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Designing Resistance Training Programmes to Enhance Muscular Fitness

A Review of the Acute Programme Variables

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Abstract

The popularity of resistance training has grown immensely over the past 25 years, with extensive research demonstrating that not only is resistance training an effective method to improve neuromuscular function, it can also be equally effective in maintaining or improving individual health status. However, designing a resistance training programme is a complex process that incorporates several acute programme variables and key training principles. The effectiveness of a resistance training programme to achieve a specific training outcome (i.e. muscular endurance, hypertrophy, maximal strength, or power) depends on manipulation of the acute programme variables, these include: (i) muscle action; (ii) loading and volume; (iii) exercise selection and order; (iv) rest periods; (v) repetition velocity; and (vi) frequency. Ultimately, it is the acute programme variables, all of which affect the degree of the resistance training stimuli, that determine the magnitude to which the neuromuscular, neuroendocrine and musculoskeletal systems adapt to both acute and chronic resistance exercise. This article reviews the available research that has examined the application of the acute programme variables and their influence on exercise performance and training adaptations. The concepts presented in this article represent an important approach to effective programme design. Therefore, it is essential for those involved with the prescription of resistance exercise (i.e. strength coaches, rehabilitation specialists, exercise physiologists) to acquire a fundamental understanding of the acute programme variables and the importance of their practical application in programme design.

Resistance training, also known as strength or weight training, is well established as an effective method of exercise for developing muscular fitness (i.e. the ability to generate muscle force).[1] Fleck and Kraemer[2] describe the primary goals of resistance training as improving muscular strength and endurance, while other health-related benefits derived from resistance training include increases in bone mass, reduced blood pressure, increase muscle and connective tissue cross-sectional area (CSA), reduced body fat, and it may relieve low back pain.[3] Although modern technology has reduced much of the need for high levels of force production during activities of daily living, it is recognised in both the scientific and medical communities that muscular strength is a fundamental physical trait necessary for health, functional ability, and enhanced quality of life.[4] Therefore, exercise-induced skeletal muscle growth (muscular hypertrophy) and accompanying gains in strength expression (neuromuscular adaptations) are areas of interest not only for the competitive athlete wishing to enhance performance, but also for non-competitive individuals who simply wish to alter their body composition or increase their capacity to perform tasks requiring muscular effort. Research over the past 50 years has utilised various forms of resistance training (i.e. single vs multiple sets, concentric vs eccentric actions, isolation vs compound movements) in order to maximise such development.[1,5-10] This has seen the incorporation of scientific literature with practical application, offering a greater understanding of resistance training programme design for the many practitioners currently involved in the prescription of resistance exercise. Proper programme design is essential to maximise the benefits associated with resistance training.[3] Thus, the purpose of this literature review is to provide recommendations for the practical application of the acute programme variables and how they relate to programme design. In addition, we outline several aspects of the adaptations associated with resistance training.

1. Resistance Training Programme Design

Designing a resistance training programme is a complex process incorporating several acute programme variables[4,11] and key training principles[2] (figure 1). Historically, programme design has been more of an art than a science, yet science remains a vital part of the process, as prescription of any exercise requires an understanding of the underlying scientific principles involved. Several key training principles govern safe and effective resistance training programme design, including overload, specificity, adaptation, progression, individualisation and maintenance.[2] When prescribing resistance exercise, one must decide what constitutes an optimal balance of these factors while considering the individual's current level of condition, trainable strength characteristics and personal goals.[10]

2. Acute Programme Variables

The effectiveness of a resistance training programme to achieve a specific training outcome depends on several acute programme variables,[4,11] all of which affect the degree of the resistance training stimuli (table I). From the pioneering work of DeLorme,[5] and DeLorme and Watkins,[12] the concept of progressive overload has become the foundation of resistance training programme design. Their work describes the classic programme variables of load, frequency, duration and intensity, which have been the cornerstone to achieve such overload. Kraemer[11] redefined the programme variables to better describe how such variables are manipulated during a workout in order to bring about the desired training adaptation. More specifically, the redefined acute programme variables included: (i) repetition maximum (RM) load; (ii) number of sets; (iii) choice of exercise; (iv) order of exercises; and (v) rest periods. A recently published position stand by the American College of Sports Medicine[4] followed revision of the above programme variables. The revised acute

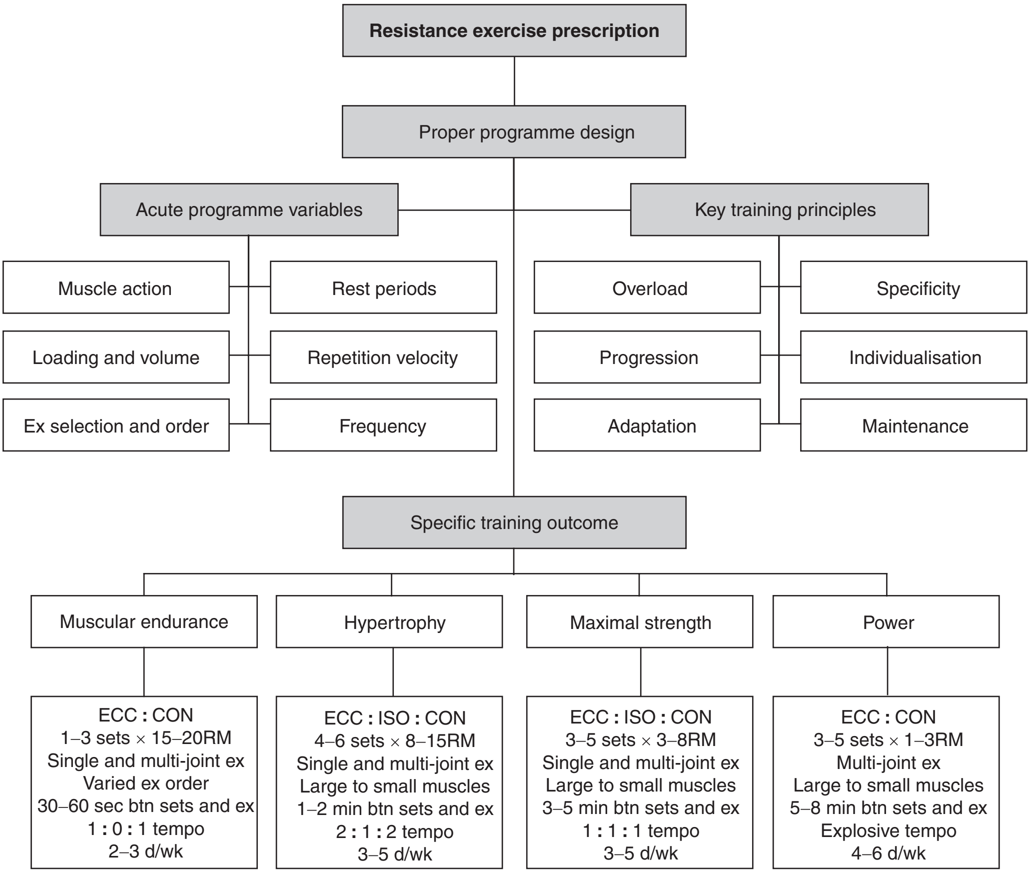

Fig. 1. Proper programme design of resistance exercise for specific training outcomes incorporates the acute programme variables and key training principles.[2,4,11] **btn** = between; **CON** = concentric; **ECC** = eccentric; **ex** = exercise; **ISO** = isometric; **RM** = repetition maximum.

programme variables are as follows: (i) muscle action; (ii) loading and volume; (iii) exercise selection and order; (iv) rest periods; (v) repetition velocity; and (vi) frequency.

2.1 Muscle Action

Most resistance training programmes include dynamic repetitions of concentric (CON) and eccentric (ECC) muscle actions, with isometric muscle actions suggested to play a secondary stabilising role.[4] Several training studies have demonstrated that dynamic muscular strength and morphological changes in muscle have been greatest when both CON and ECC actions are used in a resistance training programme.[13-15] Furthermore, data presented by Kraemer et al.[21] and Durand et al.[22] indicate that acute hormonal response is associated with the specific muscle action used in acute resistance exercise. Growth hormone (GH) secretion is specific to the muscle action used during acute resistance exercise, with CON actions producing a greater GH response.[21,22] Collectively, these data suggest that training should involve both CON and ECC muscle actions.

2.2 Loading and Volume

Alterations of training load and volume have been shown to affect hormonal,[23-25] neural[26-28] and hypertrophic[7,16,29] responses and subsequent adaptations to resistance training. Tan[30] suggests that the interplay between load and volume is the critical factor in determining the optimal range of training

Table I. Recommendations for acute programme variables[2,4,13-20]

Specific outcome	Muscle action	Loading (RM) and volume	Exercise selection and order	Rest periods	Repetition velocity	Frequency (d/wk)
Muscular endurance	ECC : CON	>20 high	SJ/MJ mixed	30–60 sec	1 : 0 : 1	1–2
Hypertrophy	ECC : CON : ISO	8–15 mod-high	SJ/MJ lge → sml	2–3 min	2 : 1 : 2	2–3
Maximal strength	ECC : CON : ISO	3–8 mod	MJ lge → sml	3–5 min	1 : 1 : 1	3–4
Power	ECC : CON	1–3 low	MJ lge → sml	5–8 min	Explosive	4–6

CON = concentric; **ECC** = eccentric; **high** = 4–6 sets per exercise; **ISO** = isometric; **lge** = large muscle mass; **low** = 2–4 sets per exercise; **MJ** = multi-joint; **mod** = 3–5 sets per exercise; **RM** = repetition maximum; **SJ** = single-joint; **sml** = small muscle mass.

stimuli in order to promote the neuromuscular adaptations associated with resistance training.

Load refers to the amount of weight assigned to an exercise set[31] and is probably the most important variable in resistance training programme design.[32] The training load can be determined by either RM (i.e. the greatest amount of weight lifted with correct technique for a specified number of repetitions) or some percentage of the one repetition maximum (1RM).[5] Prescribing load via the RM method is thought to be superior to using a percentage of 1RM.[1,30,33] From a practical perspective this eliminates the need for repeated 1RM testing to keep the exercise stimulus effective. It is recommended that training load is increased by 2–10% when the individual can perform the current load for one to two repetitions over the desired number.[4] The RM continuum relates training load to the broad training effects derived.[2] The continuum concept illustrates that a certain RM emphasises a specific outcome (i.e. muscular endurance, hypertrophy, maximum strength, power); however, training benefits are blended at any given RM.[31] Heavy loads are used if the goal is power (1–3RM) or maximum strength (3–8RM), moderate loads for hypertrophy (8–15RM), and low loads for muscular endurance (>20RM).[2]

Volume describes the total amount of work performed within a training session,[30] and is typically calculated as: (i) total repetitions (sets × repetitions);[34] or (ii) volume load (sets × repetitions × resistance).[4] Training volume is prescribed in terms of the number of repetitions per set, number of sets per session, and the number of sessions per week.[30] The importance of training volume for maximal strength and muscle size gains during the early phases of resistance training have been previously demonstrated.[14,16,35]

A meta-analysis by Rhea and co-workers[36] revealed that untrained individuals experience maximal strength gains with a mean training intensity of ≈12RM, while in trained individuals, ≈8RM elicits the greatest strength increase. Additionally, effect size data clearly demonstrate that additional strength increases accompany training beyond single-set protocols, with both untrained and trained individuals experiencing greatest gains (approximately twice the treatment effect of single sets) with a mean training volume of four sets per muscle group. Therefore, resistance training programmes targeting muscular strength and hypertrophy are best served by moderate to heavy loads (6–15RM) and moderate volume (3–4 sets per exercise).[16,35]

2.3 Exercise Selection and Order for a Specific Outcome

Exercise selection involves choosing exercises for a resistance training programme.[31] Several terms have been suggested for exercise classification, including primary or assistance, structural or body-part, and multi-joint or single-joint,[3,11] all of which are based on the size of the muscle area involved. Single-joint exercises (e.g. leg extension, bicep curl, pec deck) are often used to isolate specific muscle groups[1] and may pose a lesser risk of injury because of the reduced level of skill and technique involved.[4] However, multi-joint exercises (e.g. power clean, squats, deadlifts) are more neurally demanding[3] and generally regarded as most effective for increasing overall muscular strength because they enable a greater weight to be lifted.[4] The literature indicate that both single- and multiple-joint exercises are effective for increasing muscular strength and hypertrophy,[13,16,17] therefore, both should be incorporated into the resistance training programme design.

Exercise order refers to a sequence of resistance exercises performed during one training session.[31] Traditionally, exercises involving large muscle mass (multi-joint) are performed first, followed by exercises involving small muscle mass (single-joint).[1] The rationale behind this exercise order is that large muscle mass exercises performed in the beginning of the workout are more intense and require higher total energy expenditure than small muscle mass exercises.[37] Furthermore, exercising larger muscle groups first has been theorised to provide a greater training stimulus to all the muscles involved in an exercise,[33,38] which may offer greater potential for tissue remodelling.

Sforzo and Touey[38] examined the effect on muscular performance of manipulating exercise order in weight-trained men. The order of exercises progressed from large muscle mass (structural) to small muscle mass (body-part) exercises (i.e. squat, leg extension, leg flexion, bench press, military press, tricep pushdown) and vice versa (tricep pushdown, military press, bench press, leg flexion, leg extension, squat). Significant main effects indicated that the squat and tricep pushdown were significantly better when executed first in the workout. Completing squats or tricep pushdowns at the beginning produced 25% greater total force over four sets compared with doing them later in the workout. Additionally, when the exercise order went from body-part to structural, a 61% decline in cumulative bench press total force production across four sets was recorded, when compared with structural to body-part. These findings indicate that executing large muscle mass exercises prior to small muscle mass exercises maximises the total resistance lifted during the exercise bout.

The relevance of these findings is the contention that recruitment of a greater number of muscle fibres, due to increased total resistance lifted, may enhance hormone-tissue interaction with a larger percentage of the total muscle mass. Performing large muscle mass, multi-joint exercises early in the workout has been shown to produce significant elevations in anabolic hormones.[39,40] Kraemer and Ratamess[41] propose that such a response may potentially expose smaller muscles to a greater response than that resulting from performing small muscle mass exercises only.

2.4 Rest Periods

The time dedicated to recovery between sets and exercises is termed the rest period.[31] The length of the rest period is dependent on the training goal, the relative load lifted, and the training status of the individual. However, Fleck and Kraemer[2] point out that this variable is often overlooked in resistance exercise prescription. The rest period is a primary determinant of the overall intensity,[11] as rest period length is strongly related to the load lifted.[31] Moreover, it affects metabolic and hormonal demands,[42] as well as performance of subsequent sets.[43] The rest period length not only determines how much of the adenosine triphosphate (ATP)-phosphocreatine (PCr) energy source is recovered[3] but also how high lactate concentrations increase in the blood.[44,45] Both ATP and PCr resynthesis should be complete in 3–5 minutes.[3,46]

Kraemer and co-workers[42] examined the influence of rest period length on blood lactate, hormone concentrations, and metabolic responses to an acute bout of resistance exercise in young men and women. They used two distinctly different complete-body heavy-resistance exercise routines: protocol 1 (P-1) consisted of 5RM loads with 3-minute rest periods, while protocol 2 (P-2) was a 10RM-based workout with 1-minute rest periods. Whereas both protocols develop strength, P-2 is typical of that used by bodybuilders for increases in muscular hypertrophy.[44] P-2 (10RM; 1-minute rest periods) proved to be more demanding, with significantly greater total work (J) and blood lactate concentrations. Additionally, the more anaerobic P-2 routine produced a clear and sustained increase in the anabolic hormones (testosterone and GH). The authors concluded that the combined effects of a higher volume, shorter rest periods and moderate intensity provide a more favourable hormonal milieu for promoting skeletal muscle growth.[42]

Therefore, when prescribing rest periods, if the resistance exercise programme is designed for power then 5–8 minutes is necessary, while 3–5 minutes is required for maximal strength.[25,47] If the programme is designed for muscular hypertrophy, shorter rest periods of 1–2 minutes are prescribed.[25,42] Finally, if the goal is muscular endurance, rest periods of 30–60 seconds are used.[2,25]

2.5 Repetition Velocity

Interestingly, few studies have investigated the effects of different velocities utilising isotonic equipment, with the majority of literature citing isokinetic protocols. However, in the context of this article, the practical application of isotonic training is most pertinent as this is the most commonly available form of resistance exercise.[48] MacDougall[18] states that the magnitude of the hypertrophy response depends not only on the intensity of exercise but also on the length of time that the muscle is under tension. Therefore, the recommended ‘gold standard’ for repetition velocity as outlined by Westcott et al.[49] is a 2 : 1 : 4 cadence (2 sec CON; 1 sec pause; 4 sec ECC). Theoretically, such a cadence should maximise muscle tension, and may result in greater strength and hypertrophic adaptations. This contention is supported, in part, by the findings of Keeler and colleagues[19] who report that performing one set of 8–12 repetitions at a slow velocity (2 sec CON; 4 sec ECC) compared with super slow velocity (10 sec CON; 5 sec ECC) resulted in significantly greater strength gains (39% vs 15%, respectively). Furthermore, moderate (2 sec CON; 2 sec ECC) and fast (1 sec CON; 1 sec ECC) velocities have been shown to maximise hormone response[20] and result in significantly greater metabolic cost (155 ± 28 kcal vs 107 ± 20 kcal) than super slow (10 sec CON; 4 sec ECC) protocols.[50] Generally, it is recommended that a slow repetition velocity (2 sec CON; 4 sec ECC) be used for novice and intermediate trainers.[4] For advanced trainers the inclusion of a velocity continuum from slow to fast may maximise strength and power gains at a specific velocity; however, the use of faster velocities may increase the probability of injury to the musculoskeletal system.[49]

2.6 Frequency

Training frequency refers to the number of training sessions completed in a given time period (i.e. 1 week),[31] and is a function of the type of training session, the training status and recovery ability of the individual.[33] The rest period between sessions must be sufficient to allow for muscular recuperation and development while alleviating the potential for overtraining.[1] Numerous resistance training studies have used frequencies of 2–3 days/week in previously untrained individuals.[14,17,29,35,51,52] This frequency is suggested to be an effective initial frequency,[4] whereas, 1–2 days/week appears to be an effective maintenance frequency for novice trainers.[30] Empirically, it has been observed that competitive lifters use a training frequency of 5–7 days/week in order to maximise muscle size and strength gains.[44]

It is the view of Feigenbaum and Pollock[10] that a 2 days/week training frequency allows more time for recuperation, is less time consuming and therefore may enhance adherence. Furthermore, 2 days/week programmes appear to produce 80–90% of the strength gains of more frequent programmes in untrained individuals.[10,51,52] Additionally, Carroll et al.[52] reported that when resistance training was equated for both time and number of sessions, 2 days/week resulted in a significant increase in the proportion of myosin heavy chain IIa compared with 3 days/week. Collectively, the above studies imply that training frequencies of 2 days/week are effective in promoting muscular adaptations in novice trainers.

Most recently, Rhea and co-workers[36] determined the dose response for strength development, reporting that untrained individuals see a consistent dose response as the training frequency increases up to 3 days/week. For trained individuals, 2 days/week (per muscle group) elicited the greatest strength increases. The strength increases accompanying the lower training frequency for trained individuals may be a result of higher training volumes. Therefore, it is recommended that untrained individuals perform a complete-body protocol 2–3 days/week. As training status increases, changes in frequency to 3–4 days/week may accompany changes in programme design (i.e. upper/lower-body split), with training frequencies of 4–6 days/week suggested for advanced trainers.[4]

3. Skeletal Muscle Adaptations to Resistance Training

Skeletal muscle is a highly plastic tissue that readily adapts to changes in loading state. Increasing the load imposed on skeletal muscle elicits adaptations that result in increased muscle size and changes in contractile characteristics.[53] The fact that resistance training and other forms of mechanical loading cause an increase in muscle size is well established.[17,54-56] In theory, an increase in muscle size could occur as a result of an increase in fibre size,[17] an increase in fibre number,[55] and/or an increase in the amount of connective tissue in the muscle,[18] all of which are adaptations that contribute to the enhancements in strength observed during resistance training.

Ultimately, it appears that three processes are implicated with the hypertrophic response of skeletal muscle to resistance exercise. The first is the anabolic process necessary for the accretion of protein to support fibre enlargement.[57,58] The second process involves the proliferation of satellite cells, which may provide additional myonuclei to the enlarging fibres.[55] The third process termed an ‘anti-catabolic effect’ may be achieved by a reduction in cortisol-induced protein degradation.[17] Pharmacological doses of glucocorticoids result in increased 3-methylhistidine (3-MHIS) excretion, suggesting that proteolysis in skeletal muscle is increased,[59] as 3-MHIS is assumed to be an index of contractile protein degradation.[60] Conversely, attenuation of the cortisol response favours the conservation of myofibrillar protein, resulting in enhanced skeletal muscle growth.[17] The hormonal interaction mediating the subsequent changes in the structural and functional properties of skeletal muscle fibres provide the basis for the anabolic and anti-catabolic processes.

3.1 Muscle Fibre Size

One of the most commonly studied adaptations to resistance training is the increase in fibre CSA, or hypertrophy. It is well established that resistance training promotes hypertrophy among each of the three major fibre types in humans (type I, IIa and IIb) as identified by Brooke and Kaiser.[61] Numerous resistance training studies report that type IIa fibres display the greatest growth, followed by type IIb, with type I fibres typically exhibiting the least amount of hypertrophy.[17,29,56,58,62-64] In general, type I fibres depend on a reduction in protein degradation, whereas type II fibres depend on an increase in protein synthesis, thus resulting in an absolute increase in fibre CSA.[64]

Moreover, the percentage increase in hypertrophy in response to resistance training is similar for men and women,[15,65,66] although absolute increase in fibre CSA tends to be greater in men.[65] In untrained individuals, increases in fibre CSA are 10–31% in type I fibres[29,62] and 20–45% in type II fibres.[29,67] It is suggested that the increased hypertrophy of the type II fibres may reflect greater relative involvement during maximal or near-maximal contractions (as with heavy-resistance exercise) of these high-threshold units than would normally occur with activities of daily living.[68]

With chronic (12–26 weeks) resistance training, increases in fibre CSA are the result of increased myofibrillar area, with little or no change in the myofibrillar packing density. Myosin and actin filaments are added to the periphery of each myofibril, thus creating larger myofibrils without altering filament packing density or cross-bridge spacing.[18] However, the magnitude of this hypertrophic response varies considerably and is dependant upon a number of factors, including the individual's responsiveness to training, the intensity and duration of the training programme, and the training status of the individual prior to commencement of the programme.[69]

3.2 Muscle Fibre Type Conversion

Resistance training produces a shift in the myosin adenosine triphosphatase (mATPase) fibre type profile and the myosin heavy chain composition.[29,52,68,70] It is apparent that resistance training results in transitions within the type II subtypes, with an increase in the percentage of type IIa fibres and a proportional decrease in the percentage of type IIb fibres.[17,63,67] However, no convincing evidence has been found for detectable shifts between type I and type II fibres.[70]

A series of studies by Staron et al.[63,67,71] examined skeletal muscle adaptations following heavy-resistance training in men and women. Following 20 weeks of heavy-resistance training in untrained women, Staron et al.[67] reported a significant decrease in type IIb fibres (16.2% pre-training vs 2.7% post-training), with a concomitant increase in type IIa fibres (32.5% vs 39.3%). Staron and colleagues[71] reported similar findings while investigating the effects of a much shorter training period (6 weeks). In support of their previous works, a significant decrease in the percentage of type IIb fibres had occurred (24.9% pre-training vs 6.7% post-training).

To determine the time-course for specific muscular adaptations during the early phase of resistance training, Staron et al.[63] extracted muscle biopsies at the beginning and every 2 weeks during 8 weeks of resistance training in untrained men and women. A significant decrease in percentage of type IIb fibres was observed in women after just 2 weeks (four total workouts) and in men after 4 weeks (eight total workouts). Over the 8-week training period the type IIb fibre types decreased from 21.4% to 7.9%, and total fibre content decreased 20.7% to 9.5%. The authors concluded that the time-course for the alteration of the phenotypic expression of specific contractile proteins appears to be an adjustment that can occur after only a few workouts.

Interestingly, Andersen and Aagaard[70] reported that 90 days of detraining following 90 days of heavy-resistance training in untrained men evoked an overshoot in the amount of type IIb (IIx) fibres to values significantly higher than those observed both pre- and post-training (18.8% vs 10.2% vs 4.1%, respectively). This corresponded with a significant decrease in type IIa percentage. The authors postulated that this overshoot or 'boosting' phenomenon arises from the abrupt withdrawal of the stimulus from the muscle.

Taken together, these data lend support to the contention that transition between fibre subtypes (IIa ↔ IIb) might follow energy requirements[72] and this may represent a positive strength adaptation.[52] According to Bottinelli and colleagues,[72] type IIb fibres display the highest tension cost, while fibre types IId(x) and IIa are intermediate, and type I fibres are the lowest. Therefore, imbalance between energy requirement and energy supply may represent an important signal triggering an appropriate adjustment in fibre type expression[73] and may present a possible mechanism underlying the transition between fibre subtypes.

3.3 Muscular Strength

Strength development involves the coordinated functioning of several processes,[9] with the ability to produce maximal force attributed to both neural and muscular components.[74] Several studies have shown that 6–21 weeks of resistance training produces significant increases in maximal dynamic strength.[15,17,26,29,52,66] Collectively, these studies highlight that the early increases in strength are associated mainly with neural adaptations, while hypertrophic responses begin to occur at the latter stages of training.

Additionally, it is well established that muscular strength is proportional to fibre CSA.[75-77] However, not all resistance training studies have shown increases in muscular strength with significant changes in fibre CSA.[8,63] This supports the theory that neural adaptations are the predominant mechanism for increases in muscular strength in the early phases (first 6–8 weeks) of resistance training.[9,74] In the later phases (12–26 weeks), the gradual increase in the size of the myofibrils (hypertrophy), and perhaps greater fast fibre type conversions (IIa

↔ IIb), contribute to the strength gains associated with longer term resistance training.[52,63]

Although men are typically stronger than women,[78] both sexes respond to resistance training in a similar fashion.[65,66,79] Abe et al.[66] investigated the time-course of skeletal muscle adaptations resulting from 12 weeks of progressive heavy-resistance training (complete-body; 6 exercises; 4 sets × 8–12 repetitions at 60–70% 1RM; 3 days/week) in 50 untrained middle-aged men and women. 1RM knee extension (KE) and chest press (CP) exercises were measured at baseline and weeks 2, 4, 6, 8 and 12. Strength increased significantly at week 4 in the women, and at week 2 (KE) and at week 6 (CP) for the men. The mean relative increases in KE and CP strength were 19% and 19% for the men and 19% and 27% for the women, respectively. The authors concluded that the time-course and proportions of the increase in strength were similar for both the men and the women.

4. Conclusion

The popularity of resistance training has grown immensely over the past 25 years,[80] with extensive research demonstrating that not only is resistance training an effective method to improve neuromuscular function, it can also be equally effective in maintaining or improving one's health status.[1,3,10,80-82] Furthermore, resistance training is suggested to be beneficial in enhancing muscular fitness in the prevention and management of several pathological conditions.[83] As such, most professional and government health organisations now support the inclusion of resistance exercise in their recommendations.[4,83] Deschences and Kraemer[80] highlight that initial training and health status, along with the specific programme design, affect the magnitude of neuromuscular adaptations. Ultimately, it is the acute programme variables that determine the degree to which the neuromuscular, neuroendocrine and musculoskeletal systems adapt to both acute and chronic resistance exercise. Therefore, it is essential that those involved with the prescription of resistance training (i.e. strength coaches, rehabilitation specialists, exercise physiologists) acquire a fundamental understanding of the acute programme variables and the importance of their practical application in programme design.

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