle mass and function, the benefits of engaging in RT include reduced mortality and risk for and management of cardiovascular disease, cancer, and diabetes (4–6), reduced depression (7,8), and improved sleep quality (9).

Most guidelines call for healthy adults to complete "muscle-strengthening activities at moderate or greater intensity that involve all major muscle groups on two or more days a week" (2). Exercise programs are generally constructed by manipulating six factors comprising the framework FITT-VP: Frequency, Intensity, Time, Type, Volume, Pattern, and Progression (10). Prescription of variably RT variable (RTx), however, involves several variables within each category that are inherent to any practice of RT. However, a barrier to engaging in RT is that people and practitioners often lack understanding of how to prescribe RT (5). Thus, RTx guidelines are required to support healthcare practitioners and exercise professionals when designing RT programs.

The American College of Sports Medicine (ACSM) 2009 Position Stand, "Progression Models in Resistance Training for Healthy Adults" (11), summarized, at the time, the available evidence for RTx variables, providing guidelines to enhance RT adaptations. Research on the topic of RT has expanded significantly since the publication of that Position Stand; in fact, a simple PubMed search for "resistance training" yields over 30,000 new results since 2009, indicating a need for an update. Evidence synthesis methods have also advanced considerably, and both the current (11) and prior (12) Position Stands were criticized (13,14) for lacking evidence-based rigor. Hence, to provide contemporary, evidence-based guidance to minimize bias, an updated RTx Position Stand was required, utilizing contemporary search and evidence grading methodologies.

Provided ample systematic reviews and meta-analyses, an overview of reviews can systematically summarize an abundance of information (13). An overview of reviews (i.e., umbrella review: a review of systematic reviews) is a systematic collection and assessment of available evidence that provides a comprehensive, user-friendly summary of a research topic, enabling practitioners and professionals to make evidence-based decisions without assimilating the results of numerous systematic reviews and meta-analyses (14,15).

The purpose of this overview of systematic reviews was to provide an updated, evidence-based summary of the impact of RTx variables on various outcomes relevant to RT in healthy adults. The outcomes of interest included muscle hypertrophy, strength, power, endurance, contraction velocity, and physical function (e.g., gait speed, balance, and stair climbing). The current document updates the ACSM 2009 Position Stand entitled "Progression Models in Resistance Training for Healthy Adults" (11).

METHODS

Protocol and Registration

This review was prospectively registered on the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY202360071; https://inplasy.com/inplasy-2023-6-0071/) and conducted in alignment with the Preferred Reporting Items for Overviews of Reviews (PRIOR) (16). The completed PRIOR checklist is contained in Supplemental Appendix 1, Supplemental Digital Content, https://links.lww.com/MSS/D323.

Eligibility Criteria

The complete eligibility criteria for systematic reviews to be included are shown in Table 1. Briefly, systematic reviews of randomized trials were included when healthy adults completed an RT program for at least 6 wk and were compared with a group that completed no exercise (control [CTRL]) or a distinctly different RT program (Table 2; i.e., FITT-VP component different between groups). In most cases, reviews examined people with minimal or no RT experience (i.e., novice); however, some reviews included more advanced trainees. Previously, we showed that training experience had a minimal impact on strength and hypertrophy outcomes (17); nonetheless, much of the evidence synthesized here is from inexperienced trainees. "Healthy adults" was operationalized as humans (≥18-yr old) with no defined disease(s), including obesity, sarcopenia, and physical frailty. Body weight-supported RT was a portion of some reviews, but was not studied as a stand-alone intervention except in the case of the Nordic hamstring curl. Standard, or non-specialized, RT was defined as any RT in eligible reviews that was not specifically defined and thus excluded specific forms of RT, including power RT (explicitly stated concentric phase performed as quickly as possible),

TABLE 1. Eligibility criteria for inclusion.

	Inclusion Criteria
Population	• Healthy humans ≥18-yr old with no defined disease(s) • Any training status (novice or trained)
Intervention	• Resistance training interventions spanning at least 6 wk with a minimum of 12 exposures • If a supplement, nutritional, or other cointervention (e.g., behavioral therapy, medication, counseling) is applied, it must be received by intervention and comparator groups
Comparator	• Distinct resistance training prescription, as defined by FITT-VP (Frequency, Intensity, Time, Type, Volume, Pattern, Progression) principle, and/or • Nonexercise control group (performing no RT) and/or alternative exercise control conceived as a sham intervention (e.g., stretching)
Outcome	• Reported pre-and postintervention change in muscle function (strength, power, endurance, contraction velocity, physical function) or hypertrophy between intervention and comparator arm(s)
Study design	• A systematic review (including overviews of reviews) of randomized trials with or without statistical synthesis (e.g., meta-analysis, network meta-analysis, meta-regression)

Olympic-style weightlifting (RT with Olympic-style lifting movements), and velocity-based RT (movement velocity thresholds used to prescribe RT). We acknowledge that this is a broad definition that encompasses several variables, but we have used the definitions of the RTx provided within the reviews we compared. Eligible reviews needed to report the change of at least one muscle function (e.g., strength, power, and physical function) or muscle size (hypertrophy) outcome from pre- to postintervention. Unless otherwise specified, strength was voluntary isotonic one-repetition maximum (1RM) in the same mode as that in which the training was performed. Records were defined as a "systematic review" if they were titled as an evidence synthesis (e.g., systematic review, meta-analysis, and umbrella review) or used a specific systematic search strategy and eligibility criteria. The included reviews were not separated by participant age due to the number of eligible systematic reviews that included participants with participants who were both younger and older than the cutoff of 55-yr old. Thus, our recommendations are evidence-based across all ages.

Information Sources and Search Strategy

The systematic search strategy was executed in October 2024 in Ovid MEDLINE(R) ALL (1946 to current), Ovid Emcare (1995 to current), Ovid Embase (1974 to current), Cochrane Database of Systematic Reviews (2005 to current), EBSCOhost SPORTDiscus, and Web of Science Core Collection. Trained librarians developed the search strategies. Searches conducted on the Ovid platform were limited to English-language records, and no additional limits or filters were applied. The complete search strategy is reported in Supplemental Appendix 2, Supplemental Digital Content, https://links.lww.com/MSS/D323.

Record Selection and Data Collection

Four reviewers (B. S. C., C. V. L., A. C. D., and J. P. S.) independently screened all records (title/abstract and full text) and extracted data from eligible reviews in duplicate, with discrepancies resolved by group consensus. Relevant data from eligible overlapping records were included and extracted. Authors of reviews with missing data were contacted via email with a request for the missing data, and

TABLE 2. Resistance training prescription variables.

RTx Variable	Definition
Frequency	The number of days per week RT is performed.
Load	The amount of weight lifted per repetition and often prescribed as a proportion of maximal strength (e.g., %1RM) or maximal number of repetitions possible with a given load (RM)
Failure	Completing repetitions until volitional failure occurs when concentric movement is no longer possible.
Time under tension	The amount of time supporting weight. Time under tension per repetition is the total time required to complete one repetition.
Time of day	When RT is performed in the day (e.g., morning)
Inter-set rest	The amount of rest time between sets.
Exercise order	The order of different training forms (e.g., aerobic and resistance) or specific RT exercises are performed within a training session.
Type	Blood flow restriction: Locally reducing blood flow to and from exercising muscles. Free-weight RT: Weights that can be moved in space freely (e.g., barbell). Machine RT: Machines permitting fixed movement (e.g., leg press). Unstable RT: RT performed on an unstable surface (e.g., pressurized ball). Variable load: Altering load mid-repetition.
Contraction type	Eccentric overload: Increased load or time under tension during eccentric movement. Traditional: Proportionally completing both concentric and eccentric phases of a movement.
Technique	Olympic-style weightlifting: Snatch and clean-and-jerk movements. Partial range of motion: Performing RT through an incomplete range of motion, compared with RT as typically performed through the complete range of motion for the joint(s) involved in a movement. Power RT: Intentionally performing the concentric phase of each lift at maximal volitional speed.
Volume (sets)	The number of sets (a group of repetitions without resting) completed per exercise.
Set structure	Drop sets: Performing sets to failure then reducing load and minimal inter-set rest. Cluster: Traditional inter-set rest with preplanned intraset rest periods. Complex: Sets with heavy loads followed by sets with lighter loads. Contrast: Alternating heavy and light loads set-to-set. Rest redistribution: Short rest periods between each repetition. Traditional: Performing a set without rest until all repetitions are completed.
Periodization	Periodized: Manipulating RTx during a program to maximize adaptations. Block: Dividing program into multiweek blocks with distinct training goals. Linear (traditional): Increasing load and reducing volume during the program. Nonperiodized: Not manipulating RTx during the program. Undulating (nonlinear): Daily or weekly RTx manipulation.

%1RM, percentage of one-repetition maximum; RM, repetition maximum; RT, resistance training; RTx, resistance training prescription.

WebPlotDigitizer (version 4; https://automeris.io/) was used if data needed to be extracted from figures. Record screening and data extraction were completed using the systematic review software Covidence (https://www.covidence.org/). The complete list of data items sought is reported in Supplemental Appendix 3, Supplemental Digital Content, https://links.lww.com/MSS/D323.

Methodological Quality Assessment and Evidence Synthesis

The methodological quality of each included review was assessed independently by two reviewers using the AMSTAR (A Measurement Tool to Assess Systematic Reviews) tool, which yields a score ranging from 1 to 11 that incorporates assessment of publication bias (Supplemental Appendix 4, Supplemental Digital Content, https://links.lww.com/MSS/D323) (18,19). Outcome data were tabulated as collected, and no sensitivity analyses were conducted. Heterogeneity was reported as the I^2 statistic (meta-analyses) or the fraction of reviews showing a significant effect (systematic reviews). An outcome-level (bottom-line) statement and standardized effectiveness statement (Supplemental Appendix 5, Supplemental Digital Content, https://links.lww.com/MSS/D323) were produced by considering the methodological quality and extracted data (20). Outcome-level quality of evidence (QoE) was calculated using a method based on the Grading of Recommendations Assessment, Development and Evaluation approach for primary evidence (21). This method incorporates the design (meta-analysis: yes/no) and methodological quality (AMSTAR score) of each included review (Supplemental Appendix 6, Supplemental Digital Content, https://links.lww.com/MSS/D323). There remains no standardized method to evaluate the certainty of evidence in overviews of reviews (15,22), so a summary percentage scores were calculated to demonstrate the quality of evidence contributing to each conclusion. The summary percentage was calculated within each prescription variable for all three directions of evidence (impactful, not impactful, and cannot determine) by dividing the average QoE by four (the maximum QoE score) to yield a percentage score ranging from 0% (lowest possible QoE) to 100% (highest possible QoE). This method has been used in previous overviews of reviews (18,20,23). The effectiveness (impact) of RTx variables for each outcome was assessed based on standardized effectiveness statements and the quantity of evidence (24). The reviews, which contributed evidence for the impact of a prescription variable, were independently scrutinized to comment on favorable RTx parameters for improving each outcome.

Overlap of Papers

An issue with overviews of reviews is the possibility of "double counting" (or more) papers that are included in more than one review (25). Such counting may unduly affect the results of the analysis, resulting in spurious levels of precision and confidence in the outcomes (26). We employed the corrected covered area (CCA) index to quantify the degree of overlap between systematic reviews to be pooled in an overview of reviews (27). To obtain an estimate of the degree of publication overlap, we calculated the CCA for strength using the ccaR package (28), arguably the most relevant outcome of our analysis.

RESULTS

Included Reviews

The systematic search yielded 5751 records following duplicate removal, and 137 systematic reviews were included in this overview of reviews (Fig. 1). The AMSTAR scores for included reviews ranged from 1 (lowest) to 9 (highest) out of a possible 11 (Supplemental Appendix 7, Supplemental Digital Content, https://links.lww.com/MSS/D323). The conflict-of-interest statement for each included review is reported in Supplementary Appendix 8, Supplemental Digital Content, https://links.lww.com/MSS/D323. The details, bottom-line statement, standardized effectiveness statement, and QoE for each review are reported in the Supplemental Appendices, Supplemental Digital Content, https://links.lww.com/MSS/D323, according to the outcome.

Strength

CCA analysis of strength across all included reviews showed only "moderate" overlap, defined as between 6% and 10% of primary papers appearing in two or more reviews (27). So the results of our analyses for this variable (for which there were more reviews than for any other variable) were not unduly affected by primary data overlap.

The effects of RT versus CTRL on strength and the impact of distinct RTx variables are summarized in Tables 3 and 4, respectively. The results for each review are reported in Supplemental Appendix 11, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, strength was impacted by engaging in standard RT (17,24,29–56), circuit RT (57–59), elastic band RT (60–62), home-based RT (63,64), and velocity-based RT (65,66). There were insufficient data to determine if eccentric flywheel RT (67), Nordic hamstring RT (68), Olympic-style weightlifting (69), and unstable surface RT (70) impacted strength compared with CTRL. In comparisons between distinct RTx, strength was positively affected by training session frequency (24,71–76), load (24,77–84), eccentric flywheel RT versus standard RT (85), range of motion (86,87), volume (24,88–93), and exercise order (24,94–96), but strength was not affected in programs with lifting to fatigue/failure (24,97–99), machines versus free-weight RT (100), unstable surfaces (70), time under tension (24,101), time

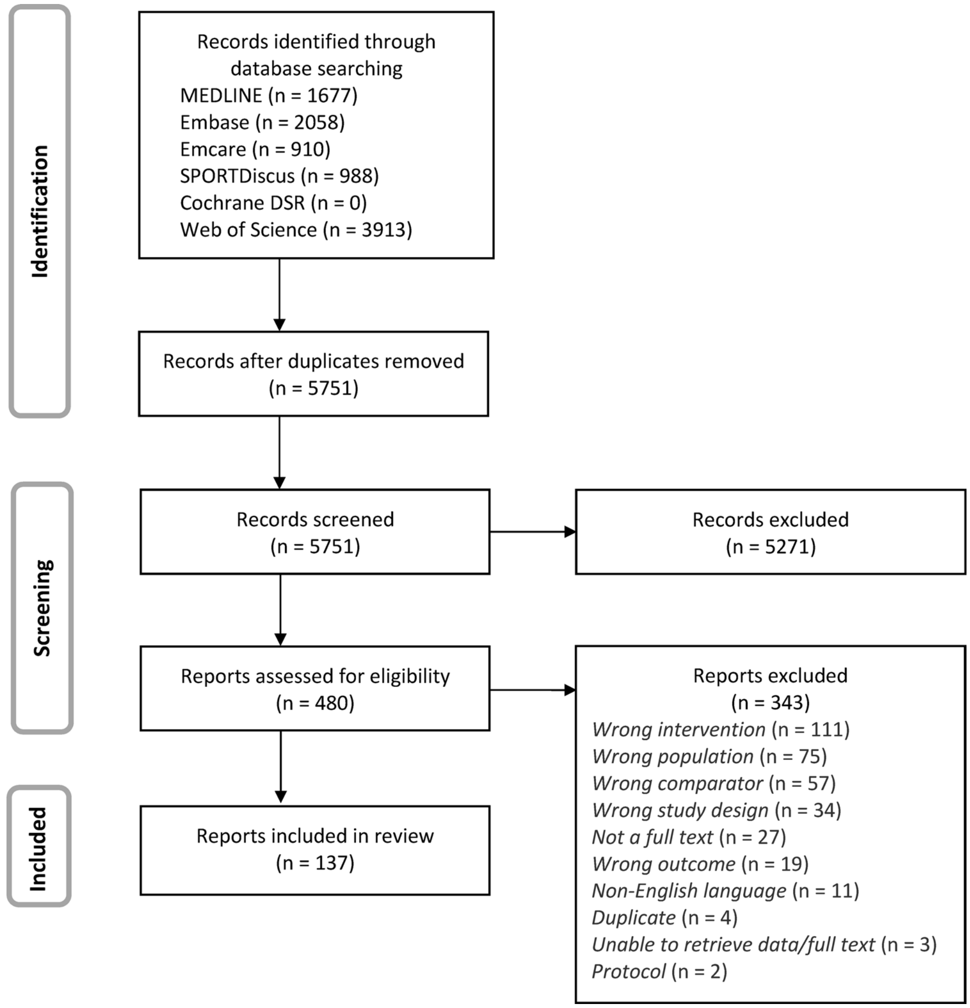

FIGURE 1—Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of review selection.

of day (24,102), inter-set rest (24,103), contraction type (24,104), power training (82,105,106), or set structure (24,107–109). There were insufficient data to determine if strength was affected by blood flow restriction (110–112), Olympic-style weightlifting (69), intrasession autoregulation (113,114), varied exercise selection (115), periodization (24,116–118), or concurrent training (i.e., aerobic and RT in the same training session) (119–124).

The impact of unilateral RT on the untrained, contralateral limb (i.e., cross-education) was only reported for the strength outcome. The impact of RT versus CTRL on strength in the untrained contralateral limb is summarized in Table 3, and results for each review are reported in Supplemental Appendix 11, Supplemental Digital Content, https://links.lww.com/MSS/D323. Unilateral RT impacted strength (125,126) such that strength improved in the untrained, contralateral limb. Comparing RTx, strength was enhanced by RT performed with higher frequency (≥2 d/wk, though the upper limit cannot, from our analysis, be undetermined), higher loads (dose-response), eccentric flywheel devices compared with standard RT, full range of motion, higher volume (multiple sets), and at the beginning of training sessions (compared with the end of training sessions). Strength was not affected by RT performed with contractions to muscle failure/fatigue, free weights versus machines, unstable versus stable surfaces; fast (<2 s) versus moderate-slow (>2 s) contractions, morning versus evening training sessions, short (<1 min) versus long (>1 min) between-set rest intervals, eccentric versus concentric contractions, power training techniques, or different set structures (cluster and complex).

Hypertrophy

The impact of RT versus CTRL on muscle hypertrophy is summarized in Table 3, and the impact of distinct RTx variables is summarized in Table 4. The results for each review are reported in Supplemental Appendix 12, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, muscle hypertrophy was positively affected by standard RT (17,24,30,32,33,37,38,40,42–47,50,127), circuit RT (57,58), and elastic band RT (60,62). There were insufficient data

TABLE 3. Resistance training forms that impact strength, hypertrophy and power when compared with CTRL.

	Strength	Hypertrophy	Power
Standard RT vs CTRL	✓ ↑ 26 reviews; n = 23,204 QoE = 73% ? 3 reviews; n = 138 QoE = 50% ↓ 1 review; n = 488 QoE = 50%	✓ ↑ 12 reviews; n = 14,924 QoE = 79% ? 3 reviews; n = 437 QoE = 83% ↓ 2 reviews; n = 775 QoE = 63%	✓ ↑ 4 reviews; n = 1,001 QoE = 63% ? 1 review; n = 152 QoE = 25%
Circuit RT vs CTRL	✓ ↑ 3 reviews; n = 843 QoE = 92%	✓ ↑ 1 review; n = 236 QoE = 100% ? 1 review; n = 190 QoE = 100%	? ND
Elastic band RT vs CTRL	✓ ↑ 2 reviews; n = 1,921 QoE = 63% ? 1 review; n = 51 QoE = 75%	✓ ↑ 1 review; n = 236 QoE = 50% ? 1 review; n = 133 QoE = 75%	? ND
Flywheel RT vs CTRL	? ? 1 review; n = 140 QoE = 50%	? ? 1 review; n = 104 QoE = 50%	? ND
Home-based RT vs CTRL	✓ ↑ 2 reviews; n = 892 QoE = 50%	? ND	? ? 1 review; n = 88 QoE = 75%
Nordic hamstring RT vs CTRL	? ↑ 1 review; n = 112 QoE = 100%	? ND	? ND
Olympic-style weightlifting vs CTRL olympic-style	? ? 1 review; n = 44 QoE = 75%	? ND	? ? 1 review; n = 112 QoE = 75%
Unilateral RT, cross-education vs CRTL	✓ ↑ 2 reviews; n = 1,194 QoE = 88%	? ND	? ND
Velocity-based RT vs CTRL	✓ ↑ 2 reviews; n = 870 QoE = 50%	? ND	? ND
Unstable surface RT vs CTRL	? ↑ 1 review; n = 172 QoE = 75%	? ND	? ND

✓: positively impacts outcome; ?: cannot determine impact on outcome; ✖: does not impact outcome. Within each box, the small symbol and text represent details of reviews for each respective decision, and the enlarged symbol represents the overall decision. The QoE is the quotient of the average QoE and the highest (best) possible quality of evidence, expressed as a percentage. The number of participants was calculated from the most common measurement in reviews reporting outcome-specific sample sizes.
CTRL, nonexercising control; ND, no data; QoE, quality of evidence.

to determine if eccentric flywheel RT (67) impacted muscle hypertrophy compared with CTRL. In comparisons between distinct RTx, muscle hypertrophy was positively affected by contraction type (24,104,128,129) and volume (24,91,128,130–133), but muscle hypertrophy was not affected by frequency (24,73,74,128,131,134,135), load (24,78–81,83,84,128,131,136), absolute fatigue/failure (24,98,99,128,137), blood flow restriction (110–112), variable loading (138), time under tension (24,131,139,140), power training (105), periodization (24,117,131,141), or exercise order (24,94,96,128,131). There were insufficient data to determine if muscle hypertrophy was influenced by eccentric flywheel versus standard RT (85), machine versus free-weight RT (100), single-joint versus multi-joint RT (128,142), time of day (24,102,131), inter-set rest (24,131,143,144), range of motion (86,87,128,145), set structure (24,107,108,146), intrasession autoregulation (113), varied exercise selection (115,128), or concurrent training (119,120,122,124,147).

Improving hypertrophy. Compared with CTRL, hypertrophy was improved by RT, including circuit RT and elastic band RT (Table 6). Between RTx, hypertrophy was enhanced by RT performed with eccentric-only contractions (versus concentric-only) and higher volume (≥10 sets/muscle group/wk). RT did not influence hypertrophy performed with low (1 d/wk) versus high (>5 d/wk) frequency when total volume was equated; low (30% 1RM) to high (100% 1RM) loads; contractions to muscle failure/fatigue; blood flow restriction; varying loads during repetitions; fast (0.5 s) versus slow (8 s) repetitions; power training techniques; periodization (linear, undulating, and nonperiodized); or exercise order within training sessions.

Power

The impact of RT versus CTRL on power is summarized in Table 3, and the impact of distinct RTx variables is summarized in Table 4. The results for each review are

TABLE 4. Resistance training prescription variables that impact strength, hypertrophy, and power when compared with standard (nonspecialized) RT.

	Strength	Hypertrophy	Power
Frequency	✓ ↑ 4 reviews; $n = 3{,}531$ QoE = 69% ↓ 3 reviews; $n = 608$ QoE = 75%	✖ ↑ 1 review; $n = 200$ QoE = 50% ? 2 reviews; $n = 166$ QoE = 38% ↓ 4 reviews; $n = 3{,}177$ QoE = 63%	? ND
Intensity: Load	✓ ↑ 6 reviews; $n = 6{,}574$ QoE = 79% ? 1 review; $n = 151$ QoE = 100% ↓ 2 reviews; $n = 734$ QoE = 63%	✖ ↑ 1 review; $n = 231$ QoE = 75% ? 1 review; $n = 108$ QoE = 75% ↓ 8 reviews; $n = 5{,}340$ QoE = 66%	✓ ↑ 2 reviews; $n = 1{,}980$ QoE = 75% ? 1 review; $n = 151$ QoE = 100%
Intensity: Fatigue/failure	✖ ↑ 1 review; $n = 199$ QoE = 75% ↓ 3 reviews; $n = 1{,}371$ QoE = 83%	✖ ↑ 1 review; $n = 189$ QoE = 100% ↓ 4 reviews; $n = 800$ QoE = 69%	? ? 1 review; $n = 150$ QoE = 100%
Type: Blood flow restriction	? ↑ 1 review; $n = 460$ QoE = 75% ? 2 reviews; $n = 364$ QoE = 88%	✖ ? 1 review; $n = 72$ QoE = 100% ↓ 2 reviews; $n = 587$ QoE = 75%	? ND
Type: Eccentric flywheel	✓ ↑ 1 review; $n = 332$ QoE = 75%	? ↑ 1 review; $n = 160$ QoE = 75%	✓ ↑ 1 review; $n = 235$ QoE = 75%
Type: Machine vs free-weight	✖ ↓ 1 review; $n = 683$ QoE = 75%	? ? 1 review; $n = 123$ QoE = 75%	? ND
Type: Single-joint vs multi-joint	? ND	? ? 1 review; $n = 65$ QoE = 25% ↓ 1 review; $n = 193$ QoE = 100%	? ND
Type: Unstable vs stable surface	✖ ↓ 1 review; $n = 438$ QoE = 75%	? ND	? ? 1 review; $n = 145$ QoE = 75%
Type: Variable load	? ND	✖ ↓ 1 review; $n = 408$ QoE = 50%	? ND
Time: Time-under-tension	✖ ?1 review; $n = 140$ QoE = 75% ↓ 1 review; $n = 509$ QoE = 75%	✖ ? 1 review; $n = 107$ QoE = 50% ↓ 3 reviews; $n = 806$ QoE = 58%	? ND
Time: Time of day	✖ ↓ 2 reviews; $n = 430$ QoE = 75%	? ? 3 reviews; $n = 336$ QoE = 75%	? ND
Inter-set rest	✖ ↓ 2 reviews; $n = 982$ QoE = 63%	? ? 4 reviews; $n = 265$ QoE = 44%	? ND
Technique: Contraction type	✖ ? 1 review; $n = 38$ QoE = 75% ↓ 1 review; $n = 1{,}051$ QoE = 75%	✓ ↑ 1 review; $n = 868$ QoE = 75% ? 2 reviews; $n = 92$ QoE = 50% ↓ 1 review; $n = 356$ QoE = 75%	? ND
Technique: Range of motion	✓ ↑ 2 reviews; $n = 1{,}262$ QoE = 50%	? ↑ 1 review; $n = 90$ QoE = 75% ? 3 reviews; $n = 276$ QoE = 33%	? ND
Technique: Power training	✖ ? 1 review; $n = 140$ QoE = 75% ↓ 2 reviews; $n = 670$ QoE = 75%	✖ ↓ 1 review; $n = 336$ QoE = 75%	✓ ↑ 2 reviews; $n = 863$ QoE = 75% ? 1 review; $n = 99$ QoE = 75%

(Continued)

TABLE 4. Continued

	Strength	Hypertrophy	Power
Volume: Sets	✔ ↑ 7 reviews; *n* = 5,633 QoE = 71%	✔ ↑ 5 reviews; *n* = 2,267 QoE = 50% ? 1 review; *n* = 181 QoE = 75% ↓ 1 review; *n* = 555 QoE = 75%	✔ ↑ 1 review; *n* = 454 QoE = 75%
Set structure	✖ ? 1 review; *n* = 199 QoE = 75% ↓ 3 reviews; *n* = 1,837 QoE = 83%	? ? 3 reviews; *n* = 401 QoE = 83% ↓ 1 review; *n* = 189 QoE = 75%	✖ ? 1 review; *n* = 142 QoE = 100% ↓ 1 review; *n* = 445 QoE = 75%
Progression: Intrasession autoregulation	? ↑ 1 review; *n* = 308 QoE = 75% ↓ 1 review; *n* = 356 QoE = 25%	? ? 1 review; *n* = 243 QoE = 75%	? ND
Progression: Varied exercise selection	? ? 1 review; *n* = 198 QoE = 50%	? ? 1 review; *n* = 95 QoE = 25% ↓ 1 review; *n* = 218 QoE = 50%	? ND
Progression: Periodization	? ↑ 1 review; *n* = 616 QoE = 75% ? 1 review; *n* = NR QoE = 50% ↓ 2 reviews; *n* = 1,075 QoE = 75%	✖ ↓ 4 reviews; *n* = 1,414 QoE = 63%	? ND
Exercise order	✔ ↑ 4 reviews; *n* = 941 QoE = 88%	✖ ? 1 review; *n* = 71 QoE = 25% ↓ 4 reviews; *n* = 759 QoE = 81%	? ND
Concurrent training	? ↑ 2 reviews; *n* = 725 QoE = 75% ? 1 review; *n* = 119 QoE = 25% ↓ 3 reviews; *n* = 354 QoE = 67%	? ↑ 1 review; *n* = NR QoE = 50% ? 3 reviews; *n* = 351 QoE = 67% ↓ 1 review; *n* = NR QoE = 25%	? ↑ 2 reviews; *n* = NR QoE = 50% ? 1 review; *n* = 18 QoE = 75%

✔: positively impacts outcome; **?**: cannot determine impact on outcome; ✖: does not impact outcome. Within each box, the small symbol and text give the details of reviews for each respective decision, and the enlarged symbol represents the overall decision. The QoE is the quotient of the average QoE and the highest (best) possible quality of evidence, expressed as a percentage. The number of participants was calculated from the most common measurement in reviews reporting outcome-specific sample sizes.
CTRL, nonexercising control; ND, no data; QoE, quality of evidence.

reported in Supplemental Appendix 13, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, power was enhanced by standard RT (41,48–50,148). There were insufficient data to determine whether home-based RT (63) and Olympic-style weightlifting (69) impacted power compared with CTRL. In comparisons between distinct RTx, power was affected by load (77,149,150), eccentric flywheel training versus standard RT (85), Olympic-style weightlifting versus standard RT (69), power training versus standard RT (82,105,148), and volume (148), but power was not affected by set structure (107,108). There were insufficient data to determine if power was affected by fatigue/failure (99), unstable surfaces (70), or concurrent training (123,124,151).

Improving power. RT improved power compared with CTRL (Table 6). Between RTx and power training, power was enhanced by RT performed with moderate loads (30%–70% 1RM), an eccentric flywheel device, Olympic-style weightlifting, and power training techniques, versus standard RT, and low-to-moderate volume (repetitions·set < 24). Power was not affected by RT performed with different set structures (cluster or rest redistribution).

Muscular Endurance

The impact of RT versus CTRL and distinct RTx variables on muscular endurance is summarized in Supplemental Appendix 9, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 14, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, muscular endurance was impacted by standard RT (41,54) and home-based

RT (63). There were insufficient data to determine whether unstable surface RT (70) or velocity-based RT (66) impacted muscular endurance compared with CTRL. There were insufficient data to determine if muscular endurance was affected by load (82), unstable surfaces (70), power training (82), volume (82), or set structure (107,108).

Improving muscular endurance. RT improved muscular endurance compared with CTRL.

Gait Speed

The impact of RT versus CTRL and distinct RTx variables on gait speed is summarized in Table 5. The results for each review are reported in Supplemental Appendix 15, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, gait speed was impacted by standard RT (17,30,32,33,36–38,47,53,152–155). There were insufficient data to determine whether elastic band RT (62) or power training (156) impacted gait speed compared with CTRL. In comparisons between distinct RTx, there were insufficient data to determine if gait speed was influenced by load (82) or power training versus standard RT (82).

Improving gait speed. RT improved gait speed compared with CTRL.

Timed Up-and-Go

The impacts of RT versus CTRL and distinct RTx variables on timed up-and-go (TUG) performance are summarized in Table 5. The results for each review are reported in Supplemental Appendix 16, Supplemental Digital Content, https://links.lww.com/MSS/D323.

SPECIAL COMMUNICATIONS

TABLE 5. Resistance training forms and prescription variables that impact physical function outcomes.

	Stair Climbing	Gait Speed	Balance	Chair Stand Performance	Timed Up-and-Go
Standard RT vs CTRL	**?** ND	**✓** ↑ 8 reviews; *n* = 3,407 QoE = 81% ? 3 reviews; *n* = 115 QoE = 50% ↓ 2 reviews; *n* = 1,660 QoE = 100%	**✓** ↑ 1 review; *n* = 406 QoE = 75% ? 2 reviews; *n* = 227 QoE = 63%	**✓** ↑ 2 reviews; *n* = 954 QoE = 88% ? 3 reviews; *n* = 291 QoE = 75% ↓ 1 review; *n* = 657 QoE = 100%	**✓** ↑ 5 reviews; *n* = 1,568 QoE = 90% ? 5 reviews; *n* = 479 QoE = 70%
Elastic band RT vs CTRL	**?** ND	**?** ? 1 review; *n* = 160 QoE = 75%	**?** ND	**?** ND	**?** ↑ 1 review; *n* = 154 QoE = 75%
Home-based RT vs CTRL	**?** ND	**?** ND	**✓** ↑ 1 review; *n* = 1,484 QoE = 75%	**?** ND	**?** ND
Power training RT vs CTRL	**?** ND	**?** ? 1 review; *n* = 165 QoE = 75%	**?** ND	**?** ND	**?** ND
Unstable surface RT vs CTRL	**?** ND	**?** ND	**?** ? 1 review; *n* = 138 QoE = 75%	**?** ND	**?** ND
Intensity: Load	**?** ? 1 review; *n* = 84 QoE = 75%	**?** ? 1 review; *n* = 38 QoE = 75%	**?** ND	**?** ? 1 review; *n* = 23 QoE = 75%	**?** ? 1 review; *n* = 38 QoE = 75%
Intensity: Fatigue/failure	**?** ND	**?** ND	**?** ND	**?** ND	**?** ND
Type: Unstable vs stable surface	**?** ND	**?** ND	**?** ? 1 review; *n* = 142 QoE = 75%	**?** ND	**?** ND
Technique: Power training	**?** ? 2 reviews; *n* = 142 QoE = 88%	**?** ? 1 review; *n* = 79 QoE = 75%	**?** ND	**?** ? 3 reviews; *n* = 442 QoE = 83%	**?** ? 2 reviews; *n* = 119 QoE = 75% ↓ 1 review; *n* = 227 QoE = 100%
Concurrent training	**?** ND	**?** ND	**?** ? 1 review; *n* = 45 QoE = 50%	**?** ND	**?** ND

✓: positively impacts outcome; ?: cannot determine impact on outcome; ✖: does not impact outcome. Within each box, the small symbol and text represent details of reviews for each respective decision, and the enlarged symbol represents the overall decision. The QoE is the quotient of the average QoE and the highest (best) possible quality of evidence, expressed as a percentage. The number of participants was calculated from the most common measurement in reviews reporting outcome-specific sample sizes.
CTRL, nonexercising control; ND, no data; QoE, quality of evidence.

TABLE 6. Resistance training prescriptions to improve muscle function and hypertrophy.

Outcome	RT vs CTRL	RTx to Enhance[a] Adaptation
Strength	Strength is improved by RT, including circuit RT, elastic band RT, home-based RT, and velocity-based RT.	Frequency: ≥2 sessions/wk Intensity: ≥80% 1RM (dose-response) Type: Eccentric flywheel RT Technique: Full range of motion Volume: 2–3 sets/session Exercise order: Beginning of training session
Hypertrophy	Hypertrophy is improved by RT, including circuit RT and elastic band RT.	Type: Eccentric contractions/overload Volume: ≥10 sets/wk (dose-response)
Power	Power is improved by RT.	Intensity: Loads = 30%–70% 1RM Type: Eccentric flywheel RT Technique: Olympic-style weightlifting; Power RT Volume: Low-moderate (repetitions · sets ≤24)
Muscular endurance	Muscular endurance is improved by RT.	ND
Gait speed	Gait speed is improved by RT.	ND
Timed up-and-go	Timed up-and-go is improved by RT.	ND
Chair stand test	Chair stand test performance is improved by RT.	ND
Balance	Balance is improved by RT.	ND
Stair climbing	ND	ND
Multicomponent function	Multicomponent function is improved by RT, including elastic band RT and home-based RT.	Technique: Power RT
SPPB	SPPB is not improved by RT.	Technique: Power RT
Walking performance	ND	Technique: Power RT
Running performance	ND	Type: Velocity-based RT
Jumping performance	Jumping performance is improved by flywheel RT and velocity-based RT.	Type: Velocity-based RT
Contraction velocity	Contraction velocity is improved by RT.	ND
Change of direction (agility)	ND	ND
Functional reach	ND	ND

[a]Enhanced compared with standard RT and based on included meta-analyses showing a significant effect.
1RM, one-repetition maximum; CTRL, no exercise; ND, insufficient data to form conclusion; RT, resistance training; RTx, resistance training prescription; SPPB, Short Physical Performance Battery.

Compared with CTRL, TUG was impacted by standard RT (30,32,33,36,38,47,50,152,154,156). There were insufficient data to determine if elastic band RT (62) impacted TUG compared with CTRL. In comparisons between distinct RTx, there were insufficient data to determine if TUG was affected by load (82) or power training versus standard RT (82,106,157).

Improving timed up-and-go. RT improved TUG compared with CTRL.

Chair Stand Test

The impacts of RT versus CTRL and distinct RTx variables on chair stand test performance are summarized in Table 5. The results for each review are reported in Supplemental Appendix 17, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, chair stand performance was impacted by standard RT (30,32,33,36,50,152). In comparisons between distinct RTx, there were insufficient data to determine if chair stand performance was affected by load (82) or power training versus standard RT (82,106,157).

Improving chair stand test. RT improved chair stand performance compared with CTRL.

Balance

The impacts of RT versus CTRL and distinct RTx variables on balance are summarized in Table 5. The results for each review are reported in Supplemental Appendix 18, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, balance was impacted by standard RT (52,54,154) and home-based RT (63). There were insufficient data to determine whether unstable surfaces (70) impacted balance compared with CTRL. In comparisons between distinct RTx, there were insufficient data to determine if unstable surfaces (70) or concurrent training (158) affected balance.

Improving balance. RT improved balance compared with CTRL.

Stair Climbing

The impacts of RT versus CTRL and distinct RTx variables on stair climbing are summarized in Table 5.

The results for each review are reported in Supplemental Appendix 19, Supplemental Digital Content, https://links.lww.com/MSS/D323. In comparisons between distinct RTx, there were insufficient data to determine if stair climbing was affected by load (82) or power training versus standard RT (82,157).

Improving stair climbing. There were insufficient data to determine the impact of RT on stair climbing performance.

Multicomponent Function

The impacts of RT versus CTRL and distinct RTx variables on multicomponent function—the aggregate performance on several physical function assessments—are summarized in Supplemental Appendix 9, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 20, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, multicomponent function was impacted by standard RT (17,24,42,45,159), elastic band RT (60,61), and home-based RT (64). In comparisons between distinct RTx, multicomponent function was affected by elastic band RT (61) and power training (105,157,160), but was not affected by time under tension (24) or volume (91). There were insufficient data to determine if the multicomponent function was positively affected by load (24), range of motion (87), or concurrent training (119).

Improving multicomponent function. Compared with CTRL, multicomponent function was improved by RT, including elastic band RT and home-based RT (Table 6). Comparing between RTx, multicomponent function was enhanced by RT performed with power training techniques, and standard RT enhanced multicomponent function compared with elastic band RT.

Short Physical Performance Battery

The impacts of RT versus CTRL and distinct RTx variables on the Short Physical Performance Battery (SPPB) are summarized in Supplemental Appendix 10, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 21, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, SPPB was not affected by standard RT (30). There were insufficient data to determine whether power training (156) had an impact on SPPB compared with CTRL. In comparing different RTx, SPPB was positively affected by power training (106,157).

Improving short physical performance battery. RT did not improve SPPB compared with CTRL. Comparing RTx, SPPB was enhanced by RT performed with power training.

Walking Performance

The impacts of RT versus CTRL and distinct RTx variables on walking test performance (e.g., 6-min walk test) are summarized in Supplemental Appendix 10, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 22, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, there were insufficient data to determine if standard RT (30) or elastic band RT (62) impacted walking performance compared with CTRL. In comparisons between distinct RTx, walking performance was positively affected by power training (106,157).

Improving walking performance. Between RTx, walking performance was enhanced only by RT performed with power training techniques.

Running Performance

The impacts of RT versus CTRL and distinct RTx variables on running performance are summarized in Supplemental Appendix 9, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 23, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, there were insufficient data to determine whether standard RT (48,69,161), eccentric flywheel RT (162), and velocity-based RT (66) impacted running performance compared with CTRL. In comparisons between distinct RTx, running performance was positively affected only by velocity-based RT versus standard RT (65). There were insufficient data to determine if running performance was affected by eccentric flywheel RT versus standard RT (85), Olympic-style weightlifting versus standard RT (69), set structure (109), or concurrent training (123).

Improving running performance. Comparing RTx, running performance was enhanced only by velocity-based RT.

Jumping Performance

The impacts of RT versus CTRL and distinct RTx variables on jumping performance are summarized in Supplemental Appendix 9, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 24, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, jumping performance was impacted by eccentric flywheel RT (162) and velocity-based RT (66). In comparisons between distinct RTx, jumping performance was positively affected by velocity-based RT versus standard RT (65), but jumping performance was not affected by set structure (108,109). There were insufficient data to determine if jumping performance was affected by load (81), eccentric flywheel RT versus standard RT (85), or machine versus free-weight

RT (100). We note that jumping performance should not be considered as a proxy for muscle power.

Improving jumping performance. Compared with CTRL, jumping performance was improved by eccentric flywheel RT and velocity-based RT (Table 6). Comparing RTx, velocity-based RT enhanced jumping performance; however, jumping performance was not affected by RT performed with different set structures (complex vs cluster).

Contraction Velocity

The impact of RT versus CTRL and distinct RTx variables on contraction velocity is summarized in Supplemental Appendix 10, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 25, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, contraction velocity was positively impacted by standard RT (163). In comparisons between distinct RTx, there were insufficient data to determine if contraction velocity was affected by cluster or rest-redistribution set structures (107,108).

Improving contraction velocity. RT improved contraction velocity compared with CTRL.

Change of Direction (Agility)

The impacts of RT versus CTRL and distinct RTx variables on the ability to change direction are summarized in Supplemental Appendix 9, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 26, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, there were insufficient data to determine whether standard RT (69) or eccentric flywheel RT (162) impacted the ability to change direction. In comparisons between distinct RTx, there were insufficient data to determine if agility was affected by Olympic-style weightlifting (69).

Improving change of direction (agility). There were insufficient data to determine the impact of RT on agility.

Functional Reach Test

The impact of RT versus CTRL on functional reach test performance is summarized in Supplemental Appendix 10, Supplemental Digital Content, https://links.lww.com/MSS/D323. The results for each review are reported in Supplemental Appendix 27, Supplemental Digital Content, https://links.lww.com/MSS/D323. Compared with CTRL, there were insufficient data to determine whether standard RT (154) impacted functional reach performance.

Improving functional reach test. There were insufficient data to determine the impact of RT on functional reach test performance.

DISCUSSION

Resistance training is a central component of exercise programs. It should be a core component of physical fitness programming, as it has broad-reaching benefits for muscular health and physical function. This overview of reviews summarized 137 systematic reviews to determine the impact of RTx variables on muscle function and hypertrophy in healthy adults. Compared with no exercise, RT improves muscle strength, hypertrophy, power, endurance, contraction velocity, and performance on several physical function tests (balance, gait speed, chair stand, and timed up-and-go; Table 3). Additionally, other forms of RT improve multiple outcomes compared with CTRL, including home-based RT, elastic band RT, power RT (which involves performing the concentric phase quickly), velocity-based RT, and circuit RT (Table 3). Based on these results, it is apparent that many forms of RT work to promote the primary hallmark outcomes of RT: increased strength, hypertrophy, and power. Our primary recommendation is that healthy adults perform RT with high effort (effort can be measured through various scales, but can be achieved with various loads and sets per the FITT-VP principle) at least twice weekly, with all major muscle groups being engaged.

Between distinct RT programs, only some RTx variables can be altered to optimize increases in muscle function and hypertrophy (Tables 4 and 6). Significant and optimal improvements are two different goals; however, participants and facilitators of RT must distinguish between them. Compared with CTRL, significant improvements in muscle function, hypertrophy, and physical performance can be accomplished with the adoption of many RT programs. This overview of reviews enhances the quality of recommendations for healthy adults to significantly increase muscle function, hypertrophy, and physical performance by providing current, comprehensive, and evidence-based insights into the impact of RTx variables.

Progressive overload is a concept considered fundamental to RT programming principles. Progressive overload refers to the need to increase the stimulus (stressor) placed upon the muscle throughout a training program. Progressive overload is often proposed as essential for continued adaptive progress with any form of exercise training as physiological systems adapt to reduce the stress of the exercise and build an increasing adaptive response (i.e., strength). Such adaptation would require increasing the stimulus, such as load, volume, training frequency, exercise selection, or duration (even if only slightly), as the muscle continues to adapt to produce further adaptations (164). Modifying an RTx (e.g., increasing relative load [percentage of one-repetition maximum, %1RM]) can support progressive overload. Still, the same relative load can also be sustained when regular strength testing is performed or perceived exertion scales are used to increase absolute load commensurate with strength gains (113,165). Notably, as the results in Table 4 highlight, progression is not necessary to achieve beneficial outcomes, and overload, or more accurately, increasing the stimulus in some manner, is likely a requirement only for those seeking continued longer term progress. We note that in some populations, due to inexperience (and potential safety concerns), RTx necessitates that loads are necessarily low and progression is a requirement to achieve a meaningful benefit. Continued progression could be a personal decision and part of the individualization of RTx (see below). A similar commentary could be made around the "need" for variation of RTx variables (see below).

The principle of specificity states that training adaptations are specific to the training stimulus applied. Some adaptations can be affected by modifying RTx variables, although there is a considerable carryover of training effects on general muscular performance in various domains in nonadvanced trainees (17,24). Individualization involves modifying RT programs to meet the unique goals, needs, and characteristics of each individual, such as their experience and performance level. Individualized programs can increase exercise adoption and adherence (10), but individualization has been scarcely discussed in previous Position Stands (11,12). With the accumulation of evidence demonstrating that many forms of RT are effective for healthy adults to improve muscle function and health, RT programs would ideally be individualized to maximize adherence, enjoyment, safety, and effectiveness specific to training goals.

Variation is the systematic modification of RTx variables over time to facilitate continued adaptation. One of the most common forms of variation is periodization—intentionally modifying prescription variables (e.g., load, volume, frequency) throughout an RT program. The impact of periodization on strength could not be determined, although one review found that periodized programs were slightly favored over nonperiodized programs to maximize strength gains under volume-equated conditions (117). With appropriate progressive overload, periodization is not significantly superior to nonperiodized programs; thus, periodization is less important than previously hypothesized (11,12) for healthy adults to improve muscle function and hypertrophy. We note, however, that definitions of periodization vary (166,167), but broadly involve the systematic manipulation of RTx variables with the goal of optimizing performance adaptations, managing fatigue, preventing overtraining/injury, and peaking for specific goals. Thus, it may be that the ordering of variables within a given RTx to achieve certain goals is understudied compared with the outcomes contained in the reviews we examined. We also note that periodization and programming are often conflated (168), which may have been the case in some reviews.

Resistance training improves numerous measures of muscle function and can result in hypertrophy compared with no exercise (Fig. 2). Provided the strikingly low RT participation levels (169–173), individuals and practitioners alike should acknowledge the tremendous benefits of completing RT of various forms compared with no exercise. Additionally, nontraditional forms of RT also yield marked benefits—for example, elastic band RT has been shown to increase strength, hypertrophy, and certain components of physical function. Similarly, home-based RT improved strength, muscular endurance, and balance. Nontraditional forms of RT may provide alternative, perhaps more accessible or approachable, strategies for completing RT with appreciable physical benefits.

We build on several aspects of the 2009 ACSM Position Stand (11), which aimed to provide evidence-based RTx guidelines for healthy adults wishing to progress beyond the first 3–4 months of training. Previous guidelines have recommended healthy adults use free weights and machines to complete two to three RT sessions per week, with eight to ten exercises involving major muscle groups per session, one to four sets per exercise, eight to twenty repetitions per set, 2–3 min rest between sets, loads 40%–70% 1RM, and follow the principles of progressive overload, specificity, and variation (10,11). Current estimates (from self-report) are that only ~30% of American adults complete some muscle-strengthening activities at least 2 d/wk, and nearly 60% complete no muscle-strengthening exercise (169–173). Estimates for older persons vary; however, data from the UK, United States, and Australia put participation rates from as low as 1% to as high as 40% (174). We suspect that rates of participation among older persons for the types of RT programs we outline here are likely 10%–15% (175). Notably, others have estimated that developing general muscular fitness (strength, hypertrophy, and power) according to previous ACSM guidelines may, in some cases, require training for 20 h or more per week (176). Thus, the recommendations of the previous Position Stand (10,11) may be less relevant for most adults, particularly older adults, many of whom do not engage in RT. The specific program details outlined in previous Position Stands may be an appropriate starting point for some individuals; however, several other RT programs, as evidenced here, can also be effective.

Deviating from previous guidelines, we propose that individualizing programs to increase RT participation is, from our perspective, more important than conforming to specific RTx criteria outlined in previous Position Stands. Research on RTx reveals that "minimal doses" of RT are able to bring about substantial strength, hypertrophy, and physical functional gains (177). We propose that our stance around encouraging participation in RT is underscored by the expanding knowledge of health benefits, some of which are unique to RT (4–6). The recommendations presented here apply to healthy adults,

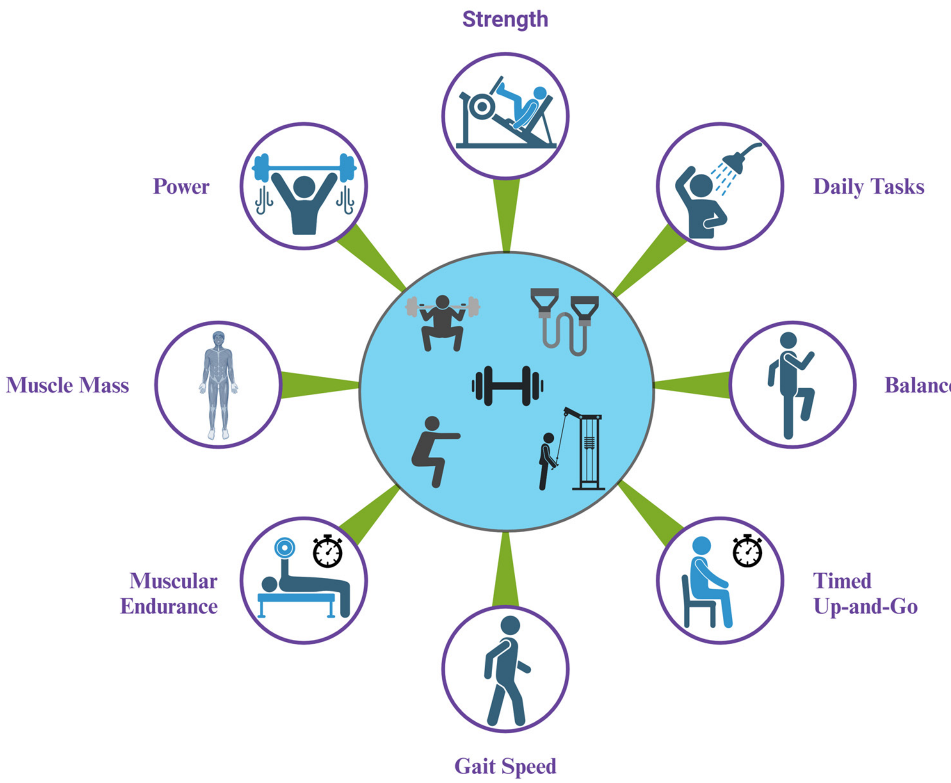

FIGURE 2—Schematic representation of the modes of RT and the outcomes that are positively influenced by engaging in regular RT.

ranging from complete novices (with no experience with RT) to experienced trainees, and support the adoption of a much broader range of RT programs to improve overall muscular strength, function, and hypertrophy. Advances enable a more comprehensive understanding of how RTx variable manipulation affects outcomes. For example, the previous Position Stand recommended novice lifters complete two to three full-body sessions per week for muscle hypertrophy, and this recommendation was graded as the highest possible quality of evidence (11). However, this recommendation was informed by only three studies (178–180) (n = 59 total participants), and two of the studies did not investigate frequency (178,179). In contrast, we present guidelines suitable for many healthy adults, supported by ample primary evidence, that were formulated with leading evidence synthesis methodologies.

Resistance training is safe for healthy adults of all ages (5), but many adults, particularly older adults, avoid RT due to misperceptions about safety and injury risks (181). In an analysis of >38,000 participants (>6700 RT participants), of which >11,000 were older adults, exercise did not increase the risk of serious adverse events. The risk of nonserious adverse events (e.g., pain, fatigue, bursitis, and edema) was not different than aerobic exercise in terms of injury rate or risk (182). Nonfatal cardiovascular complications also occur much less frequently during RT than aerobic training (5,183). In 23 studies (n = 1174) of adults with coronary heart disease, all 63 nonfatal cardiovascular complications occurred during aerobic training, and the 20 musculoskeletal complications that occurred during RT were caused by preexisting conditions (knee arthritis) and were resolved by changing RT intensity or body position (183). Clearly, RT can be safe and effective for healthy adults of all ages.

This overview of reviews summarized RTx variable-level evidence, an approach that prevents statistical insights into the comparative effectiveness (e.g., dose-response) of individual RT variables. Nuanced details of RT protocols and dose-response data require discussion for practitioners designing RT programs to enhance adaptations, since some features of RTx are not reflected in variable-level summaries. For example, RT frequency was found to impact strength; however, there was insufficient evidence to conclude a dose-response relationship, and the impact is diminished when volume is equated (73,76,90).

Load (often used synonymously with intensity) has repeatedly been shown to impact strength more than other RT adaptations (17,83,184). Load has typically been quantified as a %1RM or repetition maximum. Several methods have been used to convert loads between %1RM and repetition maximum (17,184,185), including a recent analysis that considered exercise-specific conversions and between-subject variability (186). The number of repetitions performed within a given set is inherently and inversely related to load, provided a given load and near-fatiguing effort are applied; however, not all adaptations are enhanced by fatiguing efforts (e.g., power and strength). Practitioners should consider the principle of specificity when designing RT programs to achieve specific outcomes.

Increasing the number of sets (volume) per exercise positively impacted strength (88–93) and hypertrophy (24,128,131–133), which aligns with a recent analysis by Swinton et al. (184). Clearly, one set is superior to zero sets (CTRL), and two sets are superior to one set (17,24,88–93,128,131–133), but the exact number of sets required to optimize adaptations cannot be ascertained. A meta-regression (187) of the effect of volume (weekly) sets showed progression, but as expected, a dose-response that plateaued and showed diminishing returns beyond ~2–3 sets/exercise for strength and ~18–20 weekly sets for hypertrophy with varying loads; thus, healthy adults are advised to complete at least two sets per exercise. Completing more than two sets per exercise may provide additional benefits, but we hypothesize that these benefits diminish with each subsequent set. Weekly volume load—the total amount of load lifted in each week of training, defined by load/rep • reps/set • sets/exercise • exercises/session • sessions/week—which would presumably represent the complete representation of "dose" of RT—was rarely considered in included reviews.

Completing sets to fatigue (momentary muscular failure) does not enhance gains in strength, hypertrophy, and power, and so is not necessary for benefits to occur. It may also be that lifting to fatigue is inadvisable for certain populations (e.g., older individuals) due to risks to vascular health and an increased risk of injury resulting from poor form (24,97–99). We propose that an adequate stimulus (the effort to meet the minimum stressor) is required to induce adaptations. Sufficient effort (assessed using various scales) can be accomplished by completing sets with various RTx and completion of "near-failure" or a target of 2–3 repetitions in reserve (RIR) (24,97–99,128,137,188–190).

Blood flow restriction protocols often compare different loads (e.g., higher load RT versus BFR with lower load), so the individual effect of BFR cannot be distinguished from the load in many cases. Similarly, flywheel RT typically involves eccentric overload, so the individual effect of flywheel RT and contraction type cannot be distinguished. Evidence-based conclusions on these matters cannot be determined with the available data, but consideration is warranted when designing RT programs and conducting future research. Notably, these considerations can be largely overlooked when designing RT programs for most adults who are inexperienced with RT. Untrained individuals will benefit from various RT programs, provided that progression, the variables outlined here as affecting outcomes, and adherence are core principles.

Limitations should be considered when interpreting the results presented in this analysis. Overviews of reviews provide strong (larger or consistent effects) pooled, group-level evidence, so that appropriate deviations from the reported recommendations will be required on various occasions, in accordance with the principle of individualization. We acknowledge that any RT program would need to be tailored to an individual's needs and goals. Not discussed here, but of paramount importance, is the understanding and acknowledgment of the critical role adherence plays in any RT program. Such considerations are beyond the scope of this review, but work has been done to examine this important area (191,192).

The totality of evidence in overviews of reviews is limited to interventions and outcomes summarized by systematic reviews. For example, the Short Physical Performance Battery (SPPB) is a common assessment used in randomized trials; however, only two eligible reviews have synthesized the results of the SPPB. When evaluating the results of this review, it would lead one to conclude that RT does not improve SPPB performance; however, this conclusion likely reflects the sparseness of evidence, rather than a true null effect. We note that there was ample evidence for individual components of the SPPB—gait speed, balance, and chair stand tests—and RT improved all these components. Overviews of reviews are also limited by overlapping evidence. While we estimated this overlap using the CCA method for strength, we did not do so for other variables. We acknowledge that caution is needed when examining other outcomes for which we provide no CCA analysis. Individual studies included in multiple eligible reviews could inflate the evidence supporting or refuting conclusions; for example, three reviews were included on the impact of RT time of day on hypertrophy (24,102,131), but two reviews (24,131) synthesized one original review (102). Overlapping data are an issue in overviews of reviews, and methods are being developed to improve exercise-related overviews of reviews (193,194). Overviews of reviews do not permit inferences about the comparative effectiveness of different interventions (14). This review summarizes the individual impact of RTx variables; however, alternative data synthesis methods are required to formulate evidence-based conclusions on the relative effects of multiple RTx. For example, network meta-analysis can be leveraged to statistically compare and rank the efficacy of unique RT programs (17). Reviews included in this overview of reviews were limited to healthy adults. Provided sufficient evidence, future guidelines can be developed for additional subpopulations (e.g., older adults and clinical populations). There was insufficient evidence to form recommendations on emerging RTx strategies; for example, various minimal-dose RT programs warrant further investigation and consideration when individualizing RT programs (195). The method of testing muscular endurance (e.g., absolute vs relative, pre- vs postintervention strength) was not accounted for in the data synthesis and should be considered when designing future studies (196).

Methods to quantify load based on proximity to muscular failure (e.g., RIR, perceived exertion) are appealing because they could translate to various RT forms (e.g., elastic band or body weight RT). While training to failure is not obligatory for optimizing results, there is insufficient evidence to quantify exact RIR and perceived exertion targets (189,190,197,198). The available evidence did not compare distinct body regions or muscle groups. In the view of the authors, applying the recommendations herein to the body regions "upper" and "lower" for "push" and "pull" exercises (i.e., four body regions) is sufficient to target major muscle groups. The movement directions "horizontal" and "vertical" may also be considered for upper body exercises (i.e., six body regions). The regions and movements we recommend should align with the FITT-VP principle in terms of RTx, which could be a per-training-session requirement or a per-week requirement, depending on individual goals, training status, age, and other relevant variables.

We also need to acknowledge that randomized trials in sports and exercise medicine-related fields are often poor quality with small sample sizes, poor randomization methodology, lack of preregistration, poor reporting of adverse events, and other shortcomings (199), and much remains to be done in terms of the conduct of evidence syntheses (200,201). Guidelines have been developed to improve the reporting of exercise trials, and we would encourage their adoption (202). Consequently, cohesive QoE evaluations, such as pooling Grading of Recommendations Assessment, Development and Evaluation assessments (14), were not possible. Field-specific guidelines for evidence syntheses have emerged and will continue to be developed (203). Nonetheless, to improve the quality of evidence that informs guidelines and best practices as a field, a higher, more rigorous standard of trial conduct and evidence syntheses are required in the field of RT.

This overview of reviews represents, to date, the most comprehensive summary of the impact of RTx variables on muscle function and hypertrophy in healthy adults. RT greatly enhances overall muscular health compared with no exercise, and only a few RTx variables can be manipulated to enhance adaptations in experienced trainees. Therefore, individuals should prioritize completing any form of RT to improve muscle function and hypertrophy. Exercise and healthcare practitioners can provide invaluable guidance by leveraging these conclusions to promote RT participation and adherence, helping adults of all ages improve their health and fitness.

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