PROPOSED INTENSITY AND PROXIMITY TO FAILURE RECOMMENDATIONS FOR IMPROVING RESISTANCE TRAINING STRENGTH

A Paper
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Health, Nutrition, and Exercise Sciences
Option: Exercise and Nutrition Sciences

November 2023

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Proposed Intensity and Proximity to Failure Recommendations for Improving Resistance Training Strength

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Resistance training, widely used in sports and recreation since the 1970s, can be used to achieve goals like muscular hypertrophy, strength, or endurance. Core principles to see noticeable adaptations include progressive overload, achieved by increasing sets, repetitions, frequency, weight, or training near muscle failure. However, high-intensity training may lead to chronic fatigue, which may negate the benefits. Research explores strategies like microdosing and high proximity to failure training to counter this. While high proximity to failure training may offer similar results to low proximity to failure training, microdosing may help coaches reduce fatigue, thus aiding athlete progress. Coaches must tailor training to consider injury risk, sport specificity, athlete commitment, and regular feedback for effective individualization. Ultimately, the chosen strategy should align with the athlete's goals, ensuring steady improvement. A proficiently individualized training program ensures that athletes achieve their goals, at a faster and more efficient rate.

ACKNOWLEDGMENTS

This paper would not be possible without the help of many great individuals. Thank you to Dr. Hackney for his guidance and feedback every step of the way, from choosing a topic, to assisting with formatting and revisions. His guidance has been invaluable to my experience at NDSU. Thank you to Dr. Christensen and Dr. Kotarsky who have taken time out of their schedules to revise and serve on my Master's committee to propose and defend this paper. Without their assistance, expertise, and willingness to help, this process would not be possible for myself, and for many other students. Thank you to the Graduate School for providing the opportunity to pursue knowledge and information in the HNES program that equips me to be a knowledgeable professional in the field, and to pursue research interests that are interesting to me.

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGMENTS iv

LIST OF TABLES vi

LIST OF ABBREVIATIONS vii

INTRODUCTION 1

Overview of the Topic 1

Statement of Purpose 5

Significance 5

LITERATURE REVIEW 7

Principles of Improving Strength and Hypertrophy 7

Implications of Training Intensity and Volume on Neural and Muscular Adaptation 10

Minimum Effective Dose and General Loading Recommendations 13

Advanced Resistance Training Techniques 15

Effects of Fatigue on Strength and Hypertrophy 18

Methods of Rating Training Intensity 22

Impacts of Proximity to Failure on Strength Adaptations 25

DISCUSSION 30

Proposed Recommendations 30

Limitations 31

Future Research 32

REFERENCES 33

LIST OF TABLES

Table | Page

1: Recent Literature Examining Strength Outcomes of Varying Proximities to Failure 27

LIST OF ABBREVIATIONS

1RM..One - Repetition Maximum

ACSM...American College of Sports Medicine

ATP ....Adenosine Triphosphate

CSA..Cross Sectional Area

DOMS ....Delayed Onset Muscle Soreness

DUP..Daily Undulating Periodization

EMG...Electromyography

HRR..Heart Rate Reserve

MRI ....Magnetic Resonance Imaging

NSCA ....National Strength and Conditioning Association

RIR ....Repetitions in Reserve

RPE ....Rate of Perceived Exertion

S-BIS ....Segmental Bioelectrical Impedance Spectroscopy

VBT..Velocity Based Training

INTRODUCTION

Overview of the Topic

Athletes and individuals across the world utilize resistance training to increase their strength, muscle hypertrophy, enhance their quality of life, and for recreational enjoyment. While resistance training has been anecdotally used since the late 1800's, it was not until the 1970's that this style of exercise began to gain popularity and research (Kraemer et al., 2017). As of 2015, greater than 30 percent of Americans meet strength training guidelines, which is equivalent to approximately 108 million Americans (Bennie et al., 2018).

Two primary goals of resistance training for power and strength athletes are muscular strength and muscular hypertrophy. While other goals exist, such as training for power or endurance, and while both of these training goals are popular, this paper will focus primarily on muscular strength and muscular hypertrophy. Muscular strength is defined as "the maximum force a muscle or muscle group can generate at a specific velocity" (Kell et al., 2012). Muscular hypertrophy (myofibrillar) can be defined as the increase of muscular cross-sectional area (CSA), and it occurs when the body is in a state of positive net protein balance (muscle protein synthesis exceeds the rate of muscle protein degradation) (Krzysztofik et al., 2019). Strength adaptations can occur both at the myofibrillar level, as well as the neural level. The increase in myofibrillar hypertrophy will increase muscle CSA, providing more cross bridges to elicit more force, but strength adaptations are generally through of at the neural level, and include increased rate coding, improved motor unit synchronization, and increased motor unit firing rate (Pucci et al., 2006; Vila-Cha et al., 2010).

The process of improving neural efficiency or promoting myofibrillar tissue growth for the trained athlete is not as easy as simply working hard and eating protein. It requires specific principles and progressions to continue to encourage the expected adaptations. The primary drivers of these progressions are volume, or the total amount of sets, repetitions, and load used during training for a specific muscle group or movement (Krzystofik et al., 2019). Another variable is intensity, which can be thought of as the difficulty of the bout, often expressed as an objective percentage of an athletes one repetition maximum (1RM) on a given exercise or velocity of the movement, or as a subjective rating on a scale of 10. This is commonly referred to as Rating of Perceived Exertion (RPE), or Repetitions in Reserve (RIR), respectively. (Helms et al., 2016).

Regardless of how an athlete chooses to track their volume and intensity, one overarching principle must be applied to make continued and measurable progress. This principle is termed, progressive overload, and is a concept that states that an athlete needs to progress a given variable of training over time to experience positive training adaptations (Peterson et al., 2011). In other words, one must gradually and systematically increase the specific stressor that will lead to positive training adaptations over time. This is the concept of progression. There are many variables that can be adjusted to achieve this goal. An individual can manipulate their training volume by increasing the number of repetitions or sets with the same load, or by increasing their load used for a similar number of sets or repetitions. Conversely, an individual can manipulate their training intensity by decreasing rest times, decreasing their proximity to failure, or by increasing their time under tension by altering tempo to their training. While simply progressing in training is not a difficult task, effectively progressing a training protocol to elicit a specific desired stress is a more challenging task (Peterson et al., 2011).

The complexity comes from understanding the variables that can be manipulated, and developing a plan that takes these variables into account to form a more well-rounded understanding of the athlete or individual, and how they respond to the training. Other important variables of resistance training that can be manipulated to achieve progressive overload are training frequency, or how often a movement is performed or how often a muscle is trained, type of the mode of the movement, time of movement or exercise duration, and the volume and intensity of the movement or session. A thorough resistance training program will consider all of these variables into the progression, which can be described as how the exercise protocol progresses and advances over time. All of these variables can be manipulated over the course of a training session, a microcycle, macrocycle, or any temporal reference time frame to help ensure the athlete is engaging in specific training that allows for progressive overload.

A scenario some individuals may encounter in their workouts when attempting to engage in progressive overload is that they may reach a point where they are no longer able to add meaningful progression to their training that is specific to their outcome goal. This can occur when athletes choose to 'train to failure' which elicits high levels of fatigue (Martorelli et al., 2017). Muscular failure is the point where no further repetitions can be performed. This is caused by accumulation of hydrogen ions from lactic acidosis, ion imbalances, depletion of energy stores, as well as neuromuscular fatigue where signaling from the nervous system to the local motor units becomes less efficient (Refalo et al., 2023).

Finding a solution that allows for adequate training overload, but that does not result in a significant acute or chronic fatiguing state is of utmost importance to the competitive athlete to allow for continued progress. Individuals can to some degree impact their recovery from a fatiguing stimulus. This can help through ensuring proper sleep and nutrition, to effectively managing volume and intensity (Martorelli et al., 2017; Budget, 1998; Santanielo et al., 2020). The chronic accumulation of fatigue may negatively impact an individual's performance though decreased neural drive, increased discomfort and soreness, and by taking a toll on an individual's mindset by increasing feelings of frustration or lethargy. The combination of these fatigue-related outcomes can lead to scenarios where an athlete or individual is no longer able to increase their training volume or intensity in a meaningful progressive manner, thus opening discussions for the importance of understanding fatigue with a more practical approach, to allow for a coach or individual to pivot their training or to better understand how to temporarily decrease a training stimulus to allow for recovery and future progressions.

There are two types of fatigue, commonly referred to within bodybuilding and powerlifting (i.e, sports that emphasize muscular hypertrophy and muscular strength, respectively), which are termed functional overreaching and non-functional overreaching (NSCA, 2017). Overreaching is the premise of slowly accumulating fatigue, which can 'prime' the nervous system to temporarily improve its neural coordination and efficiency beyond baseline as an adaptation from a given intense training dose (supercompensation), where overtraining is defined as accumulation of fatigue to the point of performance deficits (Carrard et al., 2021). There is a fine line between functional overreaching, and nonfunctional overreaching, and that is what competitive athletes aim to consider on each mesocycle of training, which is a periodized phase of training that can last anywhere from several weeks, to as long as a few months of the year (NSCA, 2017).

While an optimal training dose appears in the literature to be highly individualized, some general guidelines can be found for those wishing to increase muscular hypertrophy: Train 10-20 sets per muscle group per week, with most work being at an intensity of RPE 6-8 on the Borg CR10 scale (2-4 repetitions in reserve) (Krzystofik et al., 2019; Helms et al., 2016). This training intensity allows, pending repetition range of each set, for an adequate stimulus to Type IIa and

Type IIx muscle fibers (greater than 70% of 1RM), while not creating a large chronic fatigue stimulus that negatively impacts future training sessions (Krzystofik et al., 2019). These guidelines are also generally supported by the International Universities Strength and Conditioning Association, whom recommend 10 sets per muscle group per week, with varying loading ranges, with the majority of training falling within the moderate load zone of 65-85% of 1RM (Schoenfeld et al., 2021) It is important to keep in mind that these guidelines align more with individuals aiming for muscular hypertrophy. For individuals looking to maximize their muscular strength, the current body of literature could be bolstered to provide more definitive and practical guidelines beyond what is currently known and available.

Statement of Purpose

This paper aims to provide current best practices and will suggest future research topics for maximal progression for athletes and individuals looking to better improve their muscular strength. While training for muscular hypertrophy and muscular strength have significant overlap in their core principles and implementations, more distinct guidelines should be presented for strength adaptations, and gaps in the literature should be identified.

Significance

Understanding an optimal proximity to failure for neuromuscular strength and local hypertrophy is of significance for the more than 500,000 competitive athletes in the United States alone (NCAA, 2022). Development of more efficient training protocols for athletes who take training seriously can improve performance, reduce the risk of injury, and mitigate fatigue that can present in and affect areas of an athlete’s life external to training (Jones et al., 2017). There is currently no scientific consensus in the literature that displays training considerations and protocols that display adequate research to provide guidelines on an average proximity to failure, specific to the perceived number of repetitions in reserve of a training set, that is intense enough to stimulate adaptation, but easy enough to avoid unnecessary training fatigue and work which can lead to overreaching and overtraining syndrome. While the current body of literature, consisting of research articles, position statements, textbooks, and other forms of media, do provide general guidelines for improving muscular strength and hypertrophy, developing a better understanding of how emerging research on proximity to momentary muscular failure and the practical implications for training, is an area of opportunity to provide more clarity to coaches and individuals who want to maximize muscular strength.

LITERATURE REVIEW

Principles of Improving Strength and Hypertrophy

To improve hypertrophy and muscular strength, there are three main scientific principles that need to be applied to see progress: Progressive Overload, Specificity, and Variation. The American College of Sports Medicine (2009) defines progressive overload as: “the gradual increase of stress placed upon the body during exercise training”. This principle states that to continue to see progress, one must increase stress of training through manipulation of one or a combination of variables including, training volume (primarily sets of a movement and/or repetitions), intensity (objective: load, subjective: RPE) or decreasing rest times between sets or exercises to increase metabolic stress, or through changing the tempo of a movement resulting in greater time under tension on the working muscle(s) (ACSM, 2009).

The principle of specificity refers to the fact that you see progress due to adaptations that have occurred as a result of a training stimulus that is closely related to the sport-specific demands. The adaptations are specific to the stimulus. This principle, like progressive overload, has many involved variables such as muscle action, speed of movement, muscle groups trained, volume and intensity, and energy systems involved. The final principle is variation. Using an effective training program that details progression through variation is vital for continued progress. Variation is required to ensure that a training stimulus remains both specific to the goal, as well as continually challenging enough to provide progressive overload. The two primary variables of variation are volume and intensity. The common link between all three of these principles is the importance of manipulating training volume and intensity in a manner that progresses over a span of time, remains relatable and applicable to the training goal, and is manipulated to ensure the stimulus remains fresh and challenging.

The ACSM details a handful of best practices and guidelines for certain training goals. This section will primarily focus on the muscular strength aspects of training. The ACSM details two models of progression that are beneficial for muscular strength: Linear periodization and Undulating periodization. Linear periodization can be characterized as a phase of training that begins with high volume and low intensity, and over the training mesocycle intensity increases and volume decreases (ACSM, 2009). This has shown beneficial results, especially in novice lifters, over the course of six months of training on both strength and hypertrophy. Experienced lifters may need more detailed and specific training. The undulating periodization is a non-linear progression that combines multiple training goals into a single cycle of training. This may be more beneficial for advanced athletes that need to improve multiple areas of fitness to reap significant gains in their primary area of specificity (ACSM, 2009). An example may be an advanced powerlifter whose primary goal is increasing their 1RM. The undulating periodization allows for this lifter to train high intensity and low volume compound movements with high specificity to their sport, but then also improve the lifters hypertrophy (or total work capacity, depending on the specific athlete's goal) and general fitness through low intensity, high volume training in the same session or separate training session that may have significantly less specificity to their sport specific goals (ACSM, 2009). Despite this, the adaptations that occur from these general fitness adaptations may have carried over to the athlete's specific goal. The primary variables being manipulated in an undulating periodization are generally training volume and intensity (ACSM, 2009).

The ACSM discusses in the same article the importance of volume on progression outcomes. Manipulation of training volume can impact neural, hypertrophic, metabolic, and hormonal responses in the body, all of which can improve or regress training adaptations if not dosed correctly (ACSM, 2009). The primary methods of altering training volume are through sets, repetitions, and exercises performed per training session. While the article mentions that there has not been a clear optimal amount of training volume to perform for optimal results, it is mentioned that good results are seen with 8 sets per muscle group per week with 8-12 repetitions per set. While there is also not an optimal training intensity, as this is also goal specific, for strength adaptations it is mentioned that most training should occur at 85%-100% of 1RM for 3 to 6 sets per week (ACSM, 2009).

The adaptations that occur from a resistance training protocol, similar to the recommendations above, include increased rate coding, improved motor unit synchronization, and increased motor unit firing rate. Pucci et al. (2005) provided insight on how high intensity isometric resistance exercise impacts motor unit firing by testing the quadriceps in 20 men over the course of 9 training sessions across 3 weeks. Researchers tested force, voluntary activation, and motor unit recruitment/firing rate at intensities 50, 70 and 100 percent of the maximal voluntary contraction for the day. Subjects had to hold each contraction for 3 seconds. Force was measured by a dynamometer at the knee joint, and muscle activation was determined by surface EMG and intramuscular EMG. The results of this research determined that, compared to control groups, maximal voluntary contraction increased significantly in only four training days. It was also found that motor unit activation increased with force output (Pucci et al., 2005).

While the prior study investigated adaptations in participants training at 100% maximal voluntary contraction, this may not always be practical in everyday training due to fatigue accumulation and concerns with load management. A study conducted by Vila-Cha et al. (2010) investigated motor unit behavior in submaximal contractions. This study compared motor unit behavior of endurance training versus strength training over the course of eighteen sessions (3 sessions per week for 6 weeks) amongst sedentary men (Vila-Cha et al., 2010). The endurance training group performed training on a bicycle ergometer, and training intensity was determined based on heart rate reserve (HRR). The duration of training and intensity in relation to HRR increased every 2 weeks. The strength training group used bilateral resistance training on their legs (Leg press, leg extension and leg curl). Other upper body exercises were also tested (Bench press, latissimus pull down, trunk flexor and extensor exercise). The subjects trained at 60-70% of 1RM for 3 sets of 13-15 repetitions. This was increased to 70-75% for 3-4 sets of 10-12 repetitions, and the last two weeks were performed at 70-85% for 3-4 sets of 8-12 repetitions. During each visit, the subject was tested on an isokinetic dynamometer with EMG to assess force, maximal voluntary contraction, and motor unit activation. As expected, after 6 weeks, the endurance training group improved time to failure, but not maximal voluntary contraction or rate of force development. The strength training groups improved their maximal voluntary contraction and rate of force development, but no improvements were made in time to task failure. The findings of this research show that training at maximal intensity may not be required for strength improvements (Vila-Cha et al., 2010). Additionally, it continues to support that training adaptations are specific to the training performed and reinforces the importance of training specificity to match the training goal.

Implications of Training Intensity and Volume on Neural and Muscular Adaptation

Two of the primary variables to adjust to ensure progressive overload is occurring are training volume and training intensity. Mangine et al. (2015) provides insight into the importance of training volume. This paper compared high volume training with high intensity training with the goal of determining if volume or intensity is a better driver and predictor of progress (Mangine et al., 2015). The participants in this study were 33 resistance trained adult males.

They were randomly split into a high intensity, low volume training group, and a moderate intensity, high volume training group. The participants underwent eight weeks of resistance training in their specified discipline. They found that while both training groups increased their strength significantly, the high intensity, low volume training group improved significantly more than the moderate intensity, high volume training group (Mangine et al., 2015). This study is a crucial addition to this paper as it explains which variable of training may be of higher importance when considering optimal ways to improve strength.

Stress is required for improving strength. To improve strength, both mechanical tension and metabolic stress are required. One way to increase stress on mechanical tension is through modulating intensity. Recommendations by Schoenfield et al. (2017) state that training for strength should occur at 80% of 1RM. This recommendation is based on Jenkins et al. (2017). This study had 26 male participants randomly assigned to a high intensity (80%) or a low intensity (30%) group and trained the leg extension movement to failure three times per week for six weeks (Jenkins et al., 2017). They found that1RM strength improved 27.7% in the high intensity training group versus 9.5% in the low intensity group. They also note that along with these adaptations, there was evidence of greater neural adaptation through increases in voluntary activation assessed by EMG. They conclude that these neural adaptations may be linked to strength improvements (Jenkins et al., 2017). One interesting note for the purposes of this paper, is that the applicability of this protocol may not reflect real world training. It is important to understand that training at higher intensities improves strength, but to make an accurate recommendation, we should also compare how other higher intensities compare in strength adaptations. One proposed way to do this is with the same experimental design, with three groups, one training at 70%, one at 80%, and one at 90%. A final consideration is if training to failure makes a difference in strength. This topic is discussed later in this literature review more in depth. To assess how far from failure one should train, it should be understood what implications fatigue plays on: neural adaptations, acute and chronic performance, stress of mechanical tension, and metabolic stress.

Training intensity also plays a role in muscle quality and architecture. While the Otsuka et al. (2022) is primarily focused on preventing or limiting sarcopenia, it provides useful information that may be applicable to younger populations. This paper was able to collect data on 55 participants aged 50 to 79 years old (Otsuka et al., 2022). This was a single-blind randomized and controlled trial. They were assigned to a no exercise, low intensity exercise, and moderate intensity exercise group in which they followed their assigned protocols three times per week for 24 weeks. Loads of 40% were used for the low intensity group, 60% for the high intensity group, and no load for the no exercise group. They were tested pre, intra, and post-trial for muscle CSA, lean mass, and muscle electrical properties through segmental bioelectrical impedance spectroscopy (S-BIS). The outcomes showed that the moderate training intensity improved muscle quality and quantity greater than the low intensity and no training intensity group, as found by magnetic resonance imaging (MRI) and S-BIS. The low intensity group only improved muscle quantity (Otsuka et al., 2022). A limitation of this article in relation to this paper is that it is focused on older populations, thus, further research will be provided below to supplement these findings. These findings are important, as muscle architecture and quality are important for strength outcomes. Muscle architecture influences CSA, and muscles with large CSA have greater capacity to generate force (Otsuka et al., 2022). An example may be a muscle with more parallel muscle fibers as a result of a greater CSA. This muscle would be expected to be able to produce more force. Additionally, greater CSA can also improve the leverages of a muscle compared to it’s joint by improving the angle of pull, as well as producing more torque (Otsuka et al., 2022; Lee et al., 2021). This is supported by Lee et al. (2021) who found that muscle thickness was different and dependent upon the joints and muscles primarily used among athletes of various anaerobic sports (e.g., wrestling, soccer, combat sports) (Lee et al., 2021). The findings also showed that muscle thickness (i.e., rectus femoris, vastus lateralis, and gastrocnemius) correlates with anaerobic power.

Conversely, or in conjunction with, modulating intensity, an athlete or coach can also adjust training volume progressively to stimulate neural and muscular adaptations. Peterson et al. (2010) explains some of the impacts of volume manipulation on resistance exercise. This paper is specifically in relation to volume load, which is one way to monitor volume. Volume load adds up all of the weight lifted during a given time frame and is typically found by multiplying total sets of an exercise by total repetitions performed, by the weight used. This research investigated muscle hypertrophy, muscular strength and power, muscle activation, and muscular endurance (Peterson et al., 2010). The findings of this literature review show that volume load is a strong predictor of 1RM strength, and that those with a higher capacity to complete and recover from a greater amount of volume, exhibit greater strength (Peterson et al., 2010). These findings provide important background information into how strength can be predicted and may suggest that seeing an athlete's volume load capabilities increase may be indicative of improved strength.

Minimum Effective Dose and General Loading Recommendations

With the research above noting the importance of volume and intensity for improving strength adaptations and demonstrating that training at maximal intensity, or to momentary muscular failure, may not be necessary for strength or hypertrophy, it is important to understand that the polar opposite of training with too little volume or too little intensity may not be conducive to specific maximal strength adaptations. Androulakis-Korakakis et al. (2020) aimed to provide insight into determining the minimum training stimulus requirements. While 2,629 studies were found for this review, only 6 met the inclusion criteria of the researchers and were included in this review (Androulakis-Korakakis et al., 2020). From compiled results, it was found that at least two training sessions per week were required for significant increases in 1RM strength. It was also determined that the specific volume, in terms of sets, repetitions and intensity were less clear, which may be due to individualization of an athlete, such as training age, training goal, biomechanics, and more. It is, however, at least suggested that a minimum of one set per exercise should be performed at an intensity of 60-80% of 1RM to effectively see strength improvements (Androulakis-Korakakis, et al., 2020).

Schoenfield et al. (2021) published a paper where a new paradigm was proposed in regard to optimizing muscular adaptations across a variety of ‘loading zones’. In regards to strength, the authors mention that typically the ‘left side of the continuum’ is referred to as the strength zone (lower repetition ranges) (Schoenfield et al., 2021). It is discussed that the literature body does not support the existence of distinctive repetition ranges to improve strength, as strength improvements are more dose-response related. It is also mentioned that for strength improvements, that periodic exposure to heavy load may be all that is required to keep a strength athlete in practice (Schoenfield et al., 2021). Despite this, some generalizations may still be applicable and practical to give coaches and trainers a starting point for athlete progression and periodization. When training for maximal strength, training repetition ranges at or under 6 repetitions may be a beneficial way to influence mechanical tension, skill practice, and metabolic energy system such as phosphocreatine and anaerobic glycolysis. While these are important distinctions to make, the previously mentioned article is a breakthrough study suggesting that there may be many different ways to manipulate and progress maximal strength.

This is hypothetical but is also investigated by Morton et al. (2016). This research found that between high vs. low load per repetition resistance training programs, the mass lifted per repetition was not a primary determinant of changes in protein synthesis nor in muscular hypertrophy when performed to failure and volume was not matched (Morton et al., 2016). There were also no strength differences noted, as both groups significantly increased strength. These findings support the theory of a much more complex continuum, or spectrum of individualization to find an 'optimal' training stimulus. These findings suggest that an athlete can achieve similar 1RM strength with lower loads, if more overall volume is performed. To determine an optimal training stimulus, fatigue, injury risk, and an athlete's psychological preference may need to all be considered to prescribe optimal resistance training protocols (Morton et al., 2016).

Advanced Resistance Training Techniques

Krzysztofik et al. (2019) summarized the existing body of literature relating to advanced resistance training methods to determine what characteristics are constant between various training techniques to elicit the primary goal of resistance training: an increase in muscular CSA (Krzysztofik et al., 2019). The primary methods of compiling literature relating to advanced resistance training techniques were through MEDLINE and SPORTDiscus for articles published between 1996 and 2019. The researchers compiled 1088 studies for further evaluation and assessment of validity. This was achieved by requiring comparisons to different resistance training techniques performed in traditional training protocols, and outcome measures that assess muscle hypertrophy, and/or muscular strength, and / or training volume tolerated. They further specified for these outcome measures that for muscular hypertrophy there needed to be objective measures to assess change in CSA or thickness, and for strength outcomes it was required that a heavy repetition maximum was completed pre and post (1-5 repetitions). Training volume was assessed by the changes in load, volume, and time under tension to muscular failure. It was determined after the initial 1088 studies were screened, that 30 valid studies were included in the paper. The techniques evaluated by this paper were: Tempo Eccentric Technique, Accentuated Eccentric Loading Method, Low-Load Resistance Training Under Blood Flow Restriction, Cluster Sets, Supersets and Pre-Exhaustion, and Drop Sets and Sarcoplasmic Stimulation Training Technique. The researchers concluded that optional training for muscular hypertrophy should comprise both mechanical tension and metabolic stress. The researchers recommend that optimal training should consist of three to six sets of six to twelve repetitions in conjunction with short rest periods (60 seconds) at an intensity of 60%-80% of 1RM. There should also be progressive overload each week in any of the mentioned variables (Krzysztofik et al., 2019). This research is important as it provides clarity to best practices for muscular hypertrophy, and the compiled research shows that progressive overload is necessary for continued progress. It does not answer the question of what relative intensity to failure is optimal, and whether specificity of training is important.

Martorelli et al. (2017) began to answer the question of optimal training intensity for strength and hypertrophy. This research was conducted on 89 female participants aged 18 to 25 (Martorelli et al., 2017). The women followed a 10-week resistance training program that divided participants into one of three groups: the repetitions maximum to failure group performed three sets to concentric failure twice per week. The repetitions not to failure with an equalized volume group performed four sets of seven repetitions. The repetitions not leading to failure group performed three sets of seven repetitions. Researchers assessed pre and post the following outcomes: Maximal strength isokinetic peak torque, muscle endurance, and muscle thickness. All groups improved their 1RM strength, but there were no group-time interactions of significance, as well as muscle endurance which also had no group-time interactions of significance. There were significant outcomes in muscle thickness, as the repetition not to failure group was the only group that did not see a significant improvement in this category (Martorelli et al., 2017). This may be due to a decrease in total training volume, which is shown in studies to be a primary driver of muscular hypertrophy (Mangine et al. 2015, Peterson et al. 2010, Krzysztofik et al. 2019). The finding of no significant improvement in strength while training to failure versus non-failure does not provide adequate clarity to the primary purpose of this paper: Determining an optimal subjective training intensity for strength gains.

Santanielo et al. (2020) shed light on a similar question regarding training to failure versus non-failure. This research had 14 male participants (Age: 23.1 +/- 2.2) who were well trained (5.6 yr +/- 2.6) test each of their legs in a different protocol (Santanielo et al., 2020). They randomly assigned each participant's legs to either a resistance training to failure group, or a resistance training to non-failure group. They trained the legs of the participants twice per week for ten weeks. While the training to non-failure subjectively stopped the set ‘near but before’ failure, they took notes of how many repetitions in reserve the subjects stated they had in reserve. Both groups trained with 75% of their 1RM and were reassessed for strength half way through the trial period. The repetitions to failure group completed 12.0 +/- 2.1 repetitions per set, while the repetitions not to failure group completed 10.4 +/- 2.6 repetitions. What the researchers reported after their statistical analysis was that both groups improved their muscular hypertrophy, strength, and muscle architecture similarly, as well as experienced similar EMG amplitude. This is an important study as it assesses trained individuals rather than untrained as other research in the pool investigates. The researchers note that it is common thought to believe that as training experience increases, so does the need to train with higher intensity (Santanielo et al., 2020). The results of this paper would not confirm this statement, yet do not provide a clear insight on whether one method is more beneficial than another for progress. While there may be no differences in strength with training sets are matched, one hypothesis in defense of training to non-failure may be that there is less accumulation of fatigue from the non-failure group with similar outcomes, and that as a result, more total weekly volume may be tolerated, allowing for more progress over a longer period.

Effects of Fatigue on Strength and Hypertrophy

Fatigue is an important implication to making progress. Finding the balance between training stimulus and fatigue management may be compared to walking on a tightrope. The NSCA (2017) released an article on their site titled “Functional and nonfunctional overreaching and overtraining”. In this article, they mention how important it is to individualize training to the athlete, mentioning that a training stimulus that exceeds recovery capabilities leads to nonfunctional overreaching, and if this persists, it can lead to overtraining (NSCA, 2017). Nonfunctional overreaching is a negative state that occurs when accumulation of peripheral and/or central fatigue occurs at too great of a degree to recover and improve performance from. Typically, with functional or planned overreaching, an athlete will accumulate fatigue from a bout of training that temporarily decreases their performance. After a rest period (Deload, taper, etc.) their training performance should increase from its base level, a concept known as super concentration. When performance is hindered after a rest, this may be associated with nonfunctional overreaching. Continuing to train through this period of reduced performance for an extended period may lead to overtraining, which is a serious chronic condition of significant reduction in performance. This may take weeks to fully return to baseline from closely monitored recovery, and through slow and smart progressions in training (NSCA 2017).

Fatigue from resistance training can occur because of tissue damage and tension, metabolic stressors, and neural stressors. Zajac et al. (2015) provides explanations on how each mechanism of fatigue may occur, as well as their implications on training. It is mentioned that metabolic stressors can cause local fatigue, such as decreases in glycogen, phosphocreatine, and adenosine triphosphate (ATP) (Zajac et al., 2015). Additionally, the depletion of these stores, caused as a result of intense exercise, leads to increases in metabolic waste products and hydrogen ions within the muscle. Additionally, muscle damage from resistance training may lead to ATP and calcium leaking which decreases the ability of these stores to be used for contraction. This leaking is due to microtrauma at the sarcomere level, and may be primarily caused from muscular tension, more so than metabolic stressors (Zajac et al., 2015). This is supported by Pereira and Machado (2008) that found that creatine kinase levels, the byproduct of metabolizing phosphocreatine, are significantly elevated 24 hours post exercise regardless of rest duration between sets (Pereira & Machado. 2008). This research may suggest that volume is a prominent predictor of local fatigue.

To further discuss metabolic stress on local fatigue, a paper by Ribiero and colleagues in 2008 discusses exercise-induced microinjuries on 1- or 3-minutes rest time interval between series (Ribiero et al., 2008). By examining the effects of 1 vs. 3 minutes of rest interval between sets of bench press, cable pulldowns, military press, triceps curl, leg press, leg extensions, and leg curls, and training these on non-consecutive days. The researchers were able to collect blood samples at 24, 48, and 72 hours post exercise bout. What they were able to determine from the results were that creatine kinase levels may be positively correlated with training status;

however, they did not appear to differ between rest intervals of 1 minute versus 3 minutes (Ribiero at al., 2008). This leads to the topic of "microdosing" training, and raises the following question: If rest time does not affect local muscle fatigue at 1 minute versus 3 minutes, can this be extrapolated for longer rest durations? Can splitting a workout into multiple sessions per day, or even across multiple days, allow an athlete to perform greater volume with less local fatigue, and if so, does this pose any benefit to athlete's pursuit of strength?

Microdosing training is the act of spreading out the training workload into smaller but possibly more manageable sessions that allow for more consistent short-term performance, as well as reduction of injury risk. The act of microdosing training is often categorized into a similar vein as load management, where the goal is also to reduce injury risk and improve performance but may result in less total work being performed. Another potential benefit to microdosing training is that it may be able to better compensate for busy schedules of student athletes, or other busy individuals. By completing the same amount of work spread across an entire week, or even across a day, it can be easier for busy individuals to find pockets of time to complete their workouts, without needing to adjust a busy schedule to arrange an entire training session all at once. It is important to note that this use of microdosing on a daily or weekly temporal scale is in actuality a style of stimulus distribution more closely relates to "distributed practice".

Legitimate microdosing of training is more similar to minimum effective dose in the sense that the goal is distribute the stimulus, and do less of a given stimulus, that still produces the desired outcome for the athlete. In the context of this paper, this would mean finding the minimum combination of volume and intensity that is conducive to progress, and splitting it up across a training day, week, or mesocycle. These smaller subsets of training should be broken down into a total percentage of the desired training dose, rather than looking at it from a timed session. For example, half of the desired daily training dose should be performed in a morning session, and the remaining half in an evening session, rather than a single longer duration exercise session. This aims to reduce acute fatigue across a training day, rather than condensing a greater amount of acute fatigue into a single bout, thus decreasing performance.

With microdosing, the subset training sessions do still need to have some degree of difficulty and stimulus to be effective. Despite this, individuals may be able to maintain or improve performance despite significant decreases in training volume. A study by Bickel and Cross (2011) found that microdosing training with volumes as low as one third volume was sufficiently able to not only maintain neuromuscular strength adaptations, but also this was adequate to notice improvements in hypertrophy among 20–35-year-old individuals over the course of 32 weeks of training (Bickle and Cross, 2011). Use of micro-dosing for maintenance of adaptations for athletes, especially in season, appears to be a beneficial use of micro-dosing in a practical application. However, when it comes to performance improvements, specifically towards strength adaptations, the literature has yet to provide clear trends and recommendations. A hypothesis in favor of microdosing for strength improvements may be related to just how strength is typically expressed and improved. Unlike hypertrophy, strength adaptations appear to benefit more closely to high force and power outputs, under less acute fatigue. By breaking up bouts of intensity across a given time frame, and with the lesser central fatigue accumulation from potential decreases in training volume, microdosing appears to have vast opportunities for practical use and implementation once more is discovered.

In relation to strength improvements, especially amongst well-trained individuals, the nervous system plays a crucial role in strength development, and implications of central fatigue may be significant. Taylor et al. (2016) discuss central fatigue more in depth. It is mentioned that fatiguing exercise leads to changes in the neuromuscular pathway of the corticospinal tract (Taylor et al., 2016). These changes include decreased motor unit firing rates at both submaximal and high intensity exercise, but greater declines are present under high intensity tasks. Additionally, motor neuron excitability declines with frequent fatiguing contraction, requiring greater descending drive to produce the same force output (Taylor et al., 2016).

Conclusions on muscle fatigue may be that intensity plays a large role in central fatigue, where volume plays a more significant role on peripheral fatigue. While some degree of fatigue can be a positive stressor required for adaptation, the article by the NSCA mentioned how too much fatigue leads to nonfunctional overreaching and overtraining (NSCA, 2017). Understanding that training with higher volume can elicit the same strength adaptations as high intensity training, it raises the question, and may support the notion, that training for strength does not require high intensity training. This raises the question of defining an optimal proximity to failure of higher volume, lower absolute intensity training.

Methods of Rating Training Intensity

Understanding that training at high intensities or with high volume induces both central and peripheral fatigue, it is crucial comprehend how load selection and relative intensity generates a positive or negative training effect for individuals. Partaking in training at near-failure or greater, or that involve frequent and consistent exposure to high absolute training intensity can lead to non-functional overreaching. Conversely, training at low relative or absolute intensity may lead to detraining of an athlete. This leads to the original question: What is the optimal training intensity for improving strength?

There are many ways to rate training intensity. The primary, and most common, is assigning a percentage for a given repetition range. Thompson et al. (2019) provides an explanation on how percentage-based training can be prescribed. It was mentioned that after finding a 1RM, or through completing a near-maximal intensity set, and estimating 1RM, training loads can be expressed as a percentage of the maximum, based on the desired relative intensity (Thompson et al., 2019). An example given was one repetition at 85% of the 1RM. This example would provide a low proximity of failure (generally a single repetition at this intensity would allow for four to five more repetitions to be completed).

Other more subjective methods of rating intensity exist and are commonplace in intermediate to advanced resistance training athletes. Helms et al. (2016) mention a popular subjective rating method known as rating of perceived exertion, or RPE. RPE is generally prescribed based on the Borg CR10 scale when it comes to resistance training, which is a scale of 1-10 that allows an athlete to determine how difficult their training set is (Helms et al., 2016). There are multiple ways to apply RPE to training, but generally an athlete will rate each set, exercise, and or session with an associated RPE. On a micro level, when looking at specific training sets, an athlete will typically inversely associate their RPE rating with the number of repetitions they believe they could perform until failure. This is known as Repetitions in Reserve, or RIR. While these two techniques are different, in application the similarities outweigh differences. RIR may be easier for novice athletes to learn. A major drawback of the RIR and RPE style of rating intensity is human error (Helms et al., 2016).

Helms cites Hackett et al. (2012) which found that athletes tend to rate a set as easier than it actual may be among intense sets taken to volitional failure, but accurately could rate the number of repetitions they had in reserve (Hackett et al. 2012). As a result, this research may lend greater practical application of the use of RIR in training settings, rather than RPE alone.

The primary benefit of using a subjective intensity rating system in training is due to natural variations of human performance from session to session (Helms et al., 2016). These include sleep, nutrition, and life stress. These factors can improve or detract from training performance, and the RPE scale allows for these fluctuations in performance, whereas percentage-based training does not. The goal of RPE is to achieve a predictable and suitable training stimulus for the training session, or intra-session changes in performance (Helms et al., 2016).

One way to add more validity and objectivity to RPE based training is with the addition of mean repetition velocity tracking (Zhang et al., 2022). Modern technology has allowed for devices such as encoders to become more commonplace in both high-end training facilities, as well as budget-friendly options available for individual athletes. Velocity Based Training (VBT) is typically used to tell an athlete metrics of their training, generally based on barbell velocity. It can provide information such as power production, mean and peak velocity, eccentric velocity, and fatigue across set and session depending on the model of encoder. An athlete must develop an individualized velocity profile for each specific lift they intend on tracking. This generally consists of a baseline near-maximal intensity test, with training data taken with reps every 5-10% of 1RM or estimated 1RM. This profile creates a regression model that allows for each data point collected (an athlete's velocity on any given rep) to associate the repetition velocity to a predicted 1RM value. Once this profile is completed, a coach or trainer can assign a velocity range to work within on any given day, much like prescribing RPE or RIR values to a set, or a percentage of 1RM to a set (Zhang et al., 2022). A drawback of velocity-based training is that it does not account for technique variance or effort. The most valid results will come from repetitions completed with consistent technique, and maximal concentric effort applied. For this reason, it may be beneficial to use VBT as a tool to assist in RPE ratings, rather than to primarily train within a VBT range.

Impacts of Proximity to Failure on Strength Adaptations

The way that many training programs are prescribed and periodized, in addition to volume and absolute intensity, is through proximity to failure (Helms et al., 2016). All modern training intensity prescribers, from RPE and RIR, to VBT and Percentage training all consider some degree of proximity to failure. While RPE and RIR are more closely correlated with proximity to failure, and VBT is often tied closely to RIR, even percentage-based training must consider realistic expectations for repetitions at specific percentages that can be performed (Helms et al., 2016). For example, it would be unrealistic to expect a lifter to perform two repetitions with 100% of their 1-repetition maximum. Percentage based training attempts to prescribe realistic repetition expectations at a set percentage for an athlete after an individualization phase is used to determine how many repetitions an athlete can perform with specific percentages of 1RM.

The influence and impacts of understanding and applying knowledge of proximity to failure is described by Refalo et al. (2023). This paper discusses that when training at a higher proximity to failure, greater mechanical tension occurs, and higher threshold motor units are required to increase or maintain force output (Refalo et al., 2023). Additionally, neuromuscular fatigue increases as one trains closer to failure which can negatively impact contractile function that can result in decreases in absolute load lifted and/or mechanical tension. To accurately assess the impact of proximity to failure on recovery and fatigue, the researchers assessed changes in mean repetition velocity with a fixed load from pre-exercise to post exercise, and then assessed recovery at 24- and 48-hours post exercise. Twelve males and 12 females were recruited to perform two pre-trial sessions, and three trial sessions which included the resistance training session followed by two testing sessions. The pre-trial sessions were used to conduct repetitions to failure assessment. Each testing session consisted of a different experimental trial in a random order: momentary muscular failure (FAIL), 1-RIR, and 3-RIR. All experimental trials were performed with six sets of 75% of the subjects 1RM. The findings of this research conclude that acute neuromuscular fatigue is increased with training closer to muscular failure. The researchers suggest that the correlation between proximity to failure and neuromuscular fatigue exhibits a linear relationship. An important additional finding, although not significantly significant, is that the 3-RIR training group showed signs of increased velocity after 24 hours post training, which was not present in other training groups. With additional research, this may suggest that training farther away from proximity to failure may lead to neurological improvements via supercompensation / priming effects. The researchers also denote a higher discomfort in subjects training to failure and 1-RIR compared to 3-RIR, and greater acute fatigue leading to decreases in repetitions performed in subsequent sets in the FAIL and 1-RIR group, compared to 3-RIR. These findings are important considerations for training volume, as training to muscular failure, while allowing for greater volume in initial sets, may lead to an overall decline in volume performed over the course of a training session. These decreases in volume and increases in neural fatigue may lead to decreases in contractile function, force output, and mechanical tension, which may lead to poorer strength and hypertrophy improvements over time (Refalo et al., 2023).

These findings are supported by multiple other research papers investigating the effects of training to failure, versus training to near-failure, and even training that is not-near failure.

Table 1: Recent Literature Examining Strength Outcomes of Varying Proximities to Failure

Paper	Subjects	Training Methods	Results	Equated Volume / Intensity?
Refalo et al., 2023	Male and Female Adults - Trained	Randomized to Failure, 1-RIR, 3-RIR.	Lesser proximity to failure increases acute fatigue	Volume: No Intensity: Yes
Ruple et al., 2023	Male and Female Adults – Trained	Randomized to 0-1 RIR or 4-6 RIR	Similar strength outcomes in both groups	Yes
Robinson, 2021	Male Adults – Trained	Randomized to 1-3 RIR, or 4-6 RIR	Similar strength outcomes in both groups	Volume: Yes Intensity: No
Santanielo et al., 2020	Male Adults – Trained	Randomized to Failure or Non-Failure	Similar strength outcomes in both groups	Volume Load: No

As shown in the literature above, in Table 1, recent literature examining proximity to failure, and its effects on strength outcomes, shows that strength outcomes appear to be similar in high and low RIR proximities to failure. Based on this, one may conclude that an individual can train either way and elicit the same outcomes. While this does appear to be the trend in the literature, more needs to be taken into consideration before prescribing a proximity to failure. These considerations include individual tolerance to discomfort, potential injury risks of training to failure, sport specificity, and preference.

A thesis paper by Robinson in 2021 explains how training to failure appears to increase creatine kinase levels post-exercise and increase delayed onset muscle soreness and acute muscular fatigue at a higher rate than a non-failure proximity. This is an important consideration when considering individual motivation and buy in to training. For some serious athletes, training in a way that induces muscular soreness and fatigue may be a rewarding sign to themselves that can be identified as a feeling of achievement and hard work, thus increasing their psychological buy in and desire to train. To others the side effects of this fatigue may be too extreme and uncomfortable, where it has the opposite effect and rather dissuades the individual from wanting to regularly exercise. These are both subjective considerations that an athlete or trainer need to discover on a case-by-case basis, either through discussion, surveying, or to develop quickly as their athlete begins their exercise regimen.

Another consideration to choosing an appropriate proximity to failure would be sport specificity. In many “ball” sports, peak strength may not be the most important performance attribute, especially when compared to other attributes such as power, speed, agility, hand-eye coordination, and more. Despite this, strength training with the explicit goal of getting stronger is commonplace in athletic facilities around the world. In applications like this, the athletes may be better off training at a higher proximity to failure as peak strength is not a sport-specific goal. Conversely, in an application such as powerlifting, where peak force production is the primary performance attribute of the sport, an athlete may consider training at a lower proximity to failure more frequently as it aligns with sport specific demands. Being able to gain exposure to near-maximal loads and taking repetitions to near-failure is a sport specific skill that may be difficult to develop without specifically periodizing training to allow an individual to gain this exposure.

While sport specificity is a large consideration for choosing an appropriate proximity to failure, injury mitigation may be one worth weighing with more thought and diligence for an individual. Training at a low proximity to failure consistently increases risks of injury due to high levels of mechanical tension and the compounding effects of peripheral fatigue on a muscle and joint (Willardson, 2007). As a result, the risk of injury should be considered on an individualized basis by the trainer or coach, and the best decision for both long term and short-term performance should be considered in creating a periodized plan that works best for the individual.

One potential solution to the above three talking points would be uniquely periodizing the resistance training program to tailor the “best of both worlds”. If an analysis or discussion has been completed between a coach and individual, and it is determined that they do want to train at a lower proximity to failure, then the coach may be able to periodize training in a fashion that begins a training mesocycle at higher proximity to failures, and progress it to lower proximity to failure, while manipulating volume as they would depending on the goal or season of training at the time. More research may need to be completed to validate a periodization scheme that progresses in this fashion.

DISCUSSION

Proposed Recommendations

Based on the current body of literature, it is evident that more research needs to be conducted before a clear prescription for proximity to failure and intensity of training can accurately be prescribed. An additional consideration may be that many of these nuanced methods of training appear to be dependent on the individual employing them. Pain and discomfort tolerance, recovery capabilities, and resistance to fatigue all appear to be different from person to person. Recommendations based on the existing body of literature may be currently interpreted below.

A proper resistance training program to improve strength should consider acute and chronic fatiguing conditions and variables such as volume, intensity, proximity to failure, as well as an athlete's biomechanics and leverages for a given lift, injury risk, and external recovery variables such as nutrition, sleep, and general stress. Manipulation of these variables should be in a periodized manner, employing progressive overload of volume and/or intensity. Specificity of training movements, as well as volumes and intensities, should be conducive to the goal of becoming stronger at a given movement. Once these goals are determined, an athlete may train with a moderate proximity to failure (4-6 RIR) to potentially promote supercompensation effects of training, or with a low proximity to failure (0-1 RIR), depending on their motivation, buy-in, discomfort tolerance, and sport specificity. For a moderate proximity to failure, training should be coupled with 'a few' sets at high percentages of 1RM, and closer to muscular failure as a training block progresses, while allowing for greater time for recovery between sessions. Those training with a low proximity to failure should opt to keep most training at lower absolute intensity (65-85% 1RM) and consider performing less training volume. Both of these styles can be achieved through the DUP, or Daily Undulating Periodization, method, which allows for changes of intensity and volume through each micro and macro cycle.

The primary volume for moderate proximity to failure training should be performed at slightly lower absolute intensities (70%-85%), that still allow for type-II fiber firing, but that accrue less central fatigue with similar improvements for strength due to increased training volume. These sets should additionally be performed at a farther proximity to failure, to improve both central and peripheral adaptations to the training stimulus, with a lower accrual of central fatigue. Training sets should begin with 10 sets per muscle group per week, comprised of 1-4 sets per exercise per training day. While these sets may cause a higher degree of peripheral fatigue, an appropriate rest of 48 hours between training the same muscle group may allow for adequate recovery, especially with farther proximity to failure. Lifters and coaches should prescribe at least 8 sets per week, per muscle group, broken up into at least two training sessions per muscle group.

Limitations

Major limitations of the current body of research is that it is unknown how proximities very far from failure (5-10 repetitions) affects strength improvement, as well as how specifically training at moderate proximity to failure (3-RIR) may differ in strength improvements at various percentages if volume is equalized, and if volume is not equalized. It should also be explored if the increase in acute central fatigue from proximities close to failure is definitively negative. Specific training scenarios such as competition peaking phases typically intentionally employ overreaching via accumulated chronic fatigue to enhance the supercompensation period after a period of recovery.

Future Research

A brief proposed specific research study that may lead to enhanced conclusions is as follows: Trained subjects, both male and female, perform experimental trials with 70%, 77.5%, and 85% of 1RM. These trials will be randomly coupled with the proximity of failure of 5-RIR, 3-RIR, and 1-RIR for a total of nine experimental trials, with testing periods at 24- and 48-hours post-trial. This is a similar design to the Refalo et al. (2023) study but provides better insights to strength outcomes at various training intensities, and a broader range of proximity to failure.

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