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Current Results of Strength Training Research
An empirical and theoretical Approach



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Fundamental definitions of decisive training parameters of single-set training and multiple-set training for muscle hypertrophy

Keywords: single-set training, multiple-set training, hypertrophy, training intensity, strength training parameters

Introduction

One aspect of strength training that is being discussed controversially is the optimal amount of training volume necessary for inducing maximum increases in muscle strength and hypertrophy. Especially the concept of single-set training has been suggested to be a practical alternative to multiple-set training. Another factor that is directly related to this aspect is the degree of training intensity at which a set is carried out. The term *training intensity* is defined as "the possible momentary muscular effort being exerted" (Mentzer, 1996, p. 46).

When comparing the results of various studies it becomes obvious that there are various different definitions of single-set training. Single-set training has either been defined as

- one set of eight to ten repetitions to failure per muscle group (Schlumberger & Schmidtbleicher, 1999, p. 9) or
- as one set per exercise which implies that several exercises may be done per muscle group (Gießing, 2004).

In many important publications single-set training is not mentioned at all (Hollmann, Hettinger, & Strüder, 2000; Marées, 2002; Martin, Carl, & Lehnertz, 1993; Weineck, 2000). Hohmann, Lames & Letzelter (2002, p. 80) mention single-set training as a training method in strength training but do not offer a definition.

Fleck & Kraemer (2004, p. 188) describe single-set training as "performance of each exercise for one set [...] using heavy resistances and a few repetitions per set with a 5-minute rest between exercises". The American College of

Sports Medicine suggests one set of eight to ten repetitions to failure for recreational athletes who train with an emphasis on improving their health whereas elderly persons should rather keep their repetitions in the range between ten and 15 and should use lighter weights (ACSM, 1998, p. 983). Wilmore & Costill (2004, p. 107) mention single-set training as one of many strength training methods but do not give any information concerning the parameters number of repetitions, relative intensity (percentage of 1-RM) or training intensity. Boeckh-Behrens & Buskies (2000, p. 71) refer to single-set training as “one set per exercise or one set per muscle group respectively” and state that sets do not have to be carried to failure as it is often suggested as opposed to Philipp (1999, p. 31) who suggests that each set should be taken to failure or even beyond.

This shows that there exists considerable inconsistency concerning the definitions of the term single-set training itself and furthermore the degree of training intensity necessary in order to successfully apply this training method. This inconsistency is surprising especially considering the fact that single-set training is common in both recreational and competitive sports (Ebben & Blackard, 2001, p. 57).

The relevance of the parameter training intensity

The necessary training intensity is an aspect that has often been neglected when discussing training parameters applied in single-set training.

Therefore, Heiduk, Preuss & Steinhöfer (2002) differentiated between single-set training (SST) and high-intensity training (HIT) as an intense version of single-set training. They further differentiated between “high-volume training” (HVT) and “low-volume training” (LVT) defining LVT as a training volume of one or two sets per exercise and HVT as at least three sets per exercise. According to their definition SST and HIT are forms of LVT whereas multiple-set training (MST) has to be considered HVT (see figure 1).

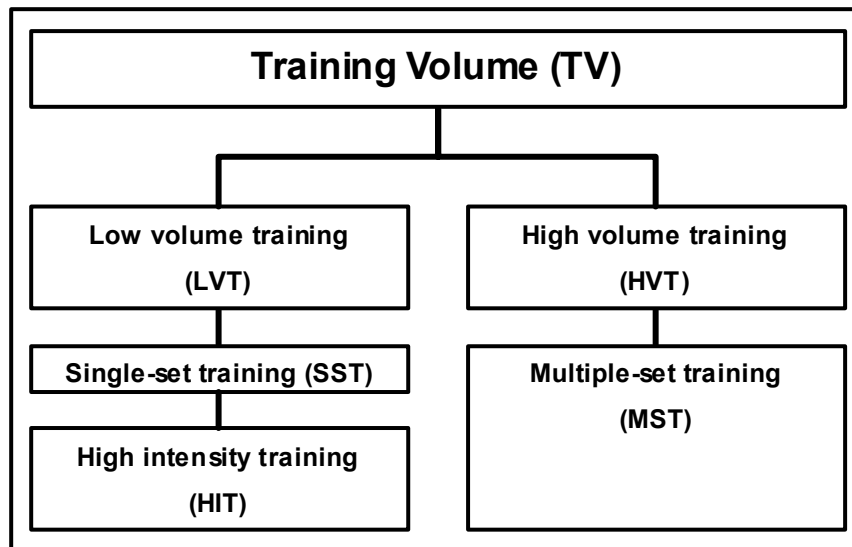


Figure 1: Differentiation of training volume (cf. Heiduk et al., 2002).

The factor training intensity should be dealt with in more detail since the publications by Zatsiorsky (1996), Buskies (1999a) and Boeckh-Behrens & Buskies (2000) imply that a distinction in SST and HIT does not cover all the necessary differentiations of this factor.

Tidow (1999, p. 52) suggests that hypertrophy training requires a compromise between the degree of tension and the time under tension at a given percentage of 1-RM. When training volume is calculated as *number of sets x number of repetitions x load*, the *time under tension* (TUT) is not included in the calculation. It has often been suggested by proponents of single-set training that this factor must not be ignored (Brzycki, 1995; Kieser, 1998). Remmert, Schischek, Zamhöfer and Ferrauti (2005) proved in their HIT study that TUT can be a useful parameter for the evaluation and regulation of strength training programs.

It can be summed up that there is a need to clarify the following aspects of SST and MST for muscle hypertrophy training:

- the controversy of SST either meaning one set per exercise or one set per muscle (group),
- the need to differentiate between different degrees of training intensity and
- repetition speed in terms of TUT.

Empirical studies

Recent meta-analyses have compared the results of SST to those of MST (Carpinelli, 2002; Peterson, Rhea, & Alvar, 2004; Rhea, Alvar, Ball, & Burkett, 2002; Rhea, Alvar, Burkett, & Ball, 2003; Winett, 2004; Wolfe, LeMura, & Cole, 2004). An analysis of the studies that these meta-analyses were based on shows that the inconsistency mentioned before is also apparent when comparing the different study designs.

Number of exercises per muscle group

Table 1 shows that only the studies by Borst et al. (2001), Capen (1956), Jacobson (1986), Kramer et al. (1997), Pollock et al. (1993), Schlumberger, Stec and Schmidtbleicher (2001) and Starkey et al. (1996) studied the results of one exercise per muscle group. The training programs in the studies by Borst et al. (2001) and Schlumberger et al. (2001) represent whole-body training programs.

Table 1: Number of exercises per muscle group in empirical SST studies

exercises per muscle group	study
1 exercise	Borst et al. (2001), Capen (1956), Jacobson (1986), Kramer et al. (1997), Pollock et al. (1993), Schlumberger et al. (2001), Starkey et al. (1996)
1 and > 1 exercise	Hass, Garzarella, de Hoyos and Pollock (2000), Kraemer (1997), Marx et al. (2001), Paulsen, Myklestad and Raastad (2003), Reid, Yeather and Ullrich (1987), Rhea, Alvar, Ball and Burkett (2002), Sanborn et al. (2000), Silvester, Stiggins, McGown and Bryce (1981), Stowers et al. (1983)
> 1 exercise	Ostrowski, Wilson, Weatherby, Murphy and Lyttle (1997)
no data	Berger (1962), De Hoyos et al. (1997), De Hoyos et al. (1998), Hass, Garzarella, De Hoyos and Pollock (1998)

This overview shows that defining SST as one set of eight to ten repetitions to failure per muscle group (Schlumberger & Schmidtbleicher, 1999, p. 9) does not cover the whole variety in which SST is used. Another problem is that many exercises do not only stress one muscle group directly but do also stress other muscle groups indirectly. Every multiple-joint exercise for the upper body does not only involve the target muscle but also smaller muscles contracting synergistically. It is not possible to perform bench presses without contracting muscles of the shoulder and the triceps. If one wanted to actually restrict training volume to one exercise per muscle group, multiple-joint exercise could not

be used at all. This would be the exact opposite of what the ACSM recommends:

“It is recommended that both exercise types be included in a resistance training program with emphasis on multiple-joint exercises for maximizing muscle strength and closed kinetic chain movement capabilities in novice, intermediate, and advanced individuals.” (ACSM, 2002, p. 368)

Fleck & Kraemer (2004, p. 159) also recommend using multiple-joint exercises since most activities of daily living in general and most sports activities in particular consist of multiple-joint movements.

Degrees of training intensity (DTI)

Training intensity can be rated by the criteria for terminating a set. There are four degrees of training intensity (DTI):

- (1) Reaching a certain number of repetitions that does *not* represent the repetition maximum (nRM),
- (2) the repetition maximum (RM),
- (3) the point of momentary muscular failure (PMF),
- (4) training beyond the point of momentary muscular failure (PMF+) by applying high-intensity training methods (HITM) like forced repetitions, cheating, drop sets etc. This methodical approach provides the athlete with an opportunity to maximise training intensity. HITM are sometimes also referred to as high-intensity techniques or systems (Fleck & Kraemer, 2004, pp. 187-206).

Looking at the empirical studies the most commonly used DTI for multiple-set training is the RM and for single-set training it is the PMF (see table 2).

Table 2: Degrees of training intensity of empirical studies concerning SST and MST. Studies using different degrees of training intensity are highlighted in *Italics*

SST		MST
nRM		<i>Kramer et al. (1997), Marx et al. (2001), Messier and Dill (1985), Stone, Johnson and Carter (1979)</i>
RM	Berger (1962), Capen (1956), Leighton, Holmes, Benson, Wooten and Schmerer (1967), Paulsen et al. (2003), Reid et al. (1987), Rhea et al. (2002), Schlumberger et al. (2001)	Borst et al. (2001), De Hoyos et al. (1998), De Hoyos et al. (1997), Hass et al. (1998), Hass et al. (2000), Ostrowski et al. (1997), Starkey et al. (1996) <i>Coleman (1977), Jacobson (1986), Kraemer (1997, study 2, 3 and 4), Kraemer et al. (2000), Sanborn et al. (2000), Silvester et al. (1981), Stowers et al. (1983)</i>
PMF	Borst et al. (2001), De Hoyos et al. (1998), De Hoyos et al. (1997), Hass et al. (1998), Hass et al. (2000), Ostrowski et al. (1997), Starkey et al. (1996) <i>Coleman (1977), Kraemer et al. (2000), Kramer et al. (1997), Marx et al. (2001), Messier and Dill (1985), Sanborn et al. (2000), Silvester et al. (1981), Stone, Johnson and Carter (1979), Stowers et al. (1983)</i>	Stowers et al. (1983)
PMF+	Pollock et al. (1993) <i>Kraemer (1997, study 2, 3 and 4), Jacobson (1986)</i>	

The difference between RM and PMF is not trivial. Quotes by Fleck and Kraemer (2004) show that there seems to be a problem distinguishing between RM and PMF:

„A repetition maximum or RM is the maximal number of repetitions per set that can be performed with proper lifting technique using a given resistance. Thus, a set at a certain RM implies that the set is performed to momentary voluntary fatigue.” (Fleck & Kraemer, 2004, p. 5)

Later they state:

„An exhaustion set is a set performed until no further complete repetitions with good exercise technique can be completed. Synonymous with exhaustion sets are the terms carrying sets to volitional fatigue, sets to failure, and sets to concentric failure. ... The use of a repetition maximum (RM) or an RM training zone (i.e., 4-6RM) in a training program indicates that sets were carried to exhaustion.” (Fleck & Kraemer, 2004, p. 196)

Obviously the terms *concentric failure* and *momentary voluntary failure* are not clearly defined. The difference between the RM and the PMF is that the RM means that the set is terminated after the final repetition has been completed in good form (Baechle, Earle, & Wathen, 2000, p. 406; Müller, 2003, p. 135; Tan, 1999, p. 291) whereas the PMF means that once the RM has been

reached another repetition is attempted but not completed. Therefore the last repetition is the failed repetition.

A part of the studies mentioned in table 2 (highlighted in Italics; Coleman, 1977; Jacobson, 1986; Kraemer, 1997; Kraemer et al., 2000; Kramer et al., 1997; Marx et al., 2001; Messier & Dill, 1985; Sanborn et al., 2000; Stone et al., 1979; Stowers et al., 1983) used different degrees of training intensity to compare SST and MST. Due to the varied training volume these studies only provide clues concerning the possible outcomes of different degrees of training intensity.

A different approach of dealing with different degrees of training intensity was shown by Buskies (1999b) and his “moderate strength training”. Training sets will be terminated at a certain rating of perceived exertion ranging from “moderate” to “heavy”, thereby using nRMs for all sets.

Repetition speed in terms of time under tension (TUT)

In most of the studies the recent meta-analyses are based on there is no information about repetition speed or TUT as table 3 shows:

*Table 3: Repetition speed in empirical SST studies (*3 phases of a repetition: concentric phase, isometric phase, eccentric phase)*

no/insufficient data	TUT per repetition concentric/isometric/eccentric* [sec]	
Berger (1962), Capen (1956), De Hoyos et al. (1997), De Hoyos et al. (1998), Hass et al. (1998), Jacobson (1986), Kramer et al. (1997), Leighton et al. (1967), Ostrowski et al. (1997), Paulsen et al. (2003), Reid et al. (1987), Rhea, Alvar et al. (2002), Sanborn et al. (2000), Schlumberger et al. (2001), Silvester et al. (1981), Stowers et al. (1983)	Coleman (1977), Kraemer (1997), Kraemer (2000), Kramer (1997), Pollock et al. (1993), Stone et al. (1979)	2/1/4
	Hass et al. (2000), Marx et al. (2001), Starkey et al. (1996)	2/0/4
	Borst et al. (2001)	2/0/3

For SST a TUT of five to seven seconds per repetition with an emphasis on the eccentric phase seems to be most common. Many authors suggest that a slow and controlled repetition speed has a positive effect on muscle hypertrophy because of

- a larger exhaustion of energy storages,
- a stronger muscle fiber activation (Hartmann & Tünnemann, 1993, p. 56; Hemmling, 1994, pp. 21-22; Kelso, 2000, p. 65; Westcott, 1995, p. 77; Westcott et al., 2001, p. 155) and
- a longer time under tension (Hollmann & Hettinger, 1990, p. 235).

A too fast execution of repetitions and too much momentum are believed to be factors which reduce the hypertrophy stimulus and might lead to injuries (Brzycki, 1995; Westcott et al., 2001).

Several authors have studied the effects of varied work loads on muscular performance (Almasbakk & Hoff, 1996; Jones, Bishop, Hunter, & Fleisig, 2001; McBride, Triplett-McBride, Davie, & Newton, 2002; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997; Schlumberger, 2000; Schlumberger & Schmidtbleicher, 2001; Schlumberger, Wirth, Liu, Steinacker, & Schmidtbleicher, 2003; Schmidtbleicher, 1980; Tidow & Wiemann, 1993; Toji, Suei, & Kaneko, 1997; Wilson, Newton, Murphy, & Humphries, 1993), however, none of the studies concentrated on training to failure for muscular hypertrophy using different repetition speeds and keeping the other training parameters the same.

Pereira & Gomes (2003) give an overview on studies applying different repetition speeds and find contradictory results:

“Although both slow and fast training improved performance, faster training showed some advantages in quantity and magnitude of training effects“ (Morrissey, Harman, Frykman, & Han, 1998, p. 221).

It has to be stated that study results concerning the effects of different repetition speeds are too inconsistent and even contradictory to draw a final conclusion, however, it is possible give fundamental definitions concerning the parameters *training volume* and *degrees of training intensity*.

Fundamental definitions

Based on the considerations explained above the following conclusions concerning definitions and specifications of single-set and multiple-set training are to be drawn (see table 4):

- (1) **Single-set training (SST)** means that one set per exercise is performed which includes the possibility of performing more than one exercise per muscle group.
- (2) **Multiple-set training (MST)** means two or more sets per exercise are performed. The break between sets takes at least 30 seconds (cf. Kraemer, 2002, p. 51).
- (3) There are four different **degrees of training intensity**: The non repetition maximum (nRM), the repetition maximum (RM), the point of mo-

mentary muscular failure (PMF) and the point of momentary muscular failure plus high-intensity training methods (PMF+).

Table 4: Overview of training volumes and degrees of training intensity

training volumes	
SST	single-set training One set per exercise is performed which includes the possibility of performing more than one exercise per muscle group.
HIT	high-intensity training Single-set training using HITM in order to train beyond concentric failure. One or more exercises per muscle group could be performed.
LVT	low-volume training One or two sets per exercise and only few sets per muscle group. One ore more exercises per muscle group may be performed.
MST	multiple-set training Two or more sets per exercise with a break of at least 30 seconds between two sets of the same exercise. One ore more exercises per muscle group may be performed.
HVT	high-volume training Multiple-set training consisting of three or more sets per exercise and several exercises per muscle group.
degrees of training intensity (DTI)	
nRM	non repetition maximum Terminating a set at a fixed number of repetitions or a certain rate of perceived exertion whereas 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 can not 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.

Conclusions

The definitions given above make it possible to distinguish between several degrees of training intensities which undeniably is an important factor in muscle hypertrophy training. It could be shown that the term single-set training has to be defined a one set *per exercise* which means that in a single-set training program several exercises may be performed for the same muscle group. Single-set training as well as multiple-set training can be performed at different degrees of training intensity. If high-intensity training methods are applied in single-set training, this version of SST is called high-intensity training (HIT). In rehabilitation and recreational training sets may be terminated at an nRM whereas in muscle hypertrophy training higher degrees of training intensity (RM, PMF or even PMF+) are generally applied.

If high degrees of of training intensity are applied, single-set training has been shown to be at least equally effective for muscle hypertrophy than multiple-set