

Opinion

Intensity of effort and momentary failure in resistance training: Are we asking a binary question for a continuous variable?

James P. Fisher^{a,*}, James Steele^a, Dave Smith^b

^a School of Sport, Health and Social Science, Solent University, Southampton, SO14 0YN, UK

^b Research Centre for Musculoskeletal and Sports Medicine, Manchester Metropolitan University, Manchester, M15 6BH, UK

Received 24 November 2021; revised 24 January 2022; accepted 18 February 2022

Available online 6 March 2022

2095-2546/© 2022 Published by Elsevier B.V. on behalf of Shanghai University of Sport. This is an open access article under the CC BY-NC-ND license. (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

1. Introduction

There is a growing body of research supporting the idea that a plethora of health benefits can result from resistance training using a low volume, high-effort approach (e.g., increased metabolic rate and bone mineral density, a reduction in blood pressure, and improved muscle quality and insulin sensitivity, among others^{1,2}). Further, muscular strength and muscle mass—primary goals and benefits of participation in resistance training—are independently strong predictors of longevity and quality of life.^{3,4} Thus, many have sought to identify how the manipulation of resistance training variables might lead to “optimal” adaptations in such outcomes, as evidenced by repeated attempts over recent decades to review the literature and provide consensus statements on this topic.^{5–10} One variable that is often hotly debated within resistance training is training to failure. The present opinion piece presents a narrative based upon 2 recent systematic reviews and meta-analyses that ask, and propose to answer, the question: “To optimize adaptations, should I train to momentary failure or not?”^{11,12}

For this piece, momentary failure is defined as the point trainees reach where “despite attempting to do so they cannot complete the concentric portion of their current repetition without deviation from the prescribed form of the exercise.”¹³ Furthermore, we have termed this momentary failure rather than muscular failure herein because there is no current consensus on where the lack of continued ability to carry on with the task despite attempts to do so arises (e.g., centrally, at a neural level, or peripherally, at a motor-neuron endplate or muscular level).

2. An argument for training to failure

A primary benefit of performing resistance training to momentary failure is that it creates parity within and between groups when considering other variables.¹⁴ Dankel et al.,¹⁴ for example, suggest that exercise prescription based upon performing a given number of repetitions at a given load for a given number of sets (e.g., 3 sets of 10 repetitions at 80% 1-repetition maximum), does not allow for the large individual variability relating to effort and fatigue. Indeed, a large variance in the number of repetitions possible at given relative loads is well established.^{15–17} More recently, 2 reviews have confronted the accepted wisdom in strength training—that of the repetition-maximum or strength-endurance continuum—suggesting instead that adaptations are not load specific, but rather a range of loads can produce similar adaptations where exercise is performed to momentary failure.^{18,19}

With this in mind, we know training to momentary failure is sufficient to induce increases in muscle size and strength, but we are still unclear as to whether it is necessary. The argument for training to momentary failure is underpinned by the size principle^{20–22} and maximizing motor unit and muscle fiber recruitment.²³ Assuming that motor-unit recruitment is an important stimulus to adaptation, as this model does, training not to momentary failure might still be efficacious if a load is heavy enough and/or if enough repetitions are completed (either in a single set or across multiple sets) to maximize recruitment and stimulate adaptation.²⁴ In this sense, training not to failure might be equally efficacious if the intensity of effort is sufficiently high to be “close enough” to training to muscular failure. Concerning volume of training, De Souza et al.²⁵ suggested that there is some “adaptation threshold” based upon the intensity of effort, and that higher intensity of effort training merely crosses this threshold with lesser volume compared to lower intensity of effort training, which relies on

Peer review under responsibility of Shanghai University of Sport.

* Corresponding author.

E-mail address: James.Fisher@solent.ac.uk (J.P. Fisher).

cumulative fatigue to allow for the threshold to be crossed at a later stage in training (i.e., with accumulation of volume).

3. A dose–response relationship

Both arguments assume that there is some continuous dose–response relationship between proximity to failure and the adaptations produced (though notably, De Souza et al.²⁵ posit some step function to this relationship). However, most empirical studies exploring our question have been designed to consider failure/not failure in a binary, dichotomous fashion (see studies recently reviewed by Grgic et al.¹¹ and Vieira et al.¹²). Whether this is due to the lack of formal representation of theories/models for how proximity to failure might influence adaptation to resistance training is not clear. Nevertheless, such study designs as these seem unlikely to reveal insights into the dose–response nature of proximity to failure. As such, we are left with general competing claims regarding whether one should or should not train to momentary failure to optimize outcomes.

First, in comparing training to failure versus not to failure, authors reported small to moderate effect sizes (ESs) for optimizing hypertrophic response (ES = 0.22 (based on Cohen's d ¹¹) and ES = 0.75 (reported as standard mean differences but without clarity of the denominator used to calculate these values¹²)) as compared to strength adaptations (ES = –0.09 and ES = –0.08).^{11,12} It is worth highlighting that increases in strength are not synonymous with increases in muscle size.²⁶ Furthermore, strength adaptations appear to be easier to attain compared to increases in muscle size, possibly based on neural adaptations. This is evidenced by studies showing: (a) much larger ESs for increases in strength compared to hypertrophy,²⁷ (b) studies showing contralateral strength adaptations,²⁸ (c) a potentially lesser stimulus for equivalent strength increases compared to hypertrophy (e.g., single sets seem to produce similar strength increases to multiple set training, whereas multiple sets seem to produce greater hypertrophic adaptations compared to single sets²⁹), and (d) that strength increases precede muscle size increases due to neural adaptations and development of the motor schema.³⁰ In this sense, it might be that increasing strength requires a lesser stimulus and thus training at a lesser intensity of effort (e.g., not to failure) might produce equivocal adaptations compared to training to failure, whereas hypertrophy requires a greater stimulus and thus requires a greater intensity of effort.

Second, Grgic et al.¹¹ reported similar ESs but a tighter and positive 95% confidence interval (95%CI) when comparing trained to untrained participants for hypertrophy: trained ES = 0.15, (95%CI: 0.03–0.26), untrained ES = 0.23 (95%CI: –0.25 to 0.71). In practice, this makes logical sense if we reasonably assume that someone naïve to resistance training will likely make adaptations in response to even a modest stimulus since their threshold for adaptation is low.³⁰ In addition, another recent meta-analysis of 119 studies²⁷ reported ESs of 1.43 for strength and 0.54 (reported standardized mean differences corrected by the bias; Hedges' g) for muscle mass for resistance training interventions when compared to non-training control conditions in previously untrained people, which is to say, resistance training compared

to doing nothing.²⁷ However, our re-analysis of 111 of the studies from which we could extract data using multilevel modelling with robust variance estimation has produced ESs of 0.88 (95%CI: 0.80–0.98) and 0.37 (95%CI: 0.32–0.43) for strength and hypertrophy, respectively. It seems justifiable to assume that any given comparison between 2 reasonably ecologically valid resistance training interventions (such as training to failure or not) would be unlikely to exhibit a between-treatment comparative effect which exceeds that seen when comparing intervention to no intervention.

Third, the binary operationalization of training to failure or not does not accurately represent the dose–response relationship from intensity of effort. While training to failure might be the operationalization of an effort of 100%, training not to failure as an operationalization implies effort that approaches but does not reach 100%. Indeed, the preferred terminology in the literature has often been “volitional fatigue” or “volitional failure”; all we can really know as third-party observers is that a person has ceased attempting the exercise when we observe that they have done so. However, we cannot know whether they chose to stop or could not continue. Indeed, in context it is perhaps useful to recognize the complexity for first- and third- person (i.e., internal and observational experiences), as well as subjective and objective assessment. Hence, even when someone perceives they have reached momentary failure, they might be physically capable of continuing. Research considering even a well-trained person's ability to predict proximity to momentary failure has repeatedly shown underestimation.^{31–33} As such, recommendations that a person train “not to failure” are limited, firstly, by a lack of objective and quantifiable effort level <100%, and secondly, by a person's ability to predict proximity to failure.

4. Re-phrasing the question with models

If the evidence suggests that resistance training to momentary failure is sufficient, though not necessary, for adaptations in strength and hypertrophy, then we should resist asking the binary question, “To optimize adaptations, should I train to momentary failure or not?” Rather, it might be better to rephrase the question as, “How close to momentary failure should I train to optimize adaptations?” Indeed, as others have, we propose that a continuous relationship exists with intensity of effort (operationalized as proximity to failure) and adaptations. By way of example, we consider 5 simple models that could be plausible candidates. These models are presented herein based on arbitrary but hypothetical potential. That is to say, we have chosen some models that might be credible, but this is not an exhaustive list; adaptations might follow a linear model, a threshold-step function model, a linear-log model, a quadratic model, a sigmoid model, or a linear plateau (Fig. 1). However, current studies that take only a single operationalization of “not to failure” (e.g., in the figure we show arbitrary effort values of 50%, 70%, and 90%) are likely to yield different conclusions depending on the real nature of that dose–response relationship—something we do not know but can posit and then test with appropriately designed studies. The

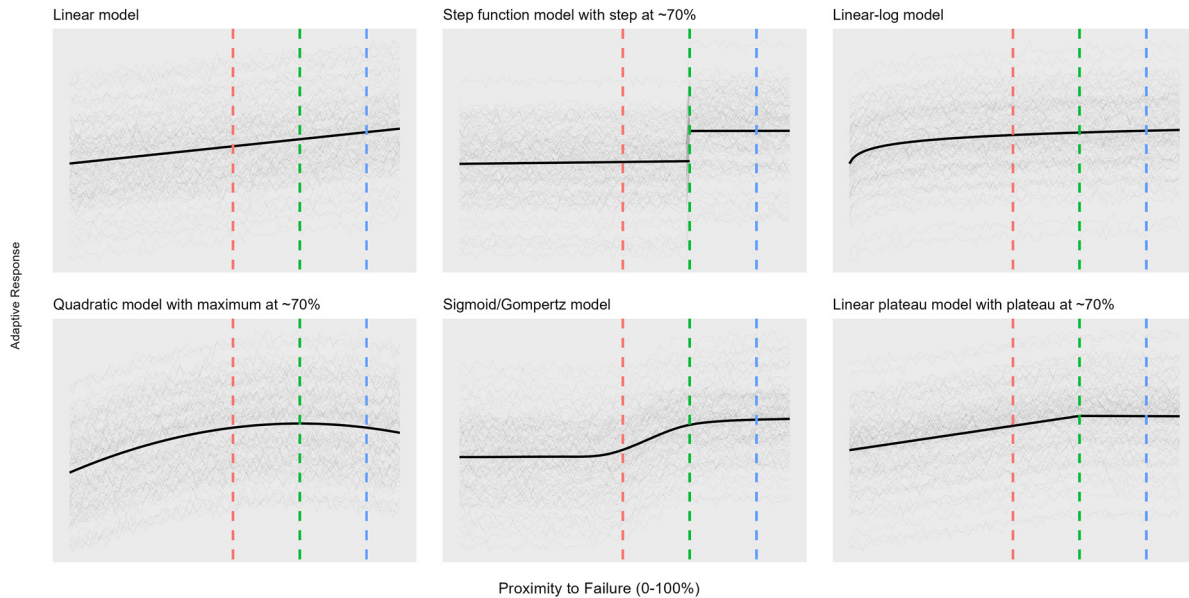


Fig. 1. Examples of possible candidate models of dose-response. Vertical dashed lines are 50% (red), 70% (green), and 90% (blue) of proximity to failure. The simulated models are shown with $n = 100$ example participants. Each has been parameterized such that the standardized mean difference between 0% (i.e., non-training control) and 100% (i.e., momentary failure) is ~ 0.9 to reflect realistic magnitude of expected effects.

current body of literature has not attempted to identify this dose-response relationship, instead focusing mostly on comparisons between exercising to momentary failure and not to momentary failure. However, based on the results of our study,²⁴ and on the similarity of our findings to those of other research, we propose that these studies have ultimately compared groups that are training at a similar level of effort.

With this in mind, it seems unwise to provide recommendations to train not to momentary failure, especially since people are poor at gauging proximity to momentary failure. Since not reaching failure exists along a spectrum, we might instead encourage people to perform resistance exercise to as high an effort as they feel comfortable doing while maintaining good technique. This, in turn, avoids the limitations of prescribing submaximal effort levels based on load/volume/repetitions. A person following the traditional prescription likely needs to make continual increases in the load used and/or the number of sets performed. In practice, this might become difficult where a person is unable to continually add weight to exercises (something that has been seen recently with gym closures due to the severe acute respiratory syndrome coronavirus 2 pandemic³⁴).

With the above in mind, it is our opinion that, given the aim of informing exercise prescription and guidance, researchers should avoid considering continuous variables in a binary fashion (e.g., training to momentary failure or not). Instead, a pragmatic and effective approach given current evidence would be to encourage people to perform resistance exercise to as high an effort as they feel comfortable, while maintaining good technique. At the very least, there is little evidence to suggest doing so would be meaningfully detrimental to outcomes. We should remember that there exists overwhelmingly poor participation and adherence to resistance training despite the aforementioned health benefits.^{35,36} The most commonly cited barriers appear to be time constraints and perceived complexity.^{37,38} If resistance

training recommendations can be more time-efficient (e.g., if performing resistance training to a high degree of effort can diminish the need for multiple/additional sets of an exercise) and reduce the complexity of performing a given number of repetitions for a given number of sets with a given load, then it is our opinion that a lower volume, higher effort approach should be encouraged.

5. Conclusion

The present piece discusses limitations of the current research on the efficacy of resistance training with respect to the question of proximity to failure, and it offers effective and practicable resistance training recommendations. While laboratory-based research suggests few discernible benefits from doing so, it is our opinion that practical recommendations should encourage people to perform resistance training to momentary failure or as high an effort as they feel comfortable. This might permit trainees to use a more time-efficient, low-volume approach and, in turn, serve to enhance participation and adherence to resistance training. Furthermore, if a trainee is less focused on performing a given number of repetitions and more focused on performing as many as possible, then the increases in repetitions as they continue are indicative of strength increases, thus eliminating the need for maximal strength testing. This guidance allows the freedom to prescribe exercise based on a more time-efficient, effort-based paradigm as opposed to on load/volume/repetitions, as has typically been suggested. This aligns with the work of Fisher et al.¹⁸ and Schoenfeld et al.,¹⁹ who have shown that, when training is performed to momentary failure, a range of loads and repetitions can be used to achieve a number of desirable adaptations, including muscular strength, local muscular endurance, and muscle hypertrophy, and more importantly, an array of health benefits.

Authors' contributions

JPF conceived the manuscript; JS provided statistical model examples; all authors helped draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

References

- Fisher JP, Steele J, Gentil P, Giessing J, Westcott WL. A minimal dose approach to resistance training for the older adult; the prophylactic for aging. *Exp Gerontol* 2017;**99**:80–6.
- Steele J, Fisher J, Skivington M, et al. A higher effort-based paradigm in physical activity and exercise for public health: Making the case for a greater emphasis on resistance training. *BMC Public Health* 2017;**17**:300. doi:10.1186/s12889-017-4209-8.
- Ruiz JR, Sui X, Lobelo F, et al. Association between muscular strength and mortality in men: Prospective cohort study. *BMJ* 2008;**337**:a439. doi:10.1136/bmj.a439.
- Srikanthan P, Karlamangla AS. Muscle mass index as a predictor of longevity in older adults. *Am J Med* 2014;**127**:547–53.
- Kraemer WJ, Adams K, Cafarelli E, American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2002;**34**:364–80.
- American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009;**41**:687–708.
- Fisher J, Steele J, Bruce-Low S, et al. Evidence-based resistance training recommendations. *Med Sport* 2011;**15**:147–62.
- Fisher J, Steele J, Smith D. Evidence-based resistance training recommendations for muscular hypertrophy. *Med Sport* 2013;**17**:217–35.
- Haff GG, Triplett NT. *Essentials of Strength Training and Conditioning*. 4th ed. Champaign, IL: Human Kinetics; 2016.
- Schoenfeld B, Fisher J, Grgic J, Haun CT, Vigotsky A. Resistance training recommendations to maximize muscle hypertrophy in an athletic population: Position stand of the IUSCA. *Int J Strength Cond* 2021. doi:10.47206/ijsc.v1i1.81.
- Grgic J, Schoenfeld BJ, Orszag J, Sabol F. Effects of resistance training performed to repetition failure or non-failure on muscular strength and hypertrophy: A systematic review and meta-analysis. *J Sport Health Sci* 2022;**11**:202–11.
- Vieira AF, Umpierre D, Teodoro JL, et al. Effects of resistance training performed to failure or not to failure on muscle strength, hypertrophy, and power output: A systematic review with meta-analysis. *J Strength Cond Res* 2021;**35**:1165–75.
- Steele J, Fisher J, Giessing J, Gentil P. Clarity in reporting terminology and definitions of set endpoints in resistance training. *Muscle Nerve* 2017;**56**:368–74.
- Dankel SJ, Jessee MB, Mattocks KT, et al. Training to fatigue: The answer for standardization when assessing muscle hypertrophy? *Sports Med* 2017;**47**:1021–7.
- Hoeger WW, Barette SL, Hale DF, Hopkins DR. Relationship between repetitions and selected percentages of one repetition maximum. *J Strength Cond Res* 1987;**1**:11–3.
- Hoeger WWK, Hopkins DR, Barette SL, et al. Relationship between repetitions and selected percentages of one repetition maximum: A comparison between untrained and trained males and females. *J Strength Cond Res* 1990;**4**:46–54.
- Shimano T, Kraemer WJ, Spiering BA, et al. Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. *J Strength Cond Res* 2006;**20**:819–23.
- Fisher J, Steele J, Androulakis-Korakakis P. The strength-endurance continuum revisited: A critical commentary of the recommendation of different loading ranges for different muscular adaptations. *J Trainology* 2020;**9**:1–8.
- Schoenfeld BJ, Grgic J, Plotkin DL, Van Every DW. Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. *Sports* 2021;**9**:32. doi:10.3390/sports9020032.
- Denny-Brown DE, Pennybacker JB. Fibrillation and fasciculation in voluntary muscle. *Brain* 1938;**61**:311–2.
- Carpinelli R. The size principle and a critical analysis of the unsubstantiated heavier-is-better recommendation for resistance training. *J Exerc Sci Fit* 2008;**6**:67–86.
- Potvin JR, Fuglevand AJ. A motor unit-based model of muscle fatigue. *PLoS Comput Biol* 2017;**13**: e1005581. doi:10.1371/journal.pcbi.1005581.
- Fisher J, Steele J, Smith D. High- and low-load resistance training: Interpretation and practical application of current research findings. *Sports Med* 2017;**47**:393–400.
- Fisher JP, Blossom D, Steele J. A comparison of volume-equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations. *Appl Physiol Nutr Metab* 2016;**41**:168–74.
- De Souza DC, Barbalho M, Gentil P. The impact of resistance training volume on muscle size and lean body mass: To infinity and beyond? *Hum Mov* 2020:2118–29.
- Loenneke JP, Buckner SL, Dankel SJ, Abe T. Exercise-induced changes in muscle size do not contribute to exercise-induced changes in muscle strength. *Sports Med* 2019;**49**:987–91.
- Polito MD, Papst RR, Farinatti P. Moderators of strength gains and hypertrophy in resistance training: A systematic review and meta-analysis. *J Sports Sci* 2021;**39**:1–10.
- Cirer-Sastre R, Beltrán-Garrido JV, Corbi F. Contralateral effects after unilateral strength training: A meta-analysis comparing training loads. *J Sports Sci Med* 2017;**16**:180–6.
- Schoenfeld BJ, Contreras B, Krieger J, et al. Resistance training volume enhances muscle hypertrophy but not strength in trained men. *Med Sci Sports Exerc* 2019;**51**:94–103.
- Sale DG. Neural adaptation to resistance training. *Med Sci Sports Exerc* 1988;**20**(Suppl. 5):S135–45.
- Steele J, Endres A, Fisher J, et al. Ability to predict repetitions to momentary failure is not perfectly accurate, though improves with resistance training experience. *PeerJ* 2017;**5**:e4105.
- Armes C, Standish-Hunt H, Androulakis-Korakakis P, et al. Just one more rep!"—Ability to predict proximity to task failure in resistance trained persons. *Front Psychol* 2020;**11**:565416. doi:10.31236/osf.io/af6dv.
- Halperin I, Malleron T, Har-Nir I, et al. Accuracy in predicting repetitions to task failure in resistance exercise: A scoping review and exploratory meta-analysis. *Sports Med* 2022;**52**:377–90.
- Steele J, Androulakis-Korakakis P, Carlson L, et al. The impact of coronavirus (COVID-19) related public-health measures on training behaviours of individuals previously participating in resistance training: A cross-sectional survey study. *Sports Med* 2021;**51**:1561–80.
- Loustalot F, Carlson SA, Kruger J, Buchner DM, Fulton JE. Muscle-strengthening activities and participation among adults in the United States. *Res Q Exerc Sport* 2013;**84**:30–8.
- Nuzzo JL. Sex difference in participation in muscle-strengthening activities. *J Lifestyle Med* 2020;**10**:110–5.
- Trost SG, Owen N, Bauman AE, Sallis JF, Brown W. Correlates of adults' participation in physical activity: Review and update. *Med Sci Sports Exerc* 2002;**34**:1996–2001.
- Winett RA, Williams DM, Davy BM. Initiating and maintaining resistance training in older adults: A social cognitive theory-based approach. *Br J Sports Med* 2009;**43**:114–9.