

Recovery and Adaptation after Weight Training Sessions with Different Number of Sets to Failure

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Abstract Increases in strength and muscle mass can be achieved with weight training and adequate recovery (including nutrition and sleep). The time course of recovery and adaptation (super-compensation) for different number of sets has not been adequately investigated in the literature. A 40-year-old well-trained male exercised the chest with (a) 3 sets of bench press, (b) 5 sets of bench press, (c) 5 sets of bench press and 4 sets of dips, all to momentary concentric muscular failure during a 6 months body split program. The recovery was assessed by comparing the number of repetitions of the first bench press set to the previous training session. The results showed that with 3 and 5 sets to failure adaptation (+1 repetition) took place after 5 days. 9 sets needed 7 days for recovery and no adaptation took place. The adaptation was faster when exercising the chest without trainings the back and/or legs, indicating that Selye's adaptation energy (resources potential) might be applicable to weight training as well. Delayed onset muscle soreness (DOMS) and motivation (mood) were found to be useful indexes of recovery. Implications on training volume and frequency and how the findings can be applied in practice are discussed.

Keywords: *weight training, recovery, adaptation, progressive overload, super-compensation, general adaptation syndrome (GAS), fitness-fatigue model, training frequency, training volume, momentary concentric muscular failure*

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1. Introduction

Weight (or resistance) training with bars, dumbbells and/or other equipment is necessary for sports like bodybuilding, weightlifting and powerlifting where strength, power, and/or muscle mass are needed. It is also used in many other sports, such as football, wrestling, and rowing, in order to increase the performance of athletes and reduce the frequency and severity of injuries [1]. Weight training has many benefits for non-athletes as well, since it can reduce the signs and symptoms of many diseases and chronic conditions [2,3]. Consequently, weight training can be viewed and adopted as a prescription for public health [4].

The effectiveness of a training program depends on many variables such as training frequency, number of sets and repetition range. Many position papers [5], reviews [6,7], and meta-analyses have examined the appropriate ranges for strength and hypertrophy: frequency [8,9], weight/load [10], volume/sets [11,12], rest intervals between sets [13,14], repetition duration [15,16], muscle action [17], failure [18].

The appropriate training program can be designed based on the above mentioned recommendations and the experience of the coaches and/or the athletes. There are also some basic principles that help to optimize the design

(i.e., the choices of the variables) of the program and their modifications over time, i.e., how to design an appropriate annual plan. The most basic principles are [19,20]:

- *Progressive overload:* There must be a stimulus (workout) and this must be gradually increasing over time to further improve performance.
- *Specificity:* The training adaptations are specific to the stimulus applied.
- *Variation (and/or Periodization):* The training stimulus should change (within the specificity limits) to remain challenging and effective.
- *Individuality:* The magnitude of the adaptation to the training stimulus (i.e., performance improvement) is different for each person.

One of the most important principles is the progressive overload. The application to weights and the term progressive resistance exercise originates from Thomas Delorme, when he rehabilitated soldiers after World War II [21]. However, to increase performance, the basic assumptions are: (i) the workout has to be more challenging than the previous one (i.e., a minimum threshold has to be exceeded), (ii) the workout has to be within the tolerance of the trainee (i.e., there is a maximum threshold), (iii) the recovery must be completed before another workout, and ideally some time for adaptation has to be given.

There are two basic models that try to mathematically explain fatigue and adaptations to training, in order to help

athletes plan their training. These models are also the basis of periodization [22], but they have been challenged recently [23].

- *Super-compensation or one-factor model*: It is based on stress theories and particularly the General Adaptation Syndrome (GAS) [24] or the stimulus-fatigue-recovery adaptation theory [25].
- *Fitness-Fatigue or two-factor model* which considers fatigue and fitness separately [26,27].

The super-compensation model is the one mainly used for weight training. The workout is the alarm phase which leads to a decline in one's "fitness" level (or performance). After the workout, the body starts recovering to reach the original "fitness" level (resistance phase). If recovery is adequate, then super-compensation occurs, increasing the "fitness" level above the original base. During the resistance or adaptation phase, the organism tries to get to homeostasis or a new homeostasis that better fits the circumstances (heterostasis or allostasis or adaptive homeostasis or hormesis) [28,29]. If the workout is extreme, the "fitness" level cannot return to its original level (exhaustion phase). Alternatively, if the accumulation of fatigue is too great, the exhaustion phase occurs, and this may be considered synonymous with overtraining.

The first version of the fitness-fatigue model is more than 40 years old and tried to quantify performance based on the training stimulus (dose) and four different components: skill, psychology, cardiovascular, and strength [26]. This model was subsequently simplified [27] by defining performance (preparedness or readiness) as the difference between two components: "fitness" and "fatigue". When a person trains, he accumulates "fatigue", but also improves "fitness". Fatigue that accumulates over the course of a training cycle "masks" the fitness gains. However, fitness persists about three times longer than fatigue and, thus, in the long term an improvement can be seen [30].

Whatever the right model is, in a research setting, the temporal responses of anabolic signaling to resistance exercise and their summation have been demonstrated in humans [31]. Repeating a bout of resistance exercise at the right time after the first one will result in a better (summation) regulatory response which, if repeated, would affect longer term alterations [32]. This would be expected to lead to increased performance (e.g., hypertrophy).

There have only been few studies regarding identifying the appropriate threshold. A study showed that muscle protein synthesis after weight training sessions contribute to muscle hypertrophy only after a progressive attenuation of muscle damage, and even more significantly when damage is minimal [33]. Eccentric repetitions that induce high damage might not result in any adaptation (super-compensation) in some persons [34]. Very few indicators have strong scientific evidence supporting their use to monitor muscle damage and recovery [35]. Some of them are: delayed-onset muscle soreness (DOMS), decreased force production, decreased range of motion, swelling of the exercised limb, increased muscle proteins in the blood (creatinase kinase and myoglobin), and feeling less motivated or focused. Recent systematic reviews concluded that subjective measures were more sensitive and consistent than objective measures in determining acute and chronic changes in athlete well-being in response to load [36,37]. Increasing the weight of the exercises is believed to be the

best test of recovery in terms of ecological validity [38]. A daily strength check protocol was applied to assess the recovery (and adaptation) of young and older subjects with different number of sets [39]. A study on the stability of this protocol with two trials found that 80% of participants returned to baseline strength levels after the same recovery duration [40]. However, individual muscle groups resulted in much poorer test-retest stability of 20-70%. Later it was shown that a perceived recovery status scale had good correlation with actual recovery and could be also an additional tool in determining the right recovery time [41].

The main objective of this paper is to present data on the time course of recovery and adaptation for different number of sets to failure, but with a different approach: the same subject conducted workouts with different number of sets to failure and frequencies over a period of 6 months. Strength changes and subjective measures (DOMS and motivation/mood) were used to determine the optimal training frequency. The findings of this study can help in personalizing the design of a training program and in determining the training frequency.

2. Methods

This case report is based on the workouts of a trainee in the first half of 2018 (January-June). After discussion with the author in July, the trainee agreed to provide the data and signed an informed consent.

2.1. Subject

The subject was 40-years-old Caucasian white male, with 1.77 m height, approximately 90 kg body mass (weight) and 92 cm waist circumference. He had a weight training experience of 20 years, but never competed (e.g., bodybuilding or powerlifting). The estimated ratios of his one repetition maximum (1RM) of squat, barbell row, and bench press to body mass (weight) were 2.33, 2.08, and 1.69 respectively. He never used illegal performance enhancement substances.

2.2. Training Program

The body was split in three parts: (1) Chest and biceps; (2) Back and side deltoids; (3) Legs (Table 1). Legs were typically trained every 10 days, while chest and back every 5 days. However, due to life obligations the actual frequency was variable, and this allowed analyzing trends between increases in strength and recovery days, as it will be explained later.

Table 1. Training Program. Body is Split in 3 parts. Number of Sets to Failure are also Shown

	(1) Chest	(2) Back	(3) Legs
Frequency	5 days	5 days	10 days
Exercise 1	Bench press x5	Barbell row x3 ²	Squat x3
Exercise 2	(Dips x4) ¹	Chins x3 ²	Calf raises x4
Exercise 3	Dumbbell curls x3	Side raises x3	

¹ Dips were added only for a short period of time. ² The sequence of barbell rows and chins was alternating every 2-3 months.

The exercises were done with 3-5 working sets (to voluntarily momentarily failure), as follows:

- 3 sets: 1 set maximum number of repetitions with 6RM, 2 sets with maximum number of repetitions with 12RM.
- 4 sets: 2 sets of maximum number of repetitions with 6RM, 2 sets with maximum number of repetitions with 12RM.
- 5 sets: 2 sets of maximum number of repetitions with 6RM, 3 sets with maximum number of repetitions with 12RM.

An example of 5 sets of bench press is (repetitions x weight in kg): Warm-up: 12x60, 6x100. Working sets: 6x140, 3x140, 12x114, 7x 114, 5x114.

When the subject could complete 8 repetitions and 14 repetitions for first of the 6RM and 12RM sets respectively he increased the weight by around 3-5%.

During the year the number of sets and exercises for the chest varied. The number of sets for back and legs remained almost constant.

- End of January to mid of March 2018: 5 sets of bench press. For the first weeks he only trained the chest (no legs and back due to a lower back pain).
- Half end of March, July 2018: 5 sets of bench press and 4 sets of dips (total 9 sets). The subject felt tired and noticed a lack of progress with 9 sets, so in March he reduced the volume to 3 sets. The same happened in May, and he returned to 5 sets in July.
- April 2018: 3 sets of bench press.
- July 2018: 5 sets of bench press.

2.3. Training Protocol

The workouts took place early in the morning. Before each session the subject recorded his body mass (weight), waist circumference, his motivation (mood) for training (1 no motivation, 10 unstoppable), and his back, legs, and chest delayed onset muscle soreness (DOMS) levels (1 no soreness, 10 extreme muscle soreness). The body mass was measured to the nearest 0.1 kg using a weight scale and the circumferences to the nearest 1.0 mm using a tape measure.

The duration of each training session was also noted (starting from the first working set). Typical duration was 20 (±2) minutes for 5 sets (the 2-3 warm-up sets not included). The rest intervals and the range of motion were not controlled, but they were probably the same during the 6 months.

2.4. Mental Techniques

No mental techniques were used, except goal setting: The target of each training session was to do one more repetition compared to the previous session (or the best performance). The subject was always listening to the same songs, most of the times in the same order. The focus was external (i.e., on the bar) for the 6RM sets, and internal (i.e., on the muscle) for the 12RM sets. The external focus is supposed to increase performance [42], while the internal hypertrophy [43].

2.5. Nutrition

The subject was drug-free and not on any prescribed medication. He was a non-smoker. He supplemented his

diet with caffeine, whey protein, and creatine. The nutrition and supplementation did not change from the one he was following before the evaluation period.

He was not logging his meals, but a typical day is summarized in Table 2. In general, he was consuming 3000 kcal per day, with at least 1.6 g of protein per kg of body mass. This protein intake is considered enough for hypertrophy in non-calories restricting diets [44]. During weekends the nutrition was not strict and the meals could contain bigger quantities and/or higher fat percentages (e.g., addition of pizza, pasta, dessert at restaurants). From March, he reduced the number of “cheat meals” and added 30-40 min fast walking once per week in order to reduce his fat.

Before training he took additionally 6 grams of instant coffee (approximately 150-180 mg caffeine) in order to feel energetic during the workout. Caffeine appears to increase muscle strength [45]. After training he added a meal with yogurt, honey, protein powder and creatine (5 g). The creatine supplementation has been shown to increase strength and hypertrophy [46].

Table 2. Typical Diet. P=Protein, C=Carbs, F=Fats

Weekday	P / C / F [g]
Milk with protein, creatine (5 g) and caffeine (50 mg) ¹	30 / 20 / 0
(after weight training) ²	(50 / 50 / 0)
Eggs, cheese, bread	30 / 100 / 30
Lunch ³	30 / 100 / 30
Yogurt or milk (not always)	25 / 25 / 0
Dinner ³	30 / 100 / 20
Yogurt or milk with protein	25 / 25 / 0

¹ Days of training: +150 mg caffeine; ² Only days with weight training: yogurt, honey, protein powder and creatine (5 g); ³ Lean fat meat, fish or chicken, with vegetables and rice or pasta. Extra calories during weekends.

2.5. Calculations and Analysis

The formula to estimate the percentage of Body Fat (BF%) was based on waist (W) and neck (N) circumferences in cm, and height (H) in cm [47]. The height and the neck circumference were considered constant throughout the evaluation period.

$$BF\% = 495 / \left\{ \begin{array}{l} 1.0324 - 0.19077 \times [\log(W - N)] \\ + 0.15456 \times [\log(H)] \end{array} \right\} - 450. \quad (1)$$

The Fat Free Mass (FFM) [kg] was calculated from the Body Mass (weight) [kg] and the Body Fat.

$$FFM = BM \times (1 - BF\%). \quad (2)$$

The one repetition maximum (1RM) was estimated by the Brzycki equation [48] using the weight lifted (L) for the specific number of repetitions (R):

$$1RM = L / [1.0278 - (1.0278 - (0.0278 \times R))]. \quad (3)$$

2.7. Experimental Approach

The study is based on the subject’s notes for duration of approximately 6 months. Although the subject was

following his typical training program, the data allowed seeing the influence of the number of working sets on the recovery of the subject. This was evaluated by plotting increases (or decreases) of number of repetitions in function of recovery days for different number of sets to failure. The data were divided to sessions of 3, 5 or 9 (chest) sets to failure. The chest muscle group was chosen for evaluation due to the completeness and consistency of the chest training. The legs were not trained often enough and back training was influenced by the fatigue of the biceps training and/or the lower back muscles from the leg training.

3. Results

Initially an overview of the training sessions, the body mass, and the fat free mass will be given. Then, the recovery and DOMS in function of the rest days will be presented. Finally, the motivation (mood) levels in function of strength changes will be given.

3.1. Training Sessions and *FFM*

Figure 1a presents the training sessions during the evaluated period. For the chest, the number of sets to failure for each training session are additionally shown. Five sub-periods can be distinguished:

- chest training with 5 sets, no legs and back training,
- chest training with 5 sets,
- chest training with 9 sets,
- chest training with 3 sets,
- chest training with 5 sets (repeat of b).

Sub-periods “b” and “e” are identical and can show the repeatability of the results. Sub-period “a” and “b” are the same in terms of chest training, but at sub-period “a” no legs or back training was included at the rest days between chest training sessions.

Figure 1b plots the *BM* (weight) of the subject. It gradually decreased from 91.5 to 89 kg (around 2.5 kg). This can be explained by the period of year. The evaluation started in winter and ended in summer. The subject was more conscious of his diet as the summer was approaching.

Figure 1c plots the *FFM* of the subject. At the beginning it was around 71.5 kg (with only chest training), but when legs and back training were added it slightly increased to 72 kg and it remained relatively constant (around 72 ± 0.5 kg). The stability of the *FFM* indicates that the drop of the body mass probably did not negatively influence the performance in any of the studied sub-periods.

Figure 2 examines in more detail the *FFM* for the five sub-periods in chronological order. After sub-period “a”, where the chest was trained with 5 sets to failure, the subject added legs and back training and this resulted in a 0.4 kg increase (from 71.6 to 72 kg), possibly due to increases in muscle glycogen (sub-period “b”). Sub-period “c”, with 9 sets to failure resulted in a 0.2 kg decrease of the *FFM*. Sub-period “d” with 3 sets slightly increased the *FFM*. When the subject returned to 5 sets for the chest the *FFM* returned to the initial levels. Figure 2 shows that there is a small difference (but not statistically significant) between the different number of chest sets, with a small advantage of 5 sets over 3 sets, and 3 over 9 sets.

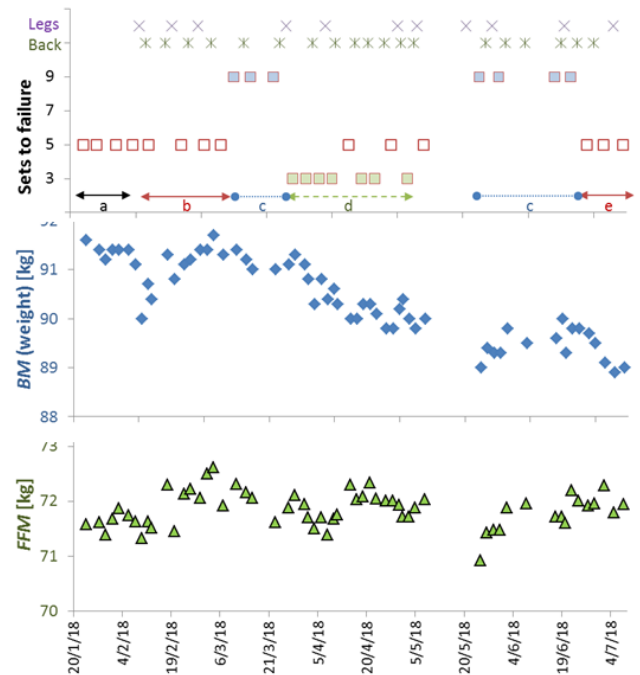


Figure 1. Overview of training period. Upper panel: Training sessions, sub-periods (a-e) and number of sets to failure for the chest. Middle panel: Body mass. Lower panel: *FFM* as calculated from equations (1) and (2)

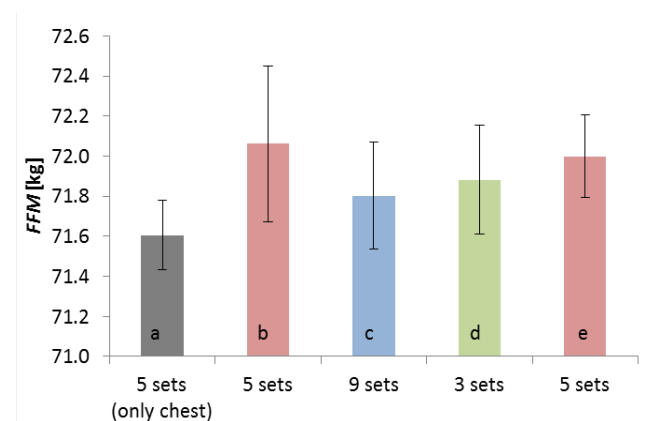


Figure 2. *FFM* for the different sub-periods with different (chest) sets to failure.

3.2. Recovery and Adaptation

Figure 3 presents the number of additional repetitions compared to the last session (for the first set of bench press) as a function of rest days for different numbers of sets to failure.

Figure 3a examines the 5 sets case where only chest was trained without legs or back training (sub-period “a”). Full recovery and adaptation happened on days 4 and 5. Figure 3b examines the 5 set case where back and legs were trained (sub-periods “b” and “e”). Full recovery happened on day 4 and adaptation on day 5. It seems that training the chest without any back and legs training in between has an advantage in recovery. Figure 3c examines the 3 set case (sub-periods “d”) and Figure 3d the 9 set case (sub-period “c”). With 3 sets to failure the recovery took 4 days and adaptation took place on day 5. With 9 sets to failure the recovery took 7 days without any adaptation.

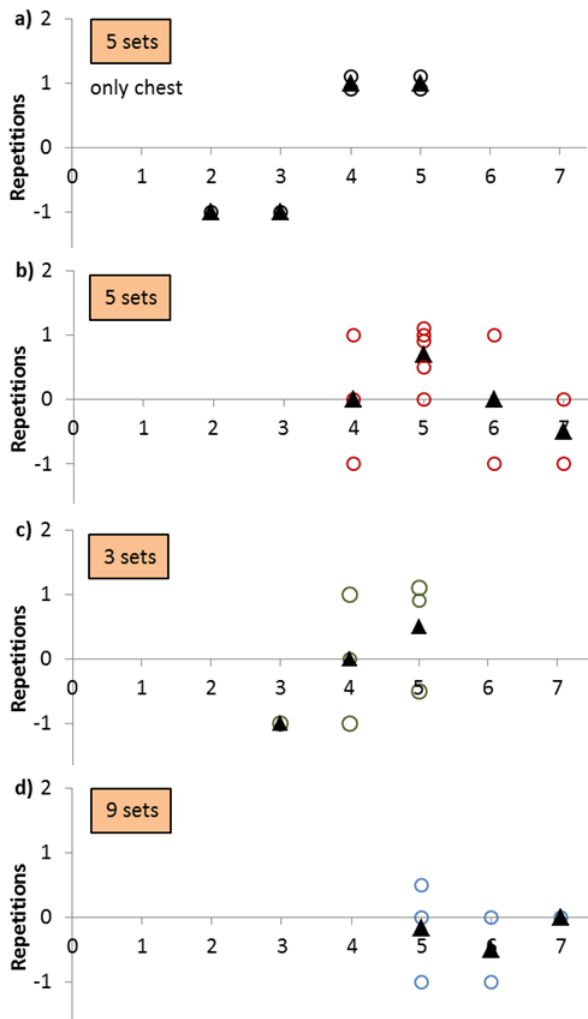


Figure 3. Time course of recovery for protocols with different number of chest sets to failure (a-d). Open circles are actual data. Solid triangles are mean values from actual data.

3.3. DOMS

Figure 4 plots the mean DOMS for the chest as a function of the recovery days. For 3 sets the DOMS lasted 2 days, while for 5 sets 3 days. For the sub-period that only the chest was trained, the DOMS with 5 sets lasted 2 days. In all cases the DOMS was low (only 1; just feeling the chest when flexing). For 9 sets, the DOMS was higher but lasted 7 days.

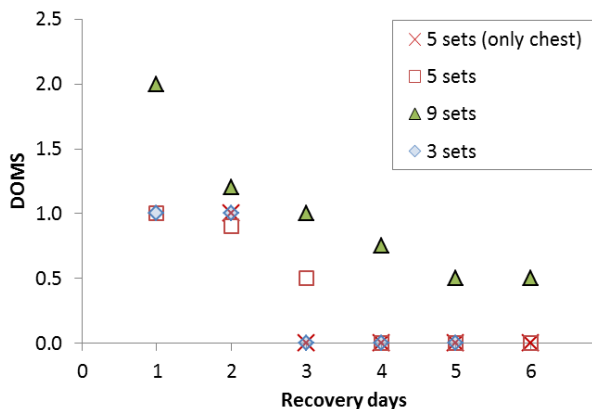


Figure 4. Mean DOMS for the chest in function of the recovery days. Individual points are not plotted for better clarity.

3.4. Motivation (Mood)

Figure 5 plots the additional repetitions for the first bench press set compared to the last session as a function of the motivation (mood) level of that day. The motivation levels varied only between 4 and 6. Nevertheless, there is a trend of strength increase (+1 repetition) with increased motivation (level 6). For the 9 sets case, even though there was some motivation, there was no strength increase, probably because no full recovery and adaptation had taken place.

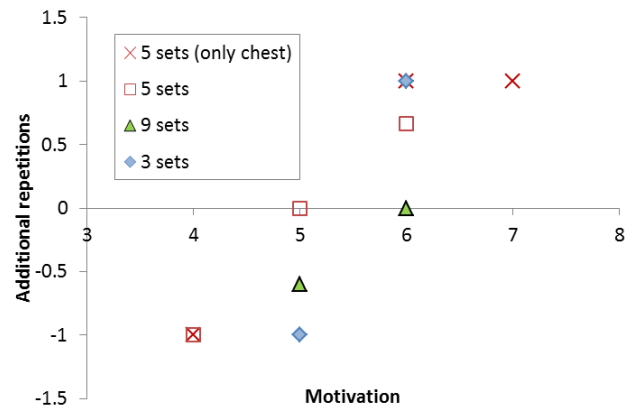


Figure 5. Additional repetitions compared to the previous session in function of the motivation (mood) level at that day. Repetitions refer to the first set of the bench press exercise

4. Discussion

Although this was not a study to compare the effect of the number of sets (to failure) to hypertrophy, there were some indications that 5 sets had better results than 3 sets, which were better than 9 sets. Besides the small difference of 0.2 kg, a detailed analysis of the recovery curves showed that with 9 sets to failure the subject needed 7 days to recover without any adaptation (super-compensation). With 3 and 5 sets the super-compensation took place on the 5th day, with 5 sets resulting in slightly better super-compensation. There are two important implications of these findings for the specific subject:

- The (chest) training frequency should be 5 days.
- The (chest) total number of sets to failure should be around 5.

4.1. Number of Sets

The literature generally reports that progressively higher weekly training volumes result in greater muscle hypertrophy [11] or strength [12]. Performing more than 10 sets per week resulted in higher hypertrophy compared to 5-9 sets, which were better than 4 or less weekly sets [11]. These results seem to apply for both trained and untrained individuals, although the studies with trained individuals are limited. For example, a study with trained persons demonstrated that the highest volume group (12 sets) displayed greater absolute increases in rectus femoris cross-sectional area compared to the medium (6 sets) and low volume (3 sets) conditions (but the differences were not statistically significant) [49]. Another study found no significant differences in fat-free mass increases when

training with 8 sets versus 4 sets or 1 set, although the mean results indicated better results with 8 sets to failure [50]. A recent study found that performing 14 sets had smaller improvements in hypertrophy and strength compared to 8 sets per muscle group (muscle training frequency once per week) [51], while another one found that only 5 sets resulted in increases of strength compared to a 10 sets protocol [52]. Thus, the results of this study, especially for 3 and 5 sets are in agreement with the literature. The worse performance with 9 sets is in agreement with some of the studies that were mentioned previously, but in contradiction with the meta-analyses [11,12]. One reason could be that all sets in this study were until failure, which is not necessarily true for the studies included in the meta-analyses. Training to failure has been shown to delay recovery [53]. Another reason could be the age of the subject. Most studies in the literature involve 20-year-old students, with better tolerance and/or recovery abilities than the 40 years old subject of this study. The worse recovery abilities of older persons has been shown in the literature [39].

4.2. Training Frequency (of a Muscle Group)

There are many studies that have examined the time course of recovery. Conducting one set (bench press) to failure needed 4 hours (trained women) to 48 hours (trained men) for recovery [54]. Four sets of 12 repetitions of bench press and another 4 sets of 12 repetitions of incline press needed 1 to 2 days for recovery for trained men depending on the repetition duration [55]. Another study of trained men with 8 sets of bench press found that recovery took 4 days [56]. The strength of trained men after eight sets (squat) of 3 repetitions returned to baseline in 24 hours; however, after eight squat sets of 10 repetitions 72 hours were not enough for recovery [57]. Five sets of 12 repetitions of leg press and another 5 sets of 12 repetitions of leg extensions needed 3 to 5 days for recovery for trained men depending on the repetition duration [58]. Eight sets of 10 repetitions (dumbbell curl) needed 2-5 days for recovery for trained men [59]. However, the strength of untrained men and women did not recover after four days when they did 8 sets of 10 repetitions of dumbbell curls [60]. Another study found that 80% of the participants completed within 1 repetition of baseline for various exercises at 48 hours except bench press (70%) and deadlift (60%) [61]. Studies that examined daily the strength recovery of trained persons with whole body training protocols found that recovery needed 2-3 days for 70-80% of the subjects [62], with adaptations taking place after 3-4 days [39]. When the sets to failure were increased from 3 to 7, there was indication that recovery needed longer [39]. For older persons (>50 years), the results showed that it can take more than 4 days for 70% of the persons to recover [62]. The 4-5 days of recovery of this study are in agreement with the studies discussed above and fiber histochemical analysis from trained trainees after typical weight training protocols [63].

Longer duration studies with protocols of different "muscle group training frequencies" have concluded that training 2 or 3 times per week yielded better strength results compared to once a week, with no apparent further advantage of three versus two sessions [64]. A meta-

analysis focusing on strength improvements found that for untrained and trained individuals, frequencies of 3 and 2 times per week respectively gave the best (strength) results [65]. Regarding hypertrophy, a review of various studies found no statistically significant difference in the daily rate of change of quadriceps size between "muscle group training frequencies" of two and three for untrained men and women [66]. A review of frequency studies equating total weekly training volume (sets \times repetitions \times resistance) indicated that frequencies of training twice per week promote superior hypertrophic outcomes compared to training once a week for both trained and untrained individuals [8]. It should be mentioned however, that other recent studies (not included in the previous reviews) showed no differences between 1 or 1.5 and 3 "muscle group frequencies" per week for trained persons [67], [68].

Based on the findings of this study (in particular Figure 3), Figure 6 can be used to explain the effect of different training sessions on the recovery of one person. The percentages plotted in Figure 6 were based on the strength loss at the end of the training session of the subject of this study and the strength increase with one more repetition (Equation 3): With 3 sets the strength was 8% less at the end of the training, with 5 sets around 18% and with 9 sets around 25% less. Adding one more repetition is equivalent to a 3.5% strength increase.

Based on Figure 6, workouts with 3-5 sets would need to be repeated every approximately 5 days for optimal results, while workouts with 9 sets every 7 days. Note though that for workouts with 5 sets, training every 4 or 6 days would result in similar (small) improvements because the super-compensation is at similar levels. This implies that different training frequencies can have similar improvements. Although in Figure 6 the super-compensation seems to last 1 day and then decreases to the original levels, the super-compensation can last for more than 3 days [69] before "detraining" or "involution". In one case the subject of this study trained the chest after 10 days and he could still increase the repetitions by 1.

The curves of Figure 6 are supported by the literature. For example, a study presented different super-compensation [70] or 1RM increases [58] for different workouts. Hard workouts that exceed a maximum stimulus, for example with eccentric repetitions, might not result in any adaptation (super-compensation) [34]. Workouts that do not reach the minimum stimulus will also not result in any adaptation. Workouts within the two limits will result in some adaptation. The adaptation however seems to be influenced by other variables such as other workouts for other muscle groups that will be discussed separately in the next section. The appropriate nutrition can increase the super-compensation [71]. Studies have shown that chronic stress can delay the recovery for a few days [72] or result in smaller improvements [73].

Alternatively, Figure 6 can be used to explain the effect of the same training session on different persons. For example, a study reported different recovery curves for the same workout [39]. For some people a specific workout is too hard (exceeds the maximum tolerated stimulus) and will not result in super-compensation. This has been reported when the workout has a lot of negatives [74]. For others, the workout might be the appropriate one, resulting in adaptation (super-compensation).

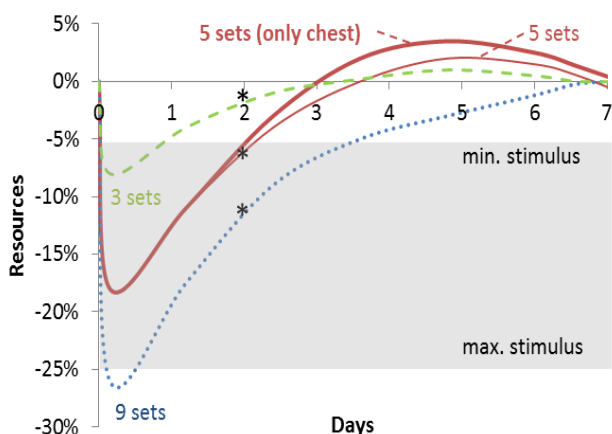


Figure 6. A theoretical example of the effect of different training sessions (different number of sets to failure) on recovery time (based on Figure 3). Resources could for example refer to the metabolic (e.g., glycogen stores), morphological (mechanical) (e.g., myofibril protein growth), neurological (peripheral or central fatigue and improvements), and/or hormonal systems. Asterisk indicates training of another muscle group.

4.3. Adaptation Energy (Recovery Resources)

One interesting finding of this study is the difference of the adaptations with 5 sets, with and without training of other muscle groups. When another workout was introduced during the recovery of the chest, the adaptation took place later and was lower compared to the adaptation without any training in between. This indicates that the concept of available “adaptation energy” introduced by Selye [75] might be applicable also to weight training: Adaptation energy (recovery resource or potential might be a better term) is a finite supply, presented at birth. As a protective mechanism, there is some upper limit to the amount of adaptation energy that an individual can use at any discrete moment in time (according to Selye). It can be focused on one activity, or divided among other activities designed to respond to multiple challenges. Later Goldstone [76] proposed that adaptation energy can be increased (created), but the increase gets slower with age. If an individual spends his adaptation energy faster than he creates it, he will have to draw on his resources. If an individual spends his adaptation energy slower than he creates it, he can store it, though the storage capacity has a fixed limit. If the concept of adaptation energy is true, then studies on training frequency that involve only one muscle group probably overestimate the true recovery time.

4.4. DOMS

DOMS becomes evident about 6-8 hours after an intense exercise bout and peaks at approximately 24-72 hours post-exercise [77]. The DOMS pattern of the subject is in agreement with the literature, but the magnitude was much lower. The subject reported much higher DOMS (around 7) for the legs. Comparing the DOMS curves (Figure 5) and the recovery curves (Figure 3) one can conclude that best training results (i.e. adaptation) probably can happen if one trains when not sore; however, letting too long time might not take advantage of the adaptation (super-compensation).

4.5. Motivation (Mood)

The motivation of the subject was medium with no particular motivation during the trainings as his scores showed (levels 4-6 out of 10). This has probably to do with the long history (20 years) of weight training of the subject. The mental techniques that were used (goal setting, music, external and internal focus) were the same for all trainings. Thus, small motivation variations may reflect the tiredness and recovery levels rather than the true motivation for achieving the specific workout goals. For this reason the term “mood” or “perceived recovery” might be more appropriate for what the subject called “motivation”. Monitoring mood is a simple and effective method for monitoring recovery: In a study, mood disturbance increased by 32% after only one week of intensified training and was restored after 1 week of recovery [78]. Another study showed that perceived recovery has good correlation with actual recovery [41].

Whatever the reason of the small changes of the motivation (mood) levels, the results showed a tendency of better performance with higher motivation. For the 3 and 5 sets cases the highest motivation (mood) (levels 6 and 7) also resulted in increases of strength. This was not the case for the 9 sets case, as the body had not recovered and could not exceed the previous maximum, even though the subject had the feeling that he could. The message is that motivation (mood) is important for good workouts, but other parameters (such as an appropriate training program, adequate recovery) are more important for long term effects.

4.6. Open Points and Limitations

Although this study shed some light on the recovery and adaptation from weight training with different number of sets, there are some points that need to be further addressed.

This study did not investigate what constitutes the best training protocol. Thus, the trainees should base their program on existing evidence regarding number of sets, training to failure, repetition range, rest time between sets (see, for instance, the studies in the introduction). Nevertheless, the repetition range that was used in this study is common for hypertrophy programs. The strength increase (in percentage) when exercising at the repetition range 2RM to 10RM translates to similar increase of 1RM [79]. Thus, the conclusions of this study should be applicable to both strength and hypertrophy programs.

The results of this study are based on one person and cannot be extrapolated to other populations, or even to the rest muscle groups of the specific subject. The program that was followed gave little attention to the legs. More frequent training of the legs could have influenced the chest recovery and the results. Addition of separate triceps or shoulders training could have also led to different conclusions. Younger persons, beginners, etc. might have much faster recovery times and demonstrate higher increase in hypertrophy or strength (e.g. [80]). Training with similar or higher number of sets, but not to failure could also lead to different results. Better or worse

nutrition, different life stress levels [81] could also influence the recovery of each person. Nevertheless, the principles and ideas discussed should be applicable to everybody.

The determination of the adaptation day(s) is not always straight-forward. The maximum number of repetitions can be influenced by many parameters; some of them were mentioned above. But even for well-defined and fixed conditions and parameters, it is highly unlikely that one would see linear progress. Thus, if once in a while the number of repetitions is not increased, this shouldn't be considered as stagnation. For the specific subject, even the best protocol of 5 sets every 5 days had no improvement (i.e. increase of the number of repetitions) every 4-5 workouts (Figure 3). As a recent review concluded, muscle growth will be slow for advanced trainees and consequently difficult to monitor, but the strength increase will not necessarily have a plateau [82].

The study did not look into periodization and whether a structured change of the number of sets could have achieved better results [83]. Similarly overreaching and tampering was not covered [84]. Any variation in this study was due to life obligations, rather than optimizing the performance. Nevertheless, it was shown that simple protocols (split routine with a few exercises and sets in this case) can work for advanced trainees as well. This expands the concept of keeping weight training uncomplicated [4] not only to beginners but also to advanced trainees (but non-competitive athletes).

Finally, this study did not investigate the mechanisms of recovery and adaptation or the models that describe it better (e.g. super-compensation model or fitness-fatigue model). Recent studies found that consecutive and non-consecutive whole-body weight training of the same volume had similar results [85], indicating that the fitness-fatigue model might be more appropriate and it might not be necessary to wait until full recovery and adaptation to train again. For non-athletes, being in a fatigue state might influence negatively the other life activities and might not worth for slightly better performance.

4.7. Practical Implications

The main message is that non-beginners and non-competing athletes can experimentally determine the recovery and adaptation time. Starting with evidence-based programs and with try-and-error the ideal workout frequency can be found. To accelerate the procedure of finding the right frequency, one should consider his DOMS (focus on days that the DOMS are gone) and motivation (mood or perceived recovery) (one should feel some motivation and not tired). This study additionally showed that the evaluation needs to be done with the complete training program in place, as avoiding some muscle groups could "overestimate" the recovery abilities.

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