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Muscle hypertrophy and strength increases after ten weeks of High Intensity Training

Results of an empirical study using bioelectrical impedance analysis

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1 Introduction

Training programs are comprised of the training parameters volume, intensity, duration, and frequency. All of those parameters do interact with each other. If one parameter increases, at least one of the others is usually reduced since recuperation capacity is limited. Following the model of supercompensation, recuperation from a workout is needed to make progress in terms of inducing the intended physiological adaptations.

When referring to strength training the parameters duration, volume and frequency are easily defined. The duration of a workout is defined as the time span between starting and finishing a workout. Training frequency is usually the number of workouts within a given space of time, e.g. a week. Training volume is usually defined as the sum of all sets performed within one workout or one week etc.

Training intensity, however, is a term that needs further consideration. When referring to cardio training, intensity is measured by the trainee's momentary heart rate and its percentage of the maximum. If a runner whose maximum heart rate is 200 beats per minute, has a heart rate of 142 beats per minute while running, then them momentary training intensity is 71%. If the heart rate increases or decreases, so does the training intensity. When referring to strength training, the definition of the intensity parameter needs further clarification.

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2 Training intensity and its implications for strength training programs

It was generally accepted that increases in muscular hypertrophy can best be achieved by applying high training volumes and moderate training intensity, allowing eight to fifteen repetitions. High training volume usually means performing several exercises per muscle group and multiple sets of each exercise. It was recommended to take sets to "failure", an expression which was often used to point out the fact that due to momentary muscular fatigue further repetitions could not be performed. Therefore, training intensity is often defined as "high" although only moderate resistance is applied. The reason is that the term "intensity" has only recently been redefined. It not only describes *relative intensity* (RI) which means the percentage of weight that can be used for a single repetition (% of the 1Repetition Maximum), it also refers to *training intensity* (TI) which is defined as "the possible momentary muscular effort being exerted" (Mentzer; 1996; 46). Consequently, training intensity is a vital aspect in designing, analysing, or evaluating training programs. The distinction whether or not sets were taken "to failure" was usually added to the information used to describe a training program. However, "training to failure" turned out to be an expression that needed further clarification. Some authors interpreted it as completing as many repetitions as possible with a given resistance whereas others understood the term "muscular failure" as a degree of local muscle exhaustion that makes it impossible to continue moving the weight at all. The generally accepted definition of training intensity now distinguishes four different degrees of training intensity:

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degrees of training intensity	
nRM	non repetition maximum Terminating a set at a fixed number of repetitions or a certain rate of perceived exertion when additional repetitions are possible.
RM	repetition maximum Terminating a set after the final repetition that can be completed in proper form.
PMF	point of momentary muscular failure Terminating a set when concentric failure has been reached, i. e. the final repetition cannot be fully completed due to fatigue.
PMF+	point of momentary muscular failure plus HITM Training beyond failure by applying high intensity training methods (HITM) like forced repetitions, drop set, cheating etc.

The four degrees of training intensity (Gießing et al.; 2005; 11).

In addition to high intensity training, a high-volume approach of several sets of each exercise was believed to be superior for inducing muscular growth. Whereas references regarding the necessity of high training intensities are supported by results of recent research, there is evidence questioning the necessity of high training volumes for inducing muscular hypertrophy.

The debate whether three or more sets of each exercise were really the best way to train for muscular hypertrophy was first put into question by Arthur Jones in 1972. In his "Nautilus Bulletin" Jones questioned the alledged superiority of multiple set training by pointing out that high training intensity was much more important than high training volume, i.e. several sets of each

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exercise. He claimed that once muscular failure was reached in one set, additional sets of the same exercise would not offer any further benefit and might even interfere with recuperation.

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3 Reasons for the alleged superiority of multiple-set training

The outstanding increases in muscle mass achieved by bodybuilders applying high volume training seemed to prove the superiority of multiple-set training over single-set training. However, this theory was based on conventional wisdom rather than the results of empirical research.

An early study, conducted in the 1960s appeared to confirm the alledged superiority of multiple-set training. This study by Berger (Berger; 1962; 168-181) found greater improvements in strength when each exercise was executed three times than when only one set was performed. Yet the difference between single-set training and three-set training was only a few percent. The study showed a three per cent difference in strength when three sets were done instead of only one. According to this study, increasing training volume by 300% offered an additional benefit of roughly 3%. The results of this study were often understood to be supporting the notion that "the number of sets used in a workout is directly related to training results" (Fleck & Kraemer; 1987; 57). However, several aspects had been overlooked when interpreting the results of the Berger study. One fact that was discovered only later was a minor mistake of transposed digits by Berger (Kieser 1998; 50-51; Philipp; 1999b; 27-33). Another aspect that had been overlooked and contributed to the alledged superiority of multiple-set training is the fact that this study actually showed no proportinal relationship between the number of sets performed for each exercise and the strength increases that can be achieved by that number of sets.

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The data presented by Berger (Berger; 1962) clearly show that the subjects who did only *one* set per test exercise improved their strength more than those subjects who did *two* sets (Berger; 1962; 172). Another fact worth mentioning is that Berger himself failed to prove the superiority of multiple-set training in later study (cf. Philipp; 1999b; 31). Nevertheless, several authors have suggested that high training volumes, i.e. training programs consisting of multiple-set training were better for gaining muscle mass than low training volumes like in single-set routines.

One reason why multiple-set trainng is still believed to produce results superior to those produced by single-set training is popularity of multiple-set training among bodybuilders and the results bodybuilders get from this kind of training:

> *"While scientific training studies have typically employed 1 to 4 sets per muscle group per session, elite bodybuilders are reputed to perform from 9 to 24 sets per muscle group in a single training session. Consequently it is generally accepted that high training volumes, say, 3-6 sets per exercise for 3-4 exercises (...) represent the best way to achieve myogenic increases." (Ostrowski et al.; 1997; 148).*

In the meantime several studies examined the question how the results of single-set training compare to those of traditional multiple-set training.

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4 Dissimilar results of studies comparing single-set training to multiple-set training

A review of several studies analysing the effects of single-set training vs. multiple-set training (Gießing; 2003; 27-32) showed no significant advantages of either method over the other one:

After the Berger study (Berger; 1962; 168-181) mentioned above 20 years passed before more studies were conducted that compared single-set to multiple-set training. Silvester et al. (Silvester et al.;1982; 30-33) had test subjects perform a routine consisting of bench presses, deadlifts, squats, biceps curls, triceps extensions and sit-ups three times a week for two months. Biceps strength increased eight per cent more for three-set training than for single-set training. Strength increases for other exercises than the biceps curl were almost identital regardless of the number of sets performed. In a study by Stowers et al. (Stowers et al.; 1983; 24-27) a similar study design was applied. Subjects performed the same exercises that were used in the study by Silvester (Silvester; 1982) with only two exceptions: Biceps curls and triceps extensions were substituted by latissimus neck presses and pull downs. The authors found no significant differences between single-set and multiple-set training and concluded that "... one set to failure was just as effective in developing strength as was performing three sets of six repetitions, regardless of the equipment used. This finding is contrary to the accepted belief that three sets of six repetitions is the optimum programme" (Silvester; 1982; 32). The last sentence of the quote refers to the conlusion drawn by Berger (Berger; 1962) whose deductive reasoning was that three set of six repetions were the best training volume for increasing strength.

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Another study that found no advantages of multiple-set training over single-set training was the study conducted by Terbizan & Bartels (Terbizan & Bartels; 1985; 267).

Messier & Dill (Messier & Dill; 1985; 345-351) compared a single-set Nautilus circuit weight training of twelve different exercises with a multiple-set training routine consisting of nine free weight exercises. No significant differences between both groups were found, however, the single-set group showed insignificantly greater strength gains than the multiple-set group: "In general, the isokinetic strength values elicited by the Nautilus circuit weight training group in this study compared favourably to those generated by the free weight group" (Messier & Dill; 1985; 350).

Westcott (1986; 104-105,123) compared strength increases of five different exercises of a Nautilus circuit weight training programme with two groups of subjects. One group performed two sets of each exercise and the other group applied a single-set approach. Strength increases were four per cent greater in the single-set group.

Jacobson (Jacobson; 1986; 315-318, 390) compared low-volume and high-volume training for one exercise (leg extensions). Strength increases were comparable in both groups of subjects.

Single-set programs and multiple-set programs consisting of nine different exercises that were trained three times per week were compared by Reid et al. (Reid et al.; 1987; 40-44) who found no significant differences between low-volume and high-volume groups.

Three sets of chin ups and dips three times a week for ten weeks did not result in significantly greater strength increases than a corresponding single-set routine studied by Westcott et al. (Westcott et al.; 1989; 98-100). However, subjects in the three-set group were able to do eight per cent more repetitions at the end of the study.

Graves et al. (Graves et al.; 1990; 504-509) examined the effects of either one set of back extensions or two sets for twelve

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weeks. Strength increases were sixteen per cent higher in the single-set group than in the two-set group.

Strength increased six per cent more after two-set training than after single-set training in a study conducted by Pollock et al. (Pollock et al.; 1993; 1080-1086). The exercise studied was cervical extensions and the differences did not reach the level of statistical significance.

Miller et al. (Miller et al.; 1994; 1122-1127) had subjects do 14 different exercises three times per week for 16 weeks. After 16 weeks strength had increased by 40 per cent in the multiple-set group and by 64 per cent in the single-set group.

Ryan et al. (Ryan et al.; 1994; 1678-1684) used the same study design and found no significant differences.

Welsch et al. (Welsch et al.; 1994; 138-144) who studied the effects of different training volumes of leg extensions and leg curls found no significant differences between between high-volume and low-volume training.

Proponents of the high-volume approach have argued that the reason that several studies could not prove the superiority of multiple-set training might have been the comparatively short period over which the training was carried out, implying that differences become obvious only after a certain time span. Therefore, it is interesting to look at the study by Kraemer et al. (Kraemer et al.; 1995; 195) who studied the effects of half a year of training consisting of either two or three workouts per week during which subjects performed bench presses and leg presses. After six months of training, no significant differences between high- or low-volume strength training were observed.

In a study by Starkey et al. (Starkey et al.; 1996; 1311-1320) subjects were divided into a high-volume group and a low-volume group. Subjects in both groups performed leg extensions and knee flexion three times a week. The high-volume group performed three sets of each exercise whereas the low-volume group did only one set of eight to ten repetitions. After 14 weeks strength increases in the single-set group were significantly higher for both exer-

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cises. Single-set training resulted in a strength increase that was six per cent higher for knee flexion and 16 per cent higher for leg extension.

Squats, push presses, bench presses, clean pulls, leg curls, bent over rows, and crunches were the exercises studied by Kraemer et al. (Kraemer et al.; 1997; 143-147) who had formerly untrained subjects train three days a week püerforming either one set per exercise or multiple sets. The multiple-set group did not train to failure but the single-set group did. After 14 weeks strength increases for the squat were significantly higher in the multiple-set group but not significantly different for the other exercises tested. Since the subjects had no weight training experience the authors concluded:

> *"The results of this study indicate that multiple sets, not performed to muscular failure, yield superior gains in 1-RM squat strength compared to one set to failure in moderately trained subjects. The results also indicate that, during the initial phase of training, volume is more important than intensity in increasing the 1-RM squat. Futhermore, after the initial phase of training, variation and intensity factors may be more important than volume considerations" (Kraemer et al.; 1997, 147).*

Ostrowski et al. (Ostrowski et al.; 1997; 148-154) had subjects perform leg presses and bench presses three times per week and divided subjects into three groups: A low-volume group (one set of each exercise), a moderate-volume group (two sets of each exercise) and a high-volume group (four sets of each exercise). No differences between the three groups were found after ten weeks of four weekly workouts, which led the authors to the conclusion: "All three training volumes significantly ($p< 0.05$) increased muscle size, strength, and upper body power, with no significant between-group differences" (Ostrowski et al.; 1997; 148).

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The exercises examined by DeHoyos et al. (DeHoyos et al.; 1998) and Pollock et al. (Pollock et al.; 1998) were bench presses, rows, biceps curls, leg extensions, and leg curls. There was a single-set group and a multiple-set group (three sets per exercise) three times a week for 25 weeks. No differences between single-set and multiple-set training were found.

In study that lasted 25 weeks and consisted of three workouts per week Vincent et al. (Vincent et al.; 1998; 163) studied the effects of single-set versus multiple-set training on leg extension strength and found insignificantly larger strength increases when subjects did only one set per exercise.

No diffences between single-set and multiple-set training were found by Hass et al. (Hass et al. 1998) for bench presses, neck presses, biceps curls, leg extensions, and leg flexion.

Sanborn et al. (Sanborn et al.; 1998) found insignificant advantages for multiple-set training for women.

Significantly greater increases in strength were reported by Marx et al. (1998; 167-168) for some exercises when multiple-set training was applied. However, results for single-set and multiple-set training cannot really be compared since the multiple-set performed 24 more workouts than the single-set group did.

Hass et al. (Hass et al.; 2000) made a very interesting observation. In their study subjects performed one set to failure on nine different exercises. After one year of progressive training subjects were divided into a single-set group and a multiple-set group. The multiple-set group increased training volume to three sets of each exercise for 13 weeks. Both groups not only improved muscular endurance and 1-RM strength but were also successful in significantly increasing lean body mass:

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> *"After 13 weeks of training, both groups had significantly improved their muscular strength, muscular endurance, and body composition. However, there were no significant differences between groups in the improvement of muscular strength or muscular endurance. Furthermore, both groups experienced similar improvements in body composition. The data show that performing additional sets of high intensity resistance exercise does not lead to significantly greater improvements in muscular strength, muscular endurance, or body composition than training using a single set in adult recreational weight lifters" (Hass et al.; 2000; 235).*

The effects of single-set versus multiple-set training for women were analysed by Schlumberger et al. (Schlumberger et al.; 2001; 284-289) who had the women do bench presses, latissimus pull downs, leg flexion, leg extensions, seated hip adduction/abduction, and crunches. Working out twice a week for six weeks, both groups significantly increased strength for leg extensions but unlike the multiple-set group the single-set group did not succeed in significantly improving bench press strength.

Carpinelli (Carpinelli; 2002; 323) points out that the alleged superiority of multiple-set training goes back to the Berger study and is hardly backed by empirical evidence:

> *"The genesis of the belief that multiple sets of each exercise are superior to a single set for maximal strength gains is one very poorly controlled 40 year old strength training study by Berger. The evidence to support the performance of multiple sets is extremely weak. Most of the evidence suggests that single and multiple sets produce similar increases in strength".*

According to Feigenbaum & Pollock (Feigenbaum & Pollock; 1999; 38) one very important advantage of single-set training is its effectiveness in terms of achieved improvements in relation to the amount of time spent training:

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"Single set programs are less time consuming and more cost efficient, which generally translates into improved program compliance. Further, single set programs are recommended for the above-mentioned populations because they produce most of the health and fitness benefits of multiple set programs".

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5 Single- vs. multiple set training: Results of a meta-analyses

For a meta-analysis of the available empirical data comparing single-set training to multiple set training 52 studies could be analysed. The results of the meta-analysis were published by Fröhlich & Gießing (2008, 9-34) in the book "Current Results of Strength Training Research".

This meta-analysis was based on the data of 1093 subjects. The subjects' average age was 27.2 (± 12.1) years and both male and female subjects were studied. Another interesting factor that could be taken into consideration is training experience. In 40.5% of the studies the subjects were untrained (N = 15) and 59.5% of the studies studied trained subjects (N = 22 studies).

There was an average of 2.5 (± 1.6) test exercises. The respective training programs consisted of 7.3 (± 5.2) exercises. The most common test exercises were the bench press for the upper body and the squat or the leg press for the lower body. In one study 24 different exercises were performed as a split-program that incorporated several different training sessions per week.

51.9% (N = 27) of the primary studies made a direct comparison of single-set training versus multiple-set training. In 48.1% (N = 25) of the primary studies the topic of single-set training versus multiple-set training was referred to but a statistically relevant comparison was not offered.

No general significant difference between the effect sizes of single-set training (ES = 0.70 ± 0.69) and multiple-set training (ES = 1.13 ± 1.06) could be found (t(1. 26) = -1.27; p = 0.21). When effect

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sizes were classified a medium effect for single-set training and a strong effect for multiple-set training could be demonstrated.

A qualitative analysis of the primary studies according to the authors of the primary studies can be summed up as follows: 19.2% (N = 10) of the 52 primary studies showed no significant difference between single-set training and multiple-set training. In 36.6% (N = 19) a significant difference could be found and in 44.2% (N = 23) efficiency was not analysed statistically. 23.1 % of the studies did not include a statistical analysis. In 17.3% of the studies the authors concluded that they did not find relevant differences between single-set training and multiple-set training.

The fact that a meta-analysis of 52 primary studies on the effects of multiple-set training vs. single-set training did not find significant differences between the two training methods is remarkable in itself since several authors have assumed that a higher training volume was likely to induce greater increases in muscle mass and strength. As a conclusion of this meta-analyses the authors point out that "… due to the lack of reliable information on what exactly induces the desired adaptations in terms of increases of strength and muscular hypertrophy on a physiological basis, recommendations as to which training method may be superior can only be made individually, considering the exact individual situation of each trainee, taking into account every relevant factor and training parameter. Especially the degree of training intensity that is applied is a factor that was not taken into consideration in most of the primary studies and needs further attention" (Fröhlich & Gießing; 2008, 26-27).

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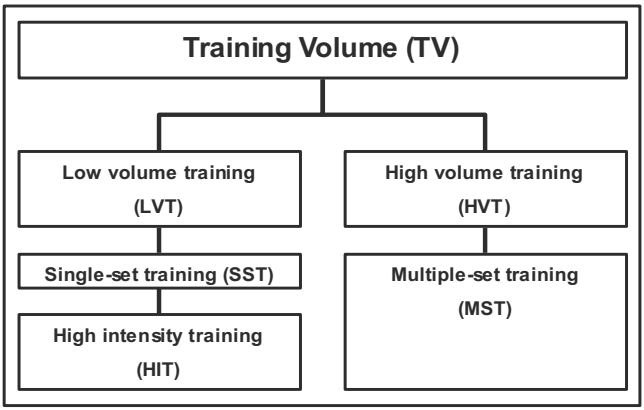
6 High Intensity Training vs. Three-Set-Training

The aim of the following study was to find out how the results of a high intensity training (HIT) program compare to those of a traditional three-sets-per exercise training program (3ST) in terms of increases in strength and muscle mass after a training period of ten weeks.

HIT is defined as kind of single-set training (single-set training). Only one set of each exercise is performed but this set is taken beyond the point of momentary muscular failure (PmF) by applying high intensity training methods like forced repetitions, cheatings, partial repetitions, drop sets etc. once the PmF has been reached.



Characterisation of the training methods HIT and multiple-set training by the factor training volume (according to Heiduk et al.; 2002; 5; Gießing et al.; 2005; 11).

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6.1 Subjects

43 subjects (23 men, 20 women) were randomly assigned to one of the following three groups: A three-set-training group (3ST), a high intensity training group (HIT) and a control group (CON). All subjects were sports students at the University of Landau.

The HIT-group consisted of 16 subjects (7 women, 9 men). The 3ST-group consisted of 14 subjects (10 women, 4 men).

group	sex	age (years)	height (cm)	weight (kg)
HIT-group	Ø	**23.3** (20;32)	**175.5** (164;192)	**68.6** (54.4; 84.5)
	female Ø	**23.7** (21;28)	**170.4** (164;176)	**53.5** (54.4; 73.6)
	male Ø	**23.0** (20;32)	**179.4** (167;192)	**73.1** (63.0; 84.5)
3-set-group	Ø	**22.0** (20;25)	**169.2** (161;185)	**62.2** (51.7; 87.6)
	female Ø	**21.6** (20;25)	**164.8** (161;179)	**57.4** (51.7; 64.7)
	male Ø	**23.0** (22;24)	**180.3** (175;185)	**74.0** (64.3; 87.6)
control group	Ø	**25.6** (21;34)	**176.8** (163;185)	**69.9** (55.6; 82.5)
	female Ø	**24.0** (23;25)	**166.3** (163;170)	**59.1** (55.6; 63.2)
	male Ø	**26.1** (21;34)	**179.9** (174;185)	**74.7** (67.6; 82.5)

Characteristics of the subjects

6.2 Training frequency and duration

The HIT-group and the 3ST-group trained twice a week. The control group did not do any weight training at all. The first workout of the week was Monday between 2 PM and 4 PM and the second workout was on Thursday between 1 PM and 3 PM.

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Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Workout 1			Workout 2			

Weekly workout schedule

Workouts were scheduled so that there was a rest period of at least 60 hours between each workout.

Training duration

It took the subjects of the 3ST-group an average of about 60 minutes to complete their training program, whereas the members in the HIT-group needed about 40 minutes on average to finish one training session, which adds up to a total training time of about 20 hours for the 3ST-group and about 13.5 hours total for the HIT-group.

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