BRIEF REVIEW

# Theoretical and Practical Aspects of Different Cluster Set Structures: A Systematic Review

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## Abstract

Tufano, JJ, Brown, LE, and Haff, GG. Theoretical and practical aspects of different cluster set structures: a systematic review. *J Strength Cond Res* 31(3): 848–867, 2017—When performing a set of successive repetitions, fatigue ensues and the quality of performance during subsequent repetitions contained in the set decreases. Oftentimes, this response may be beneficial because fatigue may stimulate the neuromuscular system to adapt, resulting in a super-compensatory response. However, there are instances in which accumulated fatigue may be detrimental to training or performance adaptations (i.e., power development). In these instances, the ability to recover and maintain repetition performance would be considered essential. By providing intermittent rest between individual repetitions or groups of repetitions within a set, an athlete is able to acutely alleviate fatigue, allowing performance to remain relatively constant throughout an exercise session. Within the scientific literature, a set that includes intermittent rest between individual repetitions or groups of repetitions within a set is defined as a cluster set. Recently, cluster sets (CS) have received more attention as researchers have begun to examine the acute and chronic responses to this relatively novel set structure. However, much of the rest period terminology within the literature lacks uniformity and many authors attempt to compare largely different protocols with the same terminology. Additionally, the present body of scientific literature has mainly focused on the effects of CS on power output, leaving the effects of CS on strength and hypertrophy relatively unexplored. Therefore, the purpose of this review was to further delineate cluster set terminology, describe the acute and chronic responses of CS, and explain the need for further investigation of the effects of CS.

**Key Words** rest-pause, periodization, rest intervals, intraset, interrepetition

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## Introduction

When designing a resistance training program, several factors such as the choice of exercise, training load, number of repetitions and sets performed, the exercise order, frequency, and length of designated rest periods must be considered to optimize the targeted training outcomes. Once all these program variables have been established, the strength and conditioning professional can effectively define and implement a training program. Ultimately, these decisions are made to construct a periodized resistance training program in accordance with the individual athlete's training goals. However, a largely overlooked and underused aspect of developing a resistance training program is the ability to alter the structure of individual sets (34). For example, the number of repetitions, training load, and rest periods contained within a set can be manipulated to alter the training stimulus. When conceptualizing a set, 2 types of general set structures can be used: traditional sets (TS) and cluster sets (CS) (34). To effectively use both types of set structure, the strength and conditioning professional must understand the fundamentals that underpin each type.

### Traditional Sets

Traditionally, the completion of a set occurs without any rest being taken between repetitions that are contained within the set. Once the set is completed, a predetermined rest interval is provided to allow recovery before the initiation of a subsequent set, and this basic set configuration is repeated for the targeted number of sets prescribed in the training session. This traditional method of resistance training set prescription can be described as training using TS.

Regardless of set structure, the manner in which repetitions are performed can largely affect the resultant training adaptations stimulated by a resistance training program. For example, strength and conditioning professionals often instruct athletes to perform concentric muscle actions as quickly as possible because explosive concentric muscle actions result in enhanced recruitment of type II muscle fibers (77) and result in greater training effects compared with intentionally slower concentric muscle actions (41,77). Unfortunately, fatigue can quickly manifest itself when repeatedly performing explosive movements under externally loaded conditions using TS training structures (21,33,37,44,45,82,89).

One of the most widely accepted causes of muscular fatigue is the reduced availability of phosphocreatine (PCr) and rate of adenosine triphosphate (ATP) resynthesis within the working muscles (8–10). Sahlin and Ren (81) showed that after a sustained fatiguing isometric muscle action, maximal force production during a subsequent isometric action can be met, but the subsequent force endurance capacity is decreased, credited to an inability to continually regenerate ATP. Building on this idea, the classic works of Bogdanis et al. (8–10) indicate that ATP and PCr stores are significantly reduced after an initial cycle sprint of 10–30 seconds and do not fully recover after 90–240 seconds of recovery (i.e., similar work-to-rest ratios of many common resistance training programs), indicated by a decrease in power output during a subsequent cycle sprint. More recently, the work of Gorostiaga et al. (29–31) has confirmed that when performing the leg press exercise at maximal effort, the accumulation of metabolic byproducts and decreased energy availability are accompanied with decreases in power output. The decrease in power output noted in these studies is the basis of the hypothesis that impairments in high velocity movements may occur when TS are chronically used without sufficient replenishment of ATP and PCr within the active muscles, especially when high volumes of work are completed (7,32,34).

Although a fatigue-induced decrease in movement velocity reduces power output (33,35,39,82) especially as the number of repetitions performed in the set increases (29–31,48), such fatigue may be useful in inducing hypertrophic responses or strength gains because a decrease in concentric velocity results in an increase in the overall time under tension (TUT) (13,67,90) and increased myoelectrical activity toward the end of a set (50,93,95), both of which have been suggested to be prerequisites for the development of strength (2,3,23). Additionally, when fatigue ensues and the energy availability from the ATP-PCr energy pathways becomes reduced, an increase in glycolytic dependence results in an accumulation of metabolites within the muscle, decreasing the pH level and subsequently, decreasing performance (9,10,29–31,72). Although an increase in metabolites such as lactate is associated with a decrease in acute performance (3,45), some researchers have explained that resistance training using TS encourages neuromuscular fatigue, which may be warranted for long-term strength development (2,3,54).

Considering the relationship between metabolites and hormonal responses to fatigue and resistance training, TS structures seem to be ideal for promoting skeletal muscle hypertrophy (23,60,64). For these reasons, the recommendations for hypertrophic development set forth by the American College of Sports Medicine (1) and the National Strength and Conditioning Association (6) favor shorter rest periods between TS to promote muscle growth. In line with these recommendations, resistance training using TS has resulted in skeletal muscle hypertrophy, especially in high-volume programs (13,16,42). Based on this reasoning, some strength and conditioning professionals suggest that the intentional use of slow movement velocities increases the TUT and thus may positively impact hypertrophic responses and strength gains. However, critical analysis of the scientific literature reveals that there is a paucity of conclusive data to support this claim and that the opposite may be true (28,78,83) because recent research has revealed that faster concentric movement velocities have the potential to stimulate greater gains in strength and hypertrophy compared with slower concentric movements (41,70).

To support this contention, Hatfield et al. (41) indicated that intentionally slow movement velocities performed with TS result in fewer repetitions being performed, lower peak force production, reduced peak power output, and less total training volume when compared with the same exercise performed at quicker movement velocities. Continuing on the cross-sectional work of Hatfield et al. (41), Gonzalez-Badillo et al. (28) found that performing the bench press exercise at maximal intended concentric velocities for 6 weeks resulted in greater strength gains when compared with performing the bench press with intentionally slower velocities. Similarly, Padulo et al. (77) reported that maximal velocity bench press training (80–100% maximal attainable velocity using 85% 1 repetition maximum [1RM]) resulted in greater strength gains and greater peak velocity at maximal loads when compared with self-selected velocities after 3 weeks of training. Ultimately, these authors (28,77) concluded that lifting a load at maximal concentric velocities may be more important than intentionally slow movements that aim to induce maximal strength gains by increasing TUT.

To determine the influence of maximal velocity resistance training on athletic performance, Pareja-Blanco et al. (78) investigated the effects of 6 weeks of maximal concentric velocity vs. half-maximal concentric velocity back squat training using TS on sprinting and jumping movements. Ultimately, the authors determined that maximal velocity resistance training may be more beneficial for improving powerful athletic movements, such as sprinting and jumping, when compared with slower velocity training with equivalent loads (78). Additionally, the authors specifically stated that a fast concentric movement velocity seemed to be of greater importance than increasing TUT when aiming to develop maximal strength.

Collectively, these studies (28,41,77,78) shed light on the importance of training at maximal concentric velocities to maximize strength, power output, and performance gains. Therefore, it may be warranted to implement strategies that limit the typical fatigue-induced reductions in movement velocity seen during TS.

One potential strategy for offsetting the fatigue-induced performance decrements associated with TS could be the use of CS (33). Based on the work of Gorostiaga et al. (29–31), using CS structures to provide more frequent rest periods should result in enhanced recovery via a greater maintenance of PCr stores and increased metabolite clearance compared with TS training (19,27,75). By using CS structures, there may be an increase in substrate availability (i.e., PCr and ATP) that could result in the maintenance of movement velocity throughout an entire set and, ultimately, an entire training session.

#### Cluster Sets

Set structures inclusive of normal interset rest periods accompanied by preplanned rest intervals within a set are referred to as CS structures (11,33,37–39,91). Conceptually, the addition of short rest periods within a set while maintaining normal rest periods between sets may offer a methodology for maximizing individual repetition performance while reducing accumulated fatigue seen during TS (27,32–35,39,91). However, because of the wide range of protocols using the CS terminology (further discussed in the "Set Structure Terminology" section of this article), CS have simply become a set structure in which rest periods are more frequent than TS.

Previous research has indicated that force production remains relatively constant throughout TS and CS (19,35,68,91), but the movement velocity and power output across multiple sets seems to decrease to a greater extent during TS when compared with CS (33,37,39,91). Therefore, it has been hypothesized that a greater training stimulus for power development may be generated in response to the increased movement velocity noted in several studies comparing CS with TS (33,34,38,39,45,76). Fundamentally, training with CS in a "recovered" state may be more beneficial than TS for movements that require large amounts of muscular power output at high velocities (7,32,34).

As previously mentioned, fatigue is oftentimes thought to be of paramount importance for the development of muscular strength (42,55). However, it has been observed that training to maximal fatigue (i.e., training to failure) is not a prerequisite for the development of maximal strength (20,24), and resistance training at maximal velocities may be more effective at developing strength when compared with slower training velocities (28,41). Because velocity is better maintained using CS than TS, CS structures may play a role in enhancing maximal strength (46,74). Additionally, CS allow for a greater number of repetitions to be performed with a given load (19,44), resulting in a greater volume load, which may also result in a greater stimulus for the development of maximal strength (55,79,87).

Finally, research investigating the hypertrophic effects of CS is scant, but evidence supports the idea of using CS to develop skeletal muscle growth. In particular, it has been shown that after 12 weeks of resistance training, CS resulted in similar gains in lean mass when compared with TS (74). Moreover, the use of CS seems to allow for a greater number of repetitions to be performed when compared with TS (19,44), which may ultimately lead to an increase in the amount of total work (i.e., volume load), providing a stimulus for increasing muscle hypertrophy (56,61,87). Alternatively, if the number of repetitions is kept constant, CS may allow for the use of greater training intensities, which may also increase the hypertrophic stimulus (25,101). Therefore, the overall volume load may be increased when using CS compared with TS, possibly resulting in a greater stimulus for skeletal muscle hypertrophy (25,42,65,87,97).

Although TS have been the longstanding set structure for resistance training programs, the alteration of TS to CS provides a different training stimulus that may benefit certain training goals. Even though there is a growing body of literature that explores the use of CS structures, the current definitions of CS are inconsistent and the applications of CS in a training environment remain inadequate. Therefore, the purposes of this review were to (a) define the CS terminology, (b) describe the acute and chronic responses to CS, and (c) explain the need for further investigation of the effects of CS on strength and hypertrophy.

## Defining Rest Periods

Before discussing the CS literature in detail, it is important to understand the rest period terminology that is used to describe set structures within the scientific literature. Defining rest periods using prefixes such as intra-(within) and inter-(between) describes the location of the rest interval in relation to the remainder of the set.

#### Interset Rest

It would be most appropriate to describe the rest interval between sets (i.e., multiple repetitions performed in sequence) as the "interset" rest period. Often, interset rest periods are established as part of the training program to facilitate recovery between sets and target-specific training adaptations (98–100). For instance, when attempting to achieve maximal strength gains, it is recommended that an interset rest interval of 2–3 minutes is used (18). To provide an example, an athlete aiming to increase maximal strength could perform 2 sets of 4 repetitions with 120 seconds of interset rest allocated between each set (Figure 1A).

#### Intraset Rest

The term "intraset" would be most appropriate when describing rest periods between groups of repetitions within CS structures. For example, if 2 sets of 4 repetitions are prescribed using clusters of 2 repetitions, each cluster of 2 could be separated by a short intraset rest interval of 15 seconds with 120 seconds of interset rest (Figure 1B). Although the number of repetitions within each cluster and the intraset rest times can largely vary, Figure 1B shows that intraset rest

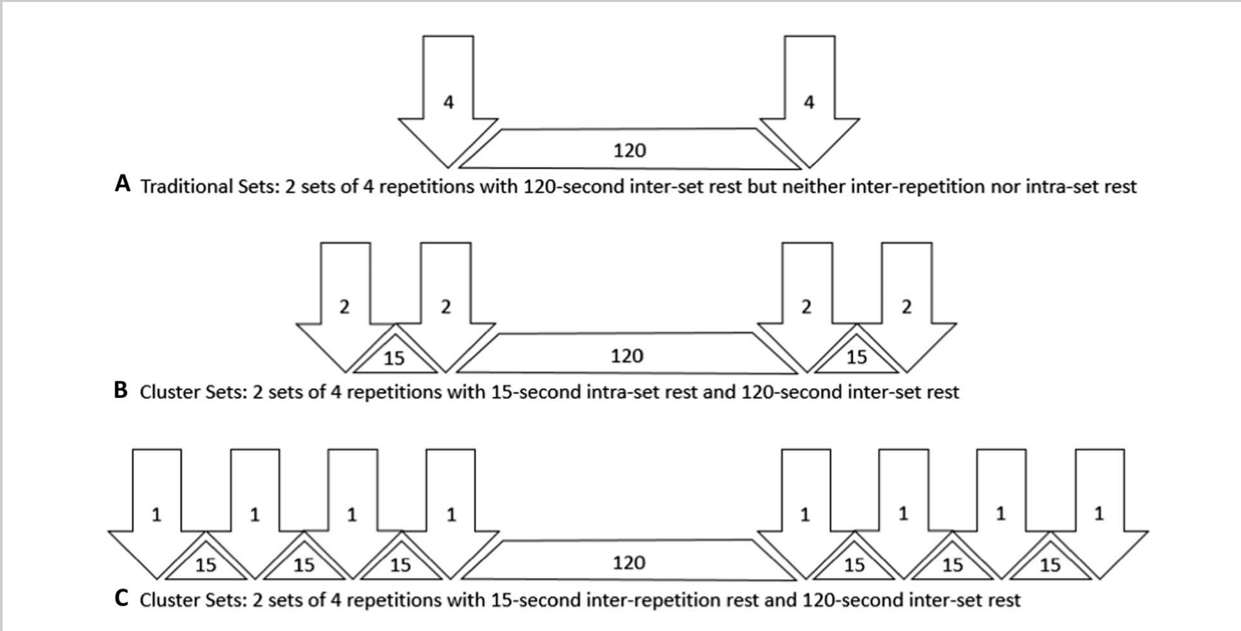


**Figure 1.** Two sets of 4 repetitions with 120 seconds of interset rest using 3 different set configurations. Arrows indicate number of repetitions performed in sequence, triangles indicate intraset or interrepetition rest periods, and quadrilateral shapes indicate interset rest periods. (A) Traditional sets with neither intraset nor interrepetition rest. (B) Cluster sets doubles with intraset rest periods. (C) Cluster sets singles with interrepetition rest periods.

intervals apply to rest periods that occur within a set but not between sets and not between individual repetitions.

#### Interrepetition Rest

Rest periods that occur between individual repetitions of a set could be best described as "interrepetition" rest periods (Figure 1C). Based on this line of reasoning, it could be advised that the use of the interrepetition rest (IRR) terminology should be limited to rest intervals that are applied only between individual repetitions within a single set but not groups of repetitions within a set (i.e., clusters) or sets of single repetitions (i.e., TS). For example, if IRR is prescribed for 2 sets of 4 repetitions, each repetition within each set of 4 could be separated by a short 15-second IRR interval in addition to 120 seconds of interset rest (Figure 1C). To conclude, the term intrarepetition should never be used because it is impossible to rest within a single repetition.

### Set Structure Terminology

Since the emergence of sport science, there has been a need for standardized terminology (53). In a field where scientists and practitioners work side-by-side, it becomes increasingly important for coaches to understand the jargon used in exercise science in addition to the scientists understanding the nomenclature used in practice. In today's world, the Internet increases the availability of information, allowing for rapid dissemination of ideas and the inability to regulate the communicative process.

At times, a minor tweak to a simple concept opens the door for various interpretations and other amendments. Consistency of terminology can help eliminate confusion between professionals or between disciplines. For example, even simple barbell exercises such as the squat and bench press leave room for interpretation that can sometimes be misconstrued (49,73). Numerous attempts have been made to standardize the nomenclature used in sport science (40,49,52,53,57,73) and the need still exists because concepts are continuously being compared and contrasted. For this article, understanding set structure terminology is of great importance.

Specifically, the use of the umbrella term "cluster set" has evolved to include many different types of set structures that simply describe a manner in which repetitions are performed which diverges from the TS structure. Although Byrd et al. (17), Rooney et al. (80), and Keogh et al. (51) used protocols inclusive of various IRR periods, the first use of the term "cluster set" in the scientific literature, to our knowledge, was used in 2003 (33). That article created a CS by breaking a single TS of 5 repetitions into a single CS of 5 repetitions with short IRR periods. However, they did not mention any terminology for performing a CS over multiple sets, leaving interset rest periods unmentioned and open for interpretation. As a result, the term "cluster set" has evolved to include many different types of protocols that do not necessarily follow a TS structure.

In theory and practice, there are 2 main things that can happen to the interset rest when using CS structures. The interset rest periods can remain unchanged, resulting in greater total rest times within the protocol, or the intraset rest/IRR can be subtracted from the interset rest to result in the same total rest time within the protocol. Careful examination of the scientific and non–peer-reviewed literature reveals that there is a great deal of disconnect when defining "cluster set" terminology since 2003.

Some authors have created CS structures by equalizing the work-to-rest ratio (35,44,63), dividing interset rest periods into shorter but more frequent intraset rest periods (19,36,50,58,59,69,74,102), or using the rest-pause method (51,62). Therefore, it is important to examine the different methods of altering a set structure and how these relate to each other. Ultimately, the purpose of the nomenclature set forth in this article is to illuminate fundamental differences between protocols that use different forms of CS and to create more appropriate subclassifications of CS. If adopted, these subclasses will allow researchers and practitioners to compare and contrast various set structure designs with more accuracy and less confusion.

#### Basic Cluster Sets

Training using the basic CS in which the interset rest periods remain unchanged requires a longer training duration to achieve a desired number of repetitions when compared with a TS structure because the intraset rest or IRR periods are added to the total rest time (Figure 2B) (4,11,26,33,37–39,47,68,71,80,91,92). For example, Verkoshansky and Siff (94) explained that "extensive cluster training" involves 4–6 repetitions with one's 4–6RM, with 10 seconds of IRR and 1–3 minutes of interset rest. By maintaining the interset rest interval, recovery between sets is facilitated as normal, but now with the addition of partial recovery within each set, the quality of repetitions within each set may be elevated across all sets performed. To simplify, a basic CS structure is essentially a TS with additional short rest periods of typically 15–45 seconds inserted within each set (34). Although it is possible to add short IRR periods of 1 to 4 seconds (4,17), the majority of basic CS structures include a minimum of about 10–15 seconds of IRR or intraset rest.

An example of basic CS structures is present in the work of Hardee et al. (37–39), where 3 sets of 6 power cleans using TS with 3 minutes of interset rest were compared with 2 different basic CS structures in which the interset rest intervals remained constant at 3 minutes. The 2 basic CS structures differed to the TS structure by adding either 20 or 40 seconds of IRR within each set. Additionally, Tufano et al. (91) used basic CS structures by comparing 3 sets of 12 with 2 minutes of interset rest with 3 sets of 12 with 30 seconds of intraset rest without adjusting the 2-minute interset rest periods. In this manner, each basic CS protocol included a greater amount of total rest time when compared with the TS protocol.

#### Interset Rest Redistribution

One type of CS subclass is created when the redistribution of interset rest intervals occurs (5,19,27,36,50,58,69,74–76,102). In these scenarios, long interset rest intervals are often divided in to shorter but more frequent interset rest intervals, keeping the total rest time equal (Figure 2D). For example, Oliver et al. (74) compared 4 sets of 10 with 2 minutes of interset rest with 8 sets of 5 with 1 minute of interset rest. In this manner, each set of 10 was split in to 2 sets of 5 and each 2-minute interset rest period was reduced to 1 minute. Fundamentally, each set of 10 repetitions was split into smaller but more frequent sets of 5, keeping the total rest period between groups the same. Similarly, Moreno et al. (69) used 3 jump squat protocols in which each prescribed set and repetition scheme contained equal total rest. Specifically, the set structures were broken into 2 sets of 10, 4 sets of 5, and 10 sets of 2, with 90, 30, and 10 seconds of interset rest, respectively. Later, Oliver et al. (76) compared 4 sets of 10 with 2 minutes of interset rest with 4 sets of 10 with 90 seconds of interset rest and 30 seconds of intraset rest. In all these cases, the investigators increased the frequency but decreased the duration of rest periods while keeping the total rest time equal between sets.

Specific terminology such as "rest redistribution" (RR) could be adapted for CS structures that equate and rearrange rest periods instead of adding additional rest periods as basic CS structures do. Therefore, an RR protocol differs from a basic CS design in that the interset rest periods during RR are shortened, the time subtracted from the interset rest is redistributed within the protocol, and extra rest is not provided.

#### Equal Work-to-Rest Ratio

Some studies have equated the work-to-rest ratio (EW:R) for the entire exercise session and described it as CS training (35,43–46,59,63). In these cases, the protocols cannot be randomized because the TS serves as the "standard" from which the work-to-rest ratio is calculated (Figure 2C). For example, the protocols of Iglesias-Soler et al. (44) included the following 2 protocols: (a) 3 sets of TS to failure (4, 4, and 3 repetitions per set for example; 11 total repetitions) with 3 minutes of interset rest for a total of 360-second rest and (b) repetitions to failure with 36 seconds of IRR to ensure an equal work-to-rest ratio for the first 11 repetitions in this example (360 seconds divided by 10 rest periods). It is important to note that these ratios will mostly be subject dependent and that subjects may be able to complete far more repetitions in the equal work-to-rest ratio protocol (i.e., 11 repetitions during TS vs. 45 during the equal work-to-rest protocol (44)). In this manner, these CS structures may be most accurately described as EW:R protocols in which the total number of repetitions was not controlled and the total number of repetitions performed could vary between subjects. Practically, an EW:R protocol of this nature (i.e., performed to failure) could take up to 20 minutes if 30 seconds of IRR was to be provided for 40 repetitions.

Hansen et al. (35) also used EW:R set structures but kept the number of repetitions in each protocol constant. Unlike

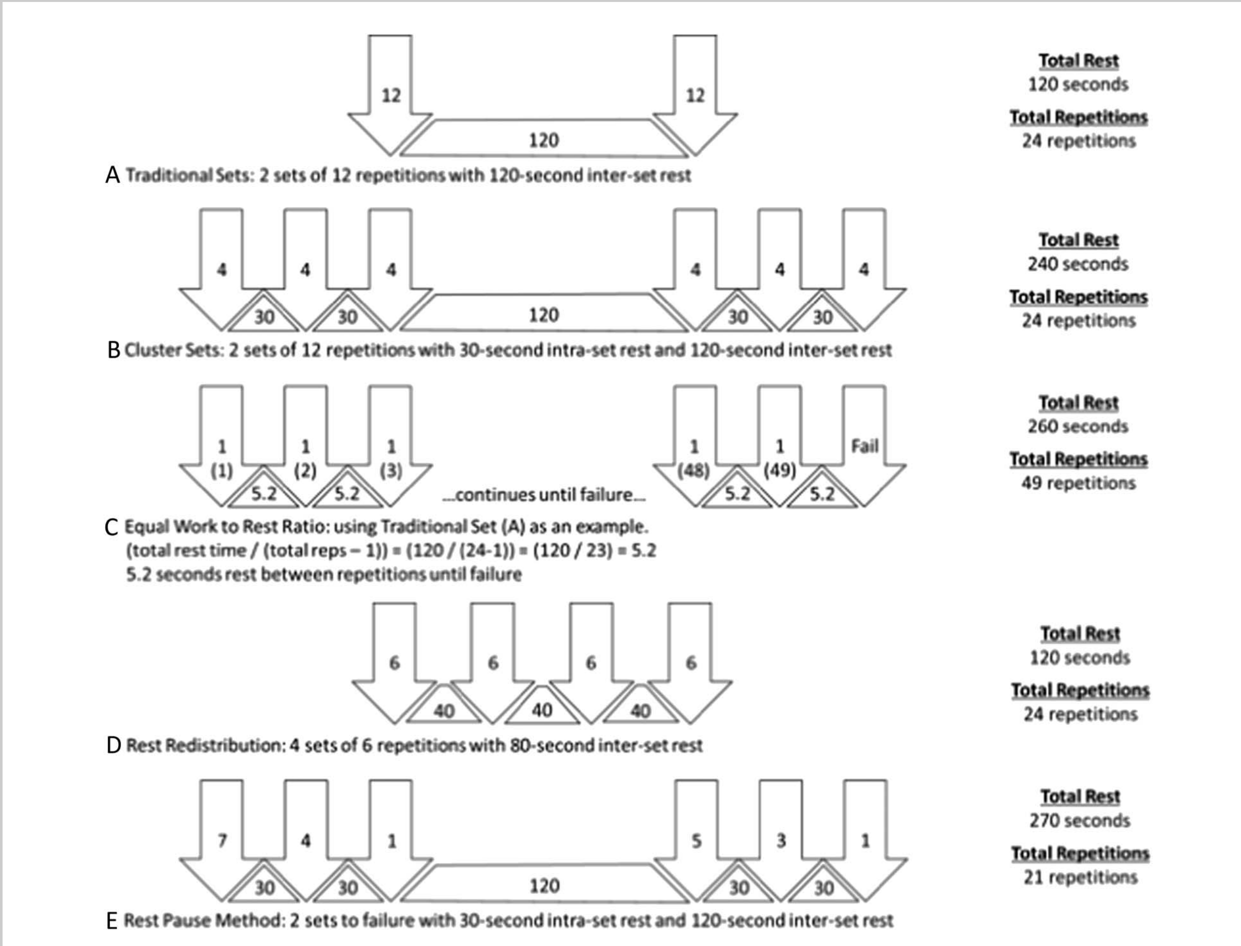


**Figure 2.** Schematic differences between various set structures. Arrows indicate number of repetitions performed in sequence, triangles indicate intraset or interrepetition rest periods, and quadrilateral shapes indicate interset rest periods. Although not identical, the following studies have used set structures that can be represented by the conceptual ideas presented in (B) (4,11,26,33,37–39,47,68,71,80,91,92), (C) (35,43–46,59,63), (D) (5,19,27,36,50,58,69,74–76,102), and (E) (4,17,51,62), whereas (A) represents a traditional set structure that is commonly used as a control, or reference, set structure. Please note, protocols (C) and (E) do not have to be performed to failure as shown in this diagram, but some studies adopt such designs.

Iglesias-Soler et al. (44), subjects in this study (35) always performed the same number of repetitions using the following 4 protocols with a work-to-rest ratio of 15 seconds of work to 3 minutes of rest: 4 sets of 6 with 3 minutes of interset rest; 4 sets of 6 with 12 seconds of IRR and 2 minutes of interset rest; 4 sets of 6 with 30 seconds of intraset rest after every 2 repetitions and 2 minutes of interset rest; and 4 sets of 6 with 60 seconds of intraset rest after every 3 repetitions and 2 minutes of interset rest. In this case, the same number of repetitions was used in each protocol, but no additional rest periods were supplied, and the work-to-rest ratio remained constant.

At first glance, RR and EW:R protocols seem to be similar because they both take the total rest time and divide it by a certain number of repetitions. However, RR protocols only take the rest time into consideration, whereas EW:R protocols take the time spent lifting the load into consideration as well. By specifically using the EW:R terminology, researchers and practitioners can understand that the total amount of rest is divided by the number of repetitions performed per unit of time, allowing a seemingly countless number of set manipulation variations that can be used to target various training goals.

#### Rest-Pause Method

Another method of varying a set structure is what can be termed as the "rest-pause" method (Figure 2E) (4,17,23,51,62). Verkoshansky and Siff (94) define "intensive cluster training" as a method of performing single repetitions of an exercise with short rest periods between each repetition for 4 to 6 repetitions, allowing a near-maximal load to be lifted multiple times: a method which has alternatively been described as the rest-pause method (12,23). Other definitions of the rest-pause method include performing a single set of an exercise with short rest intervals of increasing duration between every couple of repetitions, hoping to increase total volume load (96); an initial set to failure with subsequent sets to failure performed with 20 seconds of interset rest (62); and 1–4 seconds of unloaded rest between repetitions within an otherwise TS (4,17,51). Although the rest-pause method has not been described as CS in the scientific peer-reviewed literature, many text books (as described above) and online training blogs synonymously refer to the rest-pause method as a CS structure, making it important to discuss in this article.

Careful inspection of this method reveals that its application is different from the previously mentioned basic CS, EW:R, and RR subclassifications. Specifically, the aforementioned definitions of the rest-pause method describe a method in which training to failure often occurs, then a short rest period is applied to encourage recovery, allowing for additional repetitions to be completed until volitional failure or a predetermined number of repetitions are completed (23,62). When compared with a basic CS, EW:R, or RR protocol, the rest-pause method does not allow for ad hoc programming of repetitions or rest periods because of the rest-pause method's general reliance on training to failure, creating variable sequences of repetitions that change based on the athlete's daily fatigue level. In contrast, other subclasses of CS can allow for a consistent set structure across training days, facilitating the periodization process. Although the rest-pause method is similar to the other subclassifications of CS training in that short rest intervals are included, its lack of a constantly defined structure highlights its uniqueness among the CS subclasses.

### Summary of Different Set Structures

The ability to infinitely manipulate training variables, such as the number of repetitions, sets, and rest periods, make exercise prescription difficult to describe without providing extremely detailed information. Because of this, specific terminology may help describe subtle differences between types of set structures that otherwise may be difficult to differentiate. After elucidating the differences between the basic CS, RR, EW:R, and the rest-pause method, it may be recommended that they should not all be classified under a single CS description. Nonetheless, the investigation of basic CS, RR, EW:R, and the rest-pause method provide valuable insight regarding the effects of rest periods and intraworkout training density on acute and chronic adaptations to resistance training. A simplified visual representation of TS, basic CS, EW:R, RR, and the rest-pause method is presented in Figure 2. Additionally, references are provided for studies that fit into each subclassification. It is important to note that the referenced studies do not use the exact protocols listed in Figure 2, but the main idea of the set structures in each study generally agrees with the designated examples in Figure 2.

## Cluster Set Literature

To date, the majority of CS research focuses on the acute responses to various intraset rest and IRR intervals, frequently comparing acute power-related variables between different types of CS and TS (33,37,39,50,68,76,91). The body of literature examining the acute effects of CS is consistently growing, but the number of studies investigating the use of CS training as part of a chronic training program has received significantly less attention. To date, only 9 studies have investigated the chronic effects of CS subclasses but show inconsistent results most likely because of heterogeneous populations and protocol designs. The following sections will discuss key acute studies that focus on variables related to power, strength, and hypertrophic development. Then, each training study will be discussed in detail.

### Acute Power

There is a plethora of evidence supporting the use of CS variations to maintain power production during acute bouts of exercise (19,27,35,37,39,59,75,76,91). As mentioned previously, concentric movement velocities decrease during TS (21,45,82,89), significantly reducing power output (33,35,39,76,91). With the addition of intraset rest intervals, the velocity of repetitions toward the end of various CS protocols is maintained, resulting in the preservation of acute power output (35,39,45,91).

For example, Lawton et al. (59) reported that power output was maintained when an EW:R protocol was compared with TS. Subjects in this study performed 6 repetitions of the bench press with a 6RM load using TS and 3 different EW:R strategies. The EW:R protocols consisted of 6 sets of 1 with 20-second rest between sets, 3 sets of 2 with 50-second rest between sets, and 2 sets of 3 with 100-second rest between sets. By using these set structures, each protocol contained 100 seconds of rest and the final repetition of all 3 protocols was completed 118 seconds after the start of the first repetition, assuming 3 seconds was needed to complete each repetition. The authors concluded that the 3 EW:R protocols resulted in equally greater total power output than TS. This study (59) showed that various EW:R protocols containing shorter but more frequent rest intervals equally maintained power output during 6 repetitions of heavy bench press (i.e., about 21–25% greater total power output than TS) when compared with a single TS structure of 6 repetitions during which power output significantly decreased by approximately 50% in a near-linear fashion.

To compare the effects of RR and TS across multiple sets, Moreno et al. (69) investigated the effect of RR throughout a series of bodyweight jump squats. Total rest time was equalized between groups, but it was observed that an RR protocol consisting of 10 sets of 2 jumps with 10 seconds of interset rest better maintained power output, takeoff velocity, and jump height when compared with 2 sets of 10 jumps with 90 seconds of interset rest (TS). Building on the study by Lawton et al. (59) who examined EW:R during a single set of the bench press, these authors (69) showed that RR structures alleviate fatigue-induced decreases in movement velocity during multiple sets of bodyweight jump squats when compared with TS.

In comparison with the study by Moreno et al. (69) where bodyweight jump squats were used, Hansen et al. (35) investigated the effects of EW:R with more frequent rest periods during loaded jump squats (40 kg) in semiprofessional rugby players. The players experienced a decline in peak velocity and peak power output during 4 sets of 6 using TS. However, when EW:R protocols were used, peak velocity and power output were better maintained during the latter repetitions of each set. The authors concluded that because individual repetition peak force was not different between protocols, the maintenance of peak velocity during loaded jump squats was responsible for the maintenance of power output in the EW:R protocols when compared with TS.

As a whole, the literature shows that it is clear that power output can be maintained when using more frequent rest intervals during exercises that begin with eccentric muscle actions, use the stretch-shortening cycle (SSC), and finish with concentric muscle actions (i.e., bench press, jump squats, and back squats) (35,50,59,69,76,91). However, Hardee et al. (39) investigated the effect of CS on power during 3 sets of 6 power cleans, which are considered to be predominately concentric in nature. Using 80% 1RM, subjects performed a TS protocol (3 sets of 6 with no intraset rest) and 2 CS protocols with IRR intervals of either 20 or 40 seconds. When averaged across all 18 repetitions, peak power output, peak velocity, and peak force decreased more in TS than the 2 CS protocols. In contrast to the bench press, jump squats, and back squats (35,59,69), power cleans begin with concentric muscle actions. During the power clean, peak velocity is usually obtained during the second pull, which is preceded by the double knee bend (22,66). Therefore, the velocity of the second pull may be affected by the involvement of the SSC during the double knee bend. Although the authors did not report exactly when peak velocity occurred (39), it is likely that peak velocity occurred during the second pull, partially relying on the SSC during the double knee bend. Therefore, when compared with TS, CS using IRR intervals of 20–40 seconds maintained peak power even when using an exercise that begins with concentric muscle actions but still uses the SSC (39).

To further elaborate on this phenomenon, it seems that CS structures may be beneficial for increasing power output only for exercises that use the SSC at some point during the lift (68). Moir et al. (68) showed that greater reductions in power output were observed when a single set of 4 deadlifts was performed using CS compared with TS. The authors concluded that when implementing 30-second IRR periods, the SSC did not play a major role and the impulse of the deadlifts was greater than that of TS. When performing clusters of 2 repetitions (using an intraset rest period of 30 seconds between the second and third repetitions), the second and fourth repetitions were performed quicker and resulted in greater power output than the first and third repetitions. Force remained unchanged during all protocols meaning that, mathematically, a decrease in velocity (i.e., an increase in time) was responsible for the greater impulse observed when using IRR periods. Therefore, if maintaining power output is important, CS structures that use IRR periods may not be warranted when performing exercises that begin with a concentric muscle action and lack SSC involvement, such as the deadlift. However, if multiple repetitions are performed in sequence using the SSC at some point, intraset rest intervals may be useful.

In summary, EW:R, RR, and basic CS set structures seem to be beneficial for attenuating the acute decline in power output that occurs when using TS in exercises that include some kind of SSC component. Additionally, the maintenance of concentric movement velocity seems to be largely responsible for the maintenance of power output during an acute exercise bout. However, further investigation is necessary to determine the effect of CS on acute power-based variables using different exercises, rest periods, and number of repetitions.

#### Acute Strength

Previous authors have hypothesized that TS should be chosen over CS when training to develop maximal strength because CS alleviate fatigue, and fatigue is sometimes warranted when aiming to develop muscular strength (32,34,50). However, these claims remain relatively unexplored. Although the investigation of various types of CS on power output is more common in the literature, there are some studies that have explored the effects of CS on acute variables that are considered to be indicative of strength development, specifically force production, training volume, and muscle activity. It must be noted that acute studies cannot determine the chronic effect of a protocol on maximal strength, but the results from the following acute studies can be used to extrapolate hypotheses about the effects of CS on strength development.

In a study conducted by Denton and Cronin (19), subjects completed the bench press using 3 different protocols. The TS structure included 4 sets of 6 with 302 seconds of interset rest. One RR protocol was matched for training volume and total rest time and included 8 sets of 3 with 130 seconds of interset rest, whereas a different RR protocol was matched for total rest time and included 8 sets with 130 seconds of interset rest, but the odd-numbered sets contained 3 repetitions and even-numbered sets were performed to failure. The load in all set structures was the same (6RM load). The results of this study showed that the RR protocol that was performed to failure during the odd-numbered sets resulted in a significantly greater number of repetitions performed than the TS or RR protocol that was not performed to failure. In theory, an RR protocol that allows for the performance of more repetitions should increase training volume and, in turn, result in greater maximal strength gains (55).

Similarly, Iglesias et al. (47) showed that by using a basic CS configuration, training volume can be increased by increasing the load and number of repetitions performed. In this study, subjects completed as many repetitions as possible during a single TS of the bench press and bicep curl using 70% 1RM. Subjects then completed as many repetitions as possible of each exercise with 90% 1RM, but with 30 seconds of IRR. The protocol with IRR resulted in a greater number of repetitions performed with a greater load, indicating that CS allowed for a greater load to be used for a greater number of repetitions, increasing training volume.

Although a most of the literature shows that compared with TS, CS allow for greater volume load by increasing the number of repetitions, training load, or both, there is one study that does not show this and in fact shows that CS decrease the number of repetitions performed (4). In this study, subjects performed 4 sets of leg press and bench press to failure using 75% 1RM on 3 separate visits. Each of the 3 visits included either zero, 2, or 4 seconds of IRR. Unique to this study, the subjects continued to support the load in the extended position during the IRR periods (i.e., elbows extended during the bench press and knees extended during the leg press). As a result, subjects were able to perform more repetitions during the bench press and leg press when there was no IRR (TS) compared to the 2 protocols in which IRR periods were used (CS). Therefore, it can be concluded that when using any type of CS structure to maintain acute exercise performance or increase the number of repetitions performed, it is imperative that the lifter be unloaded and fully relaxed during the intraset rest or IRR periods.

Hansen et al. (35) determined that rugby players were able to maintain loaded jump squat peak force better when using EW:R compared with TS. Four sets of 6 jump squats were performed with a standard load of 40 kg to assess the percent change in peak force from the first repetition of each set to all subsequent repetitions per set. The absolute peak force was not different between protocols when repetitions were collapsed across sets, but the percent change from the first repetition did exhibit differences between protocols. Although the EW:R set structures did not fully maintain peak force when latter repetitions were compared with the first repetition of each set, there was a greater reduction in force across the set with the TS. Therefore, based on these data, it seems that EW:R may help attenuate the declines in peak force observed during the latter repetitions of TS structures. Although jump squats are generally not assigned to a resistance training program to increase maximal strength, the principle of force maintenance may be applied to other exercises that do focus on strength development.

To date, one study has investigated the effect of RR on muscle activity by comparing TS with RR using the back squat exercise at 75% 1RM (50). The TS protocol consisted of 4 sets of 10 with 2 minutes of interset rest, whereas the RR protocol included 8 sets of 5 with 1 minute of interset rest. To assess muscle activity, the authors reported the root-mean-square electromyography (EMG) values for the entire repetition (eccentric, amortization, and concentric phases) in the vastus lateralis and biceps femoris. When collapsed across 10 repetitions (i.e., the first TS set and the first 2 RR sets), muscle activity increased in a near-linear fashion during TS and followed the same pattern for the first 5 repetitions during RR. However, the muscle activity of the next repetition (sixth) of the RR set structure returned to the value of the first repetition and followed the same trend as repetitions 1–5. Therefore, TS resulted in greater total muscle activity when compared with RR because the muscle activity during the final 5 repetitions of each TS was greater than the muscle activity during the even-numbered sets in RR. The authors concluded that TS, rather than RR, should be used when an increase in muscle activity is desired. These conclusions display merit because various CS set structures are less fatiguing than TS when using the same load (37,63). However, because CS structures are less fatiguing (37,63), greater loads may have been used during the RR structure to match the effort of TS, and muscle activity may have been equivalent or greater in the RR protocol. However, the interaction between muscle activity, load, fatigue, and training volume is complex, resulting in only speculative claims when using EMG data to make inferences about maximal strength development.

In summary, various types of CS may help maintain peak force throughout a training session, and the duration of the IRR or intraset rest interval seems to impact the ability to attenuate force loss, with longer rest intervals resulting in a greater maintenance of peak force. Because of the capacity to maintain peak force using CS, it is possible that more force can be applied during later portions of a set, allowing the athlete to perform the set with overall higher movement velocities, which are also indicative of strength gains (28,77). However, current data (50) do not support the use of CS to increase muscle activity, and research should investigate the effects of greater loads during CS structures to match fatigue observed during TS structures. It has also been shown that greater training volumes result in greater strength adaptations (55), meaning that when designed appropriately, variations of CS structures may be used to increase training volume (19,47) and possibly maximal strength.

#### Acute Hypertrophy

As with maximal strength development, acute studies cannot directly determine the effectiveness of a protocol to induce muscle hypertrophy over time. However, it is possible to examine the existing body of CS research that can link specific acute variables with an increased potential for inducing hypertrophy. Specifically, the following acute CS studies incorporate large training volumes that are indicative of classical hypertrophic training and other variables that have previously been linked to skeletal muscle growth.

Although not designed as a study to investigate the hypertrophic potential of CS, Hardee et al. (37,38) noted that the rating of perceived exertion (RPE) was significantly lower during power cleans using CS when compared with TS and that barbell displacement was greater during CS. Because fatigue is a determinant of training volume, set structures that are less fatiguing may enable greater volumes of work to be accomplished (38) by allowing the lifter to perform more sets or more repetitions. The idea of greater training volumes resulting in greater skeletal muscle hypertrophy (56,87,88) supports the idea that CS may allow for greater training loads or training volumes and may serve as an alternative method to achieve muscular anabolism.

Building on this, Iglesias-Soler et al. (44) examined the maximal number of repetitions that could be performed using EW:R and TS. Subjects performed 3 sets of squats to failure using a 4RM load using TS with 3 minutes of interset rest. By using an EW:R protocol, subjects performed single squats with IRR periods until muscular failure was achieved. The EW:R protocol allowed subjects to complete about 5 times as many repetitions as the TS protocol (EW:R = 45.5; TS = 9.3 repetitions). These data indicate that EW:R training allows for a greater number of repetitions to be performed with the same load when compared with TS, increasing training volume and the amount of external work accomplished: key aspects of hypertrophy training (56,85,88). Therefore, according to the hypothesis that performing more repetitions with the same load results in greater amounts of work, suggesting greater hypertrophy over time (14,15,56), the results from this study (44) suggest that CS may have the ability to result in greater hypertrophy than TS.

Other authors have also showed that CS allow for greater training volumes than TS (19) and that RPE is lower during CS than TS when training volume, intensity, and work-to-rest ratios are equated (63). However, all the studies accomplished greater training volumes by increasing the number of repetitions performed, sometimes resulting in inefficient protocols in a practical strength and conditioning realm because of the time needed to complete the protocols (44). Despite the option for CS to result in greater training volumes, and in turn greater external work, the current body of CS literature has not attempted to address this possibility by increasing the load lifted for an equal number of repetitions.

Rather, studies by Girman et al. (27) and Oliver et al. (75) chose to equalize training volumes (sets × repetitions) between TS and CS protocols and investigate the effect of set structure on physiological markers of hypertrophy (84–86), such as lactate and hormonal responses. Together, these studies show that CS protocols result in less lactate and a blunted hormonal response when compared with TS (27,75). Therefore, both groups of researchers concluded that CS should not be used in place of TS when trying to induce skeletal muscle hypertrophy (27,75). However, it should be noted that the process of muscle growth is a complex phenomenon that includes both physiological and mechanical factors. Therefore, one area of future research could focus on the ability of CS to increase mechanical factors such as external work, subsequently effecting physiological markers.

In summary, the body of CS literature shows that CS loading can allow for greater training volumes than TS in an acute setting, which may result in greater hypertrophy over time (56,85,86). However, this idea is purely hypothetical because such study designs do not exist regarding the direct effects of CS on hypertrophy.

### Chronic Responses

Although the body of evidence regarding the acute responses of CS structures is vast and continually growing, few studies have chronically implemented CS in a training environment. Therefore, the relatively small number of studies allows the following section to discuss each study, to our knowledge, that has used various CS protocols inclusive of different loads, sets, repetitions, and rest periods. Because of the nature of training studies that target multiple training adaptations simultaneously, each study will be chronologically discussed as a whole rather than dividing the responses into power, strength, and hypertrophy subcategories as in the acute sections of this article.

Lawton et al. (58) compared TS and RR set structures over a 6-week training period in elite junior basketball and soccer players ($n = 26$) using a 6RM load during the bench press exercise. The subjects performed either 4 sets of 6 (TS) or 8 sets of 3 (RR) in the same amount of time in an attempt to equalize the work-to-rest ratio between groups. However, the TS group actually experienced greater TUT (36.03 seconds) than the RR group (31.74 seconds) despite the researchers trying to equate the work-to-rest ratios. Hence, RR would be considered as the most appropriate subclass of CS for this study because the total rest time was equal between groups. After the 6-week training period, subjects in both groups increased bench press throw peak power output against 20-, 40-, and 60-kg loads, but no differences were present between groups. However, training with TS resulted in significantly greater bench press strength gains when compared with RR (increases of 9.7 and 4.9% for TS and RR, respectively). Because subjects in this study used the same relative intensity across the various set structures for the duration of the training program, it is possible that implementing RR structures using the same load as TS may have resulted in a decrease in perceived effort during the RR training sessions, as seen in other studies (37,46,63). Decreasing the level of perceived effort may have allowed the athletes to increase the resistance used, resulting in an increased stimulus for the physiological adaptations that underpin the development of muscular strength. However, because no data were reported on the RPE and training loads were kept constant in this study (39), further research is warranted to determine if RR can allow for an increased training load while producing a similar RPE as in TS. Nonetheless, these data suggest that the strategic use of RR structures may serve as an alternate method for developing strength and power output but that TS may result in greater increases in strength when all training variables are equal.

Hansen et al. (36) compared RR with TS during the 8-week preseason period of elite rugby players. The team ($n = 18$) was split into a TS group and an RR group, with both groups completing the same lower-body resistance training program consisting of squat and clean variations. The only difference between groups was the redistribution of total rest time for the RR group, which included intraset rest intervals throughout the training program that were subtracted from the interset rest periods (exact times varied per week and are too complex to be summarized here). The total rest time, training load, and training volume were not different between groups at any time during the study. After 8 weeks of training, effect sizes showed that RR may have had a greater effect on power output, but neither peak velocity nor peak power assessed during loaded jump squats significantly increased for either group. Additionally, the use of TS resulted in significantly greater gains in back squat 1RM strength when compared with RR (an 18.3% increase from 203 to 240 kg, and a 14.6% increase from 191 to 216 kg for TS and RR, respectively). The greater increase in strength in the TS group shows that RR protocols may not be ideal when both groups use the same training loads, training volumes, and total rest time. Similar to the previously discussed study (58), it is possible that if the RR group experienced less fatigue (37,46,63), its subjects may have been able to tolerate greater training loads, leading to greater strength increases when compared with TS. Additionally, the authors also explained that players participated in supplementary concurrent training during the time of the study, which may have interfered with power adaptations. Therefore, the results of this study (36) show that the specific RR protocol used did not result in significant increases in power output during loaded jump squats but did result in increased back squat 1RM (although a lesser increase than TS) in rugby players participating in concurrent training during the off-season.

Zarezadeh-Mehrizi et al. (102) investigated the effect of RR and TS training in 22 male soccer players. After a standardized 4-week block of hypertrophy training, subjects in this study were assigned to an RR or TS group and performed 3 weeks of strength training (3 sets of 5 with 85% 1RM) followed by 3 weeks of power training (5 sets of 5 with 30–80% 1RM depending on the exercise) with the total rest time equal between groups. A lack of detail regarding the methods of this training program creates uncertainty of whether rest periods were controlled, evidenced by IRR ranging from 10 to 30 seconds in the RR group. To add to the lack of methodological clarity, 1RM squat strength was not directly assessed and an RM estimation technique was used, but the article did not specify how many repetitions were used in the estimation protocol. According to the 1RM estimations, both groups increased maximal strength (from 130 to 165 kg and 130–147 kg for TS and RR, respectively), with the TS group experiencing a significantly greater increase compared with the RR group. To assess power output, the velocity was calculated by dividing vertical displacement by time during 6 jump squats with 30% 1RM, and force was calculated using mass, gravity, and acceleration. Unfortunately, the authors did not state which mass was included in the calculation (barbell, body, or both) and the acceleration calculation was not provided. Ultimately, the estimated power output was determined by multiplying an estimated force and estimated velocity. With that in mind, the authors reported that the RR group experienced increases in power output (2,236–2,665 W), whereas the TS group did not (1,857–1,890 W). Although the results from this study indicate preferable power adaptations resulting from RR training, it is important to interpret these results with caution because the training methodology was not clearly reported, the TS group displayed an average 25 kg increase in back squat strength with no concomitant increase in power output, and power measurements were estimated and not directly measured.

Oliver et al. (74) investigated the effect of RR and TS throughout a 12-week total-body hypertrophy-oriented training program in resistance-trained men ($n = 22$). The TS group trained with 4 sets of 10 repetitions for all compound lifts with 120 seconds of interset rest, whereas the RR group performed 8 sets of 5 repetitions with 60 seconds of interset rest, meaning the total rest time was equalized between groups. After 12 weeks, both groups improved bench press, back squat, and vertical jump power output, but the RR group experienced greater increases in bench press and vertical jump power output compared with TS. The authors also observed similar gains in lean mass between groups, but neither group experienced shifts in myosin heavy chain isoform percentage. However, when both groups were collapsed together, the percentage of IIx (13.9–8.9%) and slow (51.1–47.5%) isoforms decreased while IIa (35.0–43.6%) increased, indicating a typical shift in fiber type resulting from resistance training. It was also noted that RR and TS increased bench press and back squat strength, but in contrast to the previously discussed studies (37,52,84), the RR group in this study experienced greater increases in strength when compared with the TS group. This anomaly may partly be explained by the inclusion of repeated 1RM tests throughout the study period. Although the relative intensities of the exercises were kept the same for each group (% 1RM), subjects were allowed to adjust their absolute load according to changes in 1RM strength, which was tested every 4 weeks. In this manner, training residuals from a previous block of training could have been translated into the subsequent training block, indicative of a typical sequential periodized training program that takes advantage of delayed training effects. Although not significantly different, the RR group trained with a greater total training volume compared with TS (effect size range of 0.42–0.71; not reported by the authors, but calculated by the authors of the present article using the effect size calculator found at www.uccs.edu/~lbecker/) for compound exercises. Therefore, it is possible that the continuous increases in strength may have allowed for greater absolute loads to be lifted, but the authors did not focus on this aspect. This study provides compelling evidence that different types of CS structures may allow for greater training loads for the same number of repetitions, resulting in greater training volumes, which may favor strength development when compared with TS.

Iglesias-Soler et al. (46) investigated the effects of a TS and an EW:R protocol over a 5-week period using unilateral knee extensions in sport science students of both genders ($n = 13$). Subjects were assigned to either the TS group (4 sets of 8, 10RM load, 180 seconds of interset rest) or RR group (32 repetitions, 10RM load, 17.4 seconds of IRR). Data collected during the training sessions showed that TS resulted in slower mean propulsive velocities (0.48 vs. 0.54 $m \cdot s^{-1}$) and greater RPE (8.3 vs. 6.6) than EW:R, respectively. Following the 5 weeks of training, subjects in the EW:R and TS groups experienced an equal increase in isometric strength, dynamic 1RM, mean propulsive power, and total work completed with the original 10RM load. The results of this study indicate that an EW:R unilateral knee extension protocol felt easier but resulted in similar increases in strength and power output compared with TS after 5 weeks of training in university students of both genders.

Asadi and Ramirez-Campillo (5) investigated the effects of TS and RR plyometric training in college-aged students ($n = 13$) who were familiar with plyometric training but had not participated in such training for at least 6 months. The TS group consisted of 5 sets of 20 maximal depth jumps from a 45-cm box with 120 seconds of interset rest. The RR group completed 5 sets of 20 but with 30 seconds of intraset rest after the first 10 repetitions of each set and 90 seconds of interset rest. After training twice per week for 6 weeks, both groups increased countermovement jump height, standing long jump distance, and decreased *t*-test and 20- and 40-m sprint times. Although there were no significant interactions between groups, the effect sizes were greater in the RR group for countermovement jump height, long jump distance, and *t*-test time, whereas the effect sizes were greater for the TS group for 20- and 40-m sprint times. Therefore, in untrained college students, plyometric training using TS and RR resulted in increased jumping, sprinting, and agility performance.

In summary, 4 studies show that TS and CS result in similar increases in power output (5,36,46,58), whereas 2 studies show that CS protocols may be favorable over TS (74,102). Differences in study designs may explain these unequivocal findings. The studies that reported similar increases in power output in TS and CS protocols equated training intensity, volume, and total rest time between protocols, not taking full advantage of the ability of CS structures to increase training volume (44). However, the 2 studies that showed preferable power output adaptations from CS structures also equated total rest time between groups (74,102), but unique to the study by Oliver et al. (74), the 12-week duration allowed for 1RM measurements every 4 weeks and possibly greater absolute loads in the RR group. Therefore, CS structures may be more beneficial than TS for the development of muscular power output, but more research must be conducted in this area to make conclusive recommendations.

To date, some studies have reported that strength gains are generally greater in TS set structures than CS (36,58,102), with only one study reporting that CS structures produce superior strength gains (74) and one study showing similar increases in strength (46). At first glance, the collective body of RR literature suggests that different CS structures may have a limited application for the development of maximal strength. However, it is important to carefully examine these studies and determine why TS resulted in greater strength development compared with RR training in these instances. Two of the main commonalities within studies that investigate RR are the equalization of the total rest time for RR and TS protocols and the lack of training load variation and systematic progression between the RR and TS set structures (36,58,102). Similar to matching total rest time, the equalization of training loads between groups is a sound scientific method. However, if RR and TS set structures are performed using the same training intensities, it is likely that the TS group will experience greater acute fatigue, a greater compensatory response, and possibly greater increases in strength. Therefore, to determine the effects of CS on chronic strength adaptations, it is necessary to determine how the RR protocols used in these studies can be reformed to create CS that may elicit strength gains equal to or greater than TS, similar but not limited to the strategy used by Oliver et al. (74).

Only one study has directly measured skeletal muscle hypertrophy after CS and TS training, showing that neither set structure is superior to the other (74). One of the advantages of CS loading is that greater training intensities can be used for the same training volume, possibly magnifying neuromuscular and morphological training adaptations (25,34,55,56). Therefore, future research should address the effects of greater total rest times, training loads, training volumes, and total external work in CS training protocols. Finally, it is important to not neglect the periodization process during training studies to elicit progressive adaptations over time in a systematic manner.

## Summary

A summary of studies investigating CS, RR, and EW:R is included in Table 1. Because of the large degree of variability of protocols between studies and even within studies, the results of each study have been summarized and do not include results for individual repetitions or sets but include the global response to each protocol as a whole.

Collectively, researchers have compiled a large body of evidence that supports the use of CS to maintain or increase acute power-related variables, such as jump height,

**TABLE 1.** Studies listed by cluster set subclass, followed by duration (acute or chronic), and author's last name.

| Author | Cluster set subclass | Duration | Subjects | Protocols | Response |
|---|---|---|---|---|---|
| Boullosa et al. (11) | Basic CS | Acute | 12 resistance-trained men, 5RM half squat 2.33× BM | Countermovement jump height measured before and 1, 3, 6, 9, and 12 min after squats with 5RM load; TS: 5 reps; CS: 5 reps with 30-s IRR | Vertical jump postactivation potentiation occurred after 1 min using CS compared with 9 min using TS |
| García-Ramos et al. (26) | Basic CS | Acute | 34 active college-aged men, 1RM bench press 1.02× BM | Bench press throws at 30, 40, and 50% 1RM; TS: 15 reps; CS1: 15 reps with 6-s IRR; CS2: 15 reps with 12-s IRR | Peak velocity was maintained best in CS2, followed by CS1, both of which maintained velocity better than TS |
| Haff et al. (33) | Basic CS | Acute | 8 male track and field athletes, 5 male weightlifters, 1RM power clean 1.32× BM | Clean pulls at 90 and 120% 1RM; TS: 5 reps; CS: 5 reps with 30-s IRR | On average, peak velocity was greater during CS compared with TS |
| Hardee et al. (37) | Basic CS | Acute | 10 male recreational weightlifters, 1RM power clean 1.39× BM | Power cleans at 80% 1RM; TS: 3 × 6 with 180-s interset rest; CS1: same as TS with 20-s IRR; CS2: same as TS with 40-s IRR | CS resulted in greater power output and less exertion than TS; CS with longer rest periods maintained power output and decreased exertion more than when CS rest periods were shorter |
| Hardee et al. (39) | Basic CS | Acute | 10 male recreational weightlifters, 1RM power clean 1.39× BM | Power cleans at 80% 1RM; TS: 3 × 6 with 180-s interset rest; CS1: same as TS with 20-s IRR; CS2: same as TS with 40-s IRR | Force, velocity, and power were better maintained during CS than TS; CS with longer rest periods maintained these variables better than when CS rest periods were shorter |
| Hardee et al. (38) | Basic CS | Acute | 10 male recreational weightlifters, 1RM power clean 1.39× BM | Power cleans at 80% 1RM; TS: 3 × 6 with 180-s interset rest; CS1: same as TS with 20-s IRR; CS2: same as TS with 40-s IRR | Vertical displacement was greater during CS, resulting in greater external work than TS |
| Iglesias et al. (47) | Basic CS | Acute | 13 men; bench press 1RM 1.2× BM; bicep curl 1RM 0.25× BM | Bench press and biceps curl with different loads; TS: reps to failure using 70% 1RM; CS: reps to failure using 90% 1RM with 30-s IRR | CS resulted in a greater number of repetitions performed with a greater load compared with the greatest number of repetitions performed using TS with a lighter load |
| Moir et al. (68) | Basic CS | Acute | 11 resistance-trained men, deadlift 1RM 1.95× BM | Deadlifts using 90% 1RM; TS: 4 reps; CS1: 4 reps with 30-s IRR; CS2: 4 reps with 30-s intraset rest after second rep | Force was similar between CS1, CS2, and TS, but CS1 resulted in greater TUT, less power output and greater impulse than TS |

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|---|---|---|---|---|---|
| Tufano et al. (91) | Basic CS | Acute | 12 resistance-trained men, back squat 1RM 1.9× BM | Squats using 60% 1RM; TS: 3 × 12 with 120-s interset rest; CS1: 3 × 12 with 120-s interset rest and 30-s intraset rest after every 2 reps; CS2: 3 × 12 with 120-s interset rest and 30-s intraset rest after ever 4 reps | CS1 and CS2 maintained velocity and power output better than TS; more frequent intraset rest (CS1) resulted in greater maintenance of velocity and power output (CS2) |
| Valverde-Esteve et al. (92) | Basic CS | Acute | 16 physical education men, bench press 1RM 1.15× BM | Bench press using subject-dependent "optimal load" of about 49% 1RM; TS: 1 × 15; CS1: 1 × 15 with 5-s IRR; CS2: 1 × 15 with 10-s IRR | Peak power output was maintained best in CS2, followed by CS1, both of which maintained power output better than TS |
| Nicholson et al. (71) | Basic CS | 6 wk | 46 trained college men, no baseline data provided | TS Strength: 4 × 6, 85% 1RM, 900-s total rest; TS hypertrophy: 5 × 10, 70% 1RM, 360-s total rest; CS1: 4 × 6, 85% 1RM, 1,400-s total rest; CS2: 4 × 6, 90% 1RM, 1,400-s total rest | All CS and TS groups resulted in similar increases in isometric force, muscle activity, and jump height; CS2 and TS strength resulted in greater strength gains compared with TS hypertrophy and CS1 |
| Rooney et al. (80) | Basic CS | 6 wk | 18 men and 24 untrained women, bicep curl 1RM 11–14 kg | TS: 6–10 reps at 6 RM; CS: 6–10 reps at 6RM with 30-s IRR | TS resulted in greater gains in strength compared with CS |
| Hansen et al. (35) | EW:R | Acute | 20 (semi) and professional male rugby players, strength level not provided | TS: 4 × 6 with 180-s interset rest; CS1: 4 × 6 with 120-s interset rest and 12-s IRR; CS2: 4 × 6 with 120-s interset rest and 30-s intraset rest after every 2 reps; CS3: 4 × 6 with 120-s interset rest and 60-s intraset rest after every 3 reps | Power and velocity were greater during CS than TS, with no differences in force between the protocols |
| Iglesias-Soler et al. (45) | EW:R | Acute | 10 male judoists, back squat 1RM 1.58× BM | Back squats with 4RM load; TS: 3 sets to failure, 180-s interset rest; CS: same volume as TS with subject-dependent IRR with same EW:R as TS | CS resulted in greater movement velocity during the protocol and less lactate after compared with TS |
| Iglesias-Soler et al. (44) | EW:R | Acute | 9 male judoists, back squat 1RM 1.57× BM | Back squats with 4RM load; TS: 3 sets to failure, 180-s interset rest; CS: same volume as TS with subject-dependent IRR with same EW:R as TS | CS resulted in a greater number of repetitions while also resulting in greater movement velocity than TS |
| Iglesias-Soler et al. (43) | EW:R | Acute | 10 male judoists, back squat 1RM 1.58× BM | Back squats with 4RM load; TS: 3 sets to failure, 180-s interset rest; CS: same volume as TS with subject-dependent IRR with same EW:R as TS | CS resulted in lower exercise heart rates, systolic blood pressure, and rate pressure product compared with TS |
| Lawton et al. (59) | EW:R | Acute | 26 elite junior, male basketball and soccer players, bench press 6RM 0.8× BM | Bench press with 6RM load; TS: 6 reps; CS1: 6 × 1 with 20-s IRR; CS2: 3 × 2 with 50-s interset rest; CS3: 2 × 3 with 100-s interset rest | Power output was greater during CS compared with TS |

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| Mayo et al. (63) | EW:R | Acute | 7 male and 1 female sport science students, bench press 10RM 0.71× BM; back squat 10RM 1.29× BM | Bench press and back squats with 10RM load; TS: 5 sets to failure with 180-s interset rest; CS: same volume as TS with subject-dependent IRR with same EW:R as TS | CS resulted in greater movement velocity and less exertion compared with TS |
| Iglesias-Soler et al. (46) | EW:R | 5 wk | 6 and 7 female and male sport science students, respectively; strength level not provided for each gender | Unilateral knee extensions with 10RM load; TS: 4 × 8 with 180-s interset rest; CS: 32 reps with 17.4-s IRR | CS and TS resulted in similar increases in 1RM, power output, and muscular endurance |
| Denton et al. (19) | RR | Acute | 9 healthy men, bench press 6RM 1.01× BM | TS: 4 × 6, 302-s interset rest; CS1: 8 × 3, 130 interset rest; CS2: 8 sets, 130 interset rest* (3 reps during odd sets, reps to failure during even sets)* | CS1 resulted in similar power output, force, and work compared with TS; CS2 resulted in a greater number of repetitions, work, and lactate than CS1 and TS |
| Girman et al., 2014 (27) | RR | Acute | 11 resistance-trained men, strength level not provided | TS: 1 × 6 clean pull 75% and 1 × 10 back squat 70% with 2-min interset rest; CS: same as TS, but 15-s intraset rest and 90-s interset rest | Blood lactate was lower and jump performance was greater after CS compared with TS; both protocols resulted in similar growth hormone and cortisol responses |
| Joy et al. (50) | RR | Acute | 9 resistance-trained men, back squat 1RM 1.76× BM | Back squats with 75% 1RM; TS: 4 × 10 with 120-s interset rest; CS: 8 × 4 with 60-s interset rest | CS resulted in greater power output but less muscle activity compared with TS |
| Moreno et al. (69) | RR | Acute | 26 recreationally trained college men, strength levels not reported | Plyometric bodyweight jump squats; TS: 2 × 10 with 90-s interset rest; CS1: 4 × 5 with 30-s interset rest; CS2: 10 × 2 with 10-s interset rest | CS1 and CS2 resulted in similar force but greater jump height, power output, and take off velocity compared with TS |
| Oliver et al. (76) | RR | Acute | 12 resistance-trained men, back squat 1RM 1.7× BM 12 untrained men, back squat 1RM 1.1× BM | Back squats with 70% 1RM; TS: 4 × 10 with 120-s interset rest; CS: 4 × 10 with 90-s interset rest and 30-s intraset rest | Velocity and power output were better maintained during CS compared to TS |
| Oliver et al. (75) | RR | Acute | 12 resistance-trained men, back squat 1RM 1.75× BM; 11 untrained men, back squat 1RM 1.07× BM | Back squats with 70% 1RM; TS: 4 × 10 with 120-s interset rest; CS: 4 × 10 with 90-s interset rest and 30-s intraset rest | CS resulted in greater volume load and power output than TS, while CS also resulted in less TUT, less lactate, and similar hormonal responses |
| Asadi and Ramirez-Campillo (5) | RR | 6 wk | 13 college men, 40-m sprint 6.31 s; countermovement jump 43 cm | Depth jumps from a 45-cm box; TS: 5 × 20 with 120-s interset rest; CS: 5 × 20 with 90-s interset rest and 30-s intraset rest | Both groups improved countermovement jump height, standing long jump distance, and *t*-test agility, 20- and 40-m sprint times; sprinting effect sizes were greater in TS, but jumping effect sizes were greater in CS |

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| Hansen et al. (36) | RR | 8 wk | 18 elite rugby union men, 1RM back squat 1.9× BM | Squat and pull variations, 80–95% 1RM; TS: 3–5 sets of 3–8 with 180-s interset rest; CS: same as TS but with 120-s interset rest and 10- to 30-s IRR | CS and TS both resulted in increases in strength, but a greater increase after TS; neither protocol had a significant change in jump squat force, velocity, or power |
| Lawton et al. (58) | RR | 6 wk | 26 men, elite junior basketball and soccer players; strength levels not reported | Bench press using 80–105% 6RM load; TS: 4 × 6 with 260-s interset rest; CS: 8 × 3 with similar work-to-rest ratios as TS (but not controlled, making this RR, not EW: R) | Increases in power and strength were present after both CS and TS, but strength increases were greater after TS; TUT during training was greater during TS |
| Oliver et al. (74) | RR | 12 wk | 22 men in the military; bench press 1RM 1.67× BM; back squat 1RM 2.09× BM | Total body workout using 60–75% 1RM; TS: 4 × 10 with 120-s interset rest; CS: 8 × 5 with 60-s interset rest | CS and TS resulted in similar increases in lean mass, but CS resulted in greater gains in strength and power |
| Zarazadeh-Mehrizi et al. (102) | RR | 6 wk | 22 male soccer players; back squat 1RM 1.83× BM | Total body workout using 85% 1RM during strength phase and 30–80% 1RM during power phase; TS: 3 × 3–5 with 180-s interset rest; CS: 3 × 3–5 with 120-s interset rest and 10- to 30-s IRR | CS and TS resulted in increased strength, but increases were greater after TS; CS resulted in increases in power output, whereas TS did not |
| Arazi et al. (4) | Rest-pause†/basic CS | Acute | 20 resistance-trained men; strength level not reported | Bench press and leg press with 75% 1RM; TS: 4 sets to failure with 3-min interset rest; CS1: same as TS but with 2-s IRR; CS2: same as TS but with 4-s IRR | The only study to show that TS resulted in a greater number of repetitions than CS, most likely because of the subjects supporting the load at full elbow (bench press) or knee (leg press) extension during the IRR periods; possible that CS where subjects support the load during IRR is more fatiguing than TS |
| Keogh et al. (51) | Rest-pause†/basic CS | Acute | 12 weight-trained men; bench press 1RM 1.41× BM | Bench press using 6RM load; TS: 6 reps; CS: 6 reps with 2-s IRR | Concentric pectoralis major muscle activity was less during CS compared with TS, whereas power output, triceps muscle activity, TUT, blood lactate, and force were not different between protocols |
| Marshall et al. (62) | Rest-pause | Acute | 14 resistance-trained men; back squat 1RM 2.08× BM | Back squats using 80% 1RM; TS1: 5 × 4 with 180-s interset rest; TS2: 5 × 4 with 20-s interset rest; CS: sets to failure with 20-s interset rest until 20 reps completed | CS resulted in greater muscle activity than TS1 and TS2 with similar amounts of postexercise fatigue |

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| Byrd et al. (17) | Rest-pause†/ basic CS | 10 wk | 50 untrained men; bench press 1RM ~1.0× BM; leg press 1RM 2.1–2.6× BM | TS: 6–10RM circuit training 3; CS1: same as TS with 1-s IRR; CS2: same as TS with 2-s IRR | CS1 and CS2 resulted in a greater cardiovascular work capacity than TS and all had similar gains in bench press 1RM; leg press strength increased greater in TS than CS1 |

*CS = cluster sets; TS = traditional sets; EW:R = equal work-to-rest ratio; RM = repetition maximum; BM = body mass; IRR = interrepetition rest; RR = rest redistribution; TUT = time under tension.

†Arazi et al. (4), Keogh et al. (51), and Byrd et al. (17) did not perform repetitions to failure as usually described during rest-pause, but the IRR was only 1–4 seconds, too short to be classified as only a CS. Therefore, these 2 studies can be described as CS/rest-pause hybrid designs.

force, velocity, and power. Additionally, there is compelling evidence that CS structures acutely allow for a greater volume load, and in turn greater external work, by increasing the number of repetitions performed at a given load or increasing the load for a given number of repetitions.

In a training context, researchers have used various protocols inclusive of different exercises on a variety of subjects, but future research should continue to explore the possibilities of different CS structures on hypertrophy, strength, power, and sport-specific performance. Furthermore, research is needed to determine the effects of CS protocols that use different total rest periods and loads compared with TS. Finally, because of various protocol designs that possibly play a role in the development of inconsistent data within the body of CS literature, the need for consistent terminology when explaining basic CS, RR, and EW:R set structures is of utmost importance.

## Practical Applications

According to the present scientific literature, CS structures should be used when:

- Velocity and power maintenance are warranted (26,33,35,39,44,45,47,50,59,69,75,76,91,92).
- Aiming to increase the total volume load and total work within a session (19,44,47,75).
- Aiming to increase vertical jump performance (27,69,74).
- Aiming to decrease an athlete's RPE (37,46,63).
- Technique and displacement of an exercises is to be maintained (33,38).
- The SSC plays a large role in the designated movement (68).
- Aiming to acutely decrease cardiovascular stress during resistance training (43).
- Using post-activation potentiation (PAP) under strict time constraints (11).

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