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MONTHLY APPLICATIONS IN STRENGTH SPORT

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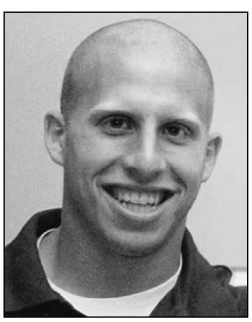
Greg Nuckols has over a decade of experience under the bar and a B.S. in exercise and sports science. Greg earned his M.A. in exercise and sport science from the University of North Carolina at Chapel Hill. He's held three all-time world records in powerlifting in the 220lb and 242lb classes. He's trained hundreds of athletes and regular folks, both online and in-person. He's written for many of the major magazines and websites in the fitness industry, including Men's Health, Men's Fitness, Muscle & Fitness, Bodybuilding.com, T-Nation, and Schwarzenegger.com. Furthermore, he's had the opportunity to work with and learn from numerous record holders, champion athletes, and collegiate and professional strength and conditioning coaches through his previous job as Chief Content Director for Juggernaut Training Systems and current full-time work on StrongerByScience.com.



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Welcome to the 2021-2022 "Best Of" issue of MASS! Whether this is the first time you're getting a peek inside our research review or you've been subscribed since day 1, we think you'll love what you find in this special edition of MASS.

This month marks 5 years of MASS. Since we started in April 2017, we've published 60 issues – that's about 550 articles and videos, 6,000 pages of content, 380 audio episodes, 1,500 illustrative graphics, and 100 hours of video. We offer CEUs for NSCA and NASM and CECs for ACSM and ACE. As of April 2022, we have more than 4,300 active subscribers. (Not a subscriber yet? Join here.)

What you'll find in these pages is a glimpse at some of our favorite content from the fifth year of MASS, but you can be confident that every issue is packed with rigorously examined and visually stunning reviews of the research that's most relevant to strength and physique athletes, coaches, and enthusiasts.

If you (or your clients) want to build muscle, get stronger, and/or drop fat as efficiently and effectively as possible, MASS is for you. We know you want to stay on top of the research, but doing so can be time-consuming, expensive, and confusing. That's why we do all the heavy lifting for you and distill the most important findings into an easy-to-read monthly digest.

Each issue of MASS covers more than a dozen recent studies, keeping you up to date with the current research and giving you a thorough understanding of the best science-based practices. We hope you enjoy it, and we hope you'll subscribe so you can stay on the cutting edge of our field to get the best results possible for yourself or your clients.

Thanks so much for reading.

The MASS Team

Eric Helms, Mike Zourdos, Eric Trexler, and Greg Nuckols

Study Reviewed: Effects of a Flexible Workout system on Performance gains in Collegiate Athletes. Walts et al. (2021)

When and How are Flexible Templates Actually Useful?

BY MICHAEL C. ZOURDOS

Flexible programming – choosing which training session you'll do based on how you feel that day – is a logical strategy. However, a new study adds to the surprisingly null findings on the topic. This article discusses specific situations in which a flexible template may have merit and how to implement flexibility.

KEY POINTS

1. Collegiate lacrosse players performed eight weeks of either flexible training or fixed order training. Athletes tested hex bar deadlift and bench press strength before and after training, along with vertical jump and agility performance.
2. The flexible training group could choose between four options for their daily workout, while the fixed order group had a predetermined weekly training order. Each group trained three times per week.
3. The findings showed very similar rates of progress in all outcome measures between groups. This article discusses the circumstances in which flexible templates may enhance strength performance, and whether or not the autonomy that flexible templates offer is a positive for lifters.

Autoregulating training session load and volume helps match the daily training stimulus to your daily readiness. However, quantitative assessments of daily readiness can sometimes be hard to implement. Not everyone has access to a device they can use to assess bar velocity, and not everyone can accurately assess repetitions in reserve (RIR)-based rating of perceived exertion (RPE) values. Therefore, it may be worth having a mechanism to choose the overall workout structure based on your subjective readiness when you enter the gym instead of having a specific day of the week pre-planned. Enter flexible training templates, which I've covered before (one, two). A basic example of a flexible template is having six heavy, six moderate, and six light training sessions within a month. In this case, you could perform each training session whenever you feel ready for it (i.e., if poor sleep, choose a light session) rather than in a set order (i.e., moderate, light, and heavy on M, W, F). One previous study has shown flexible training to enhance strength (2), while another showed a slight improvement in training adherence (3 – MASS Review). However, there isn't much more data on the topic. The reviewed study from Walts et al (1) had collegiate athletes perform either flexible non-linear periodization (flexible group), or fixed-order non-linear periodization (fixed group) for two four-week training blocks (eight weeks total). Before each session, the flexible group would indicate their state of readiness (green, yellow, or red) and then choose a corresponding workout. A green response meant the subject could choose either a high-volume or high-intensity session, while researchers matched a yellow response with a low volume or low-intensity session. A readiness response of red meant the athlete skipped that day's training session. The fixed order group performed training sessions in a predetermined order but could still select red and skip a session. Researchers equated the specific number of each training session (green or yellow) between groups.

Findings showed that all outcome measures (bench press and hex bar deadlift 1RM, vertical jump, sprinting speed, and agility) improved, but without significant differences between groups ($p > 0.05$). Despite the lack of significant between-group differences, I don't believe we should discard flexible templates entirely. A positive spin is that a lifter may receive the same training benefit while avoiding the typical rigidity of a fixed order program. However, I think the more salient argument is that the current study didn't provide a framework for the flexible template to work. In other words, a flexible template is probably most beneficial when readiness to train is often low due to either consistently fatiguing training or extenuating life circumstances. Therefore, this article will aim to deliver the following information:

1. Break down the existing data on flexible training templates.
2. Discuss in what situations flexible training may be most useful.
3. Discuss different levels of flexibility (i.e., weekly, monthly, or all-time flexibility).
4. Examine the efficacy of various metrics to assess daily readiness.
5. Provide practical examples of how to implement this concept.

Purpose and Hypotheses

Purpose

The purpose of this study was to compare the effects of flexible and fixed-order training templates equated for session type on gains in strength, power, and agility over eight weeks in both men and women.

Hypotheses

The researchers hypothesized that flexible training would enhance performance in all outcome measures.

Subjects and Methods

Subjects

32 Division III collegiate lacrosse players (15 men and 17 women) completed the study. The researchers provided no information regarding previous resistance training experience, but all athletes completed a six-week familiarization phase before the study (more below). Further, the full manuscript indicated that some athletes were freshmen (which can also be inferred by the average age in Table

Table 1 Subject characteristics

GROUP AND SUBJECTS	AGE (YEARS)	BODY MASS (KG)	HEIGHT (CM)	BENCH PRESS 1RM (KG)	RELATIVE HEX BAR DEADLIFT 1RM (1RM/BM)	ATHLETIC DESIGNATION
Flexible (8 men, 9 women)	19.4 ± 1.4	72.29 ± 13.73	172 ± 10	56.2 ± 27.9	115.5 ± 46.6	Member of University Varsity Lacrosse Team
Fixed (7 men, 8 women)	19.9 ± 1.5	71.68 ± 13.55	172 ± 8	65.6 ± 31.8	117.2 ± 41.1	Member of University Varsity Lacrosse Team

Data are Mean ± SD
Subject characteristics Walts et al. 2021 (1). 1RM = One-Repetition Maximum.

1). Overall, I suspect that subjects had some structured resistance training experience, but this experience varied between individuals, which is not uncommon for young athletes at the Division III level. Table 1 provides the available details of the subjects.

Study Overview

The athletes were split into two training groups for eight weeks. A flexible group performed a daily training session that matched their readiness. In contrast, the non-flexible (fixed order) group performed training sessions in a predetermined order (details in the next section). Athletes trained three times per week for eight weeks on non-consecutive days, but the first session of week one and last session of week eight served as pre- and post-training testing sessions; thus, each group had 22 training sessions. Both groups performed non-linear (or undulating, if you prefer) periodization. Pre- and post-testing measures were one-repetition maximum (1RM) bench press and hex bar deadlift, vertical jump height, sprint time (28.7m), and an agility test consisting of a 6.1m fly-in sprint followed by a turn and 6.1m sprint back. Lastly, all subjects completed a six-week familiarization program before the eight-week intervention. However, researchers did not provide any further details regarding the familiarization.

Training Protocol

The original paper doesn't provide many details of the training program. However, the senior author (Dr. Kenneth Clark) put me in touch with the first author (Cory Walts), who graciously suffered through a phone call and various email exchanges with me to provide details. Huge thanks to these gentlemen for their assistance.

Researchers split the eight-week program into two four-week training blocks. There were 11 total training sessions in each four-week block (remember pre- and post-testing bookended weeks one and eight, respectively). There were two strength-focused sessions (i.e., traditional strength exercises) each week and one power-focused session (i.e., Olympic lift variations), except in weeks one and eight, when there were only two strength-focused sessions (plus a testing day). Each week also fluctuated volume and intensity; thus, the programming was non-linear both within and between weeks. There were two main workout categories, "Green" and "Yellow," and each category had two subtypes (green: high volume or high intensity; yellow: low volume or low intensity) to make four different session-type possibilities. Further, the workouts were rated on a 1-4 scale (arbitrary units) for both volume and intensity. In other words, the workout with the highest volume was rated a 4, and the lowest volume workout was rated a 1. Table 2 displays all session types and their volume/intensity ratings.

In both groups, athletes answered the question (using the TeamBuildr phone app) "based on how your body feels and your current mindset, how ready are you for today's training?" Subjects had the option of answering "green (good feel and mindset)," "yellow (fair feel or mindset)," or "red (poor feel or mindset)." In the fixed group, subjects performed training weeks in the order of yellow (low intensity), green (high volume), yellow (low vol-

Table 2 Training session types

SESSION TYPE	VOLUME RATING	INTENSITY RATING
Green – High Volume	4	3
Green – High Intensity	2	4
Yellow – Low Volume	1	2
Yellow – Low Intensity	3	1

From Walts et al. 2021 (1).

ume), and green (high intensity) regardless of their response, as seen in Figure 1. The only caveat is that if an athlete in the fixed group answered "red," then they skipped the training session and performed one less training session for that block.

Similar to the fixed group, a flexible athlete also skipped a workout if they answered "red" to the readiness question. However, on each training day, flexible group athletes had four workouts to choose from (the two greens and the two yellows), but no session type could be performed more than once on a specific day of the week during each block. For example, there were four Wednesdays in each training block, and if an athlete answered green on Wednesday of week one, then they chose a high volume or high intensity workout. If they chose high volume, then that workout could not be completed again on a future Wednesday during the first training block. Athletes followed the same procedures for each individual day during the training blocks. One of the four workouts was not chosen on a Monday during block one since there were only three Monday training days (i.e., the first Monday was pre-testing), and the same for Friday in block two since that's when post-testing was conducted. Table 3 displays a possible example of the protocol in the flexible group for a four-week training block.

Additional Notes

It's also worth noting that researchers did not supervise training in this study. Athletes an-

Figure 1 Weekly training undulation

This order was then repeated in the fixed order group during weeks 5-8.

Table 3 Flexible group example protocol

WEEK	DAY 1	DAY 2	DAY 3
Week 1	Pre-Testing	Green High Volume	Yellow Low Volume
Week 2	Green High Volume	Yellow Low Volume	Yellow Low Volume
Week 3	Green High Intensity	Green High Intensity	Green High Volume
Week 4	Yellow Low Volume	Yellow Low Intensity	Green High Intensity

Table 4 Bench press 1RM strength findings

MEASURE	TIME POINT	BENCH PRES 1RM (KG)	MEAN INCREASE (PERCENTAGE INCREASE)
Flexible group	Pre-Study	56.2±27.9	+4.3%
	Post-Study	58.6±27.7	
Fixed order group	Pre-Study	65.6±31.8	+4.6%
	Post-Study	68.6±31.6	

Data are Mean ± SD
From Walts et al. 2021 (1)

Table 5 Hex bar deadlift 1RM strength findings

MEASURE	TIME POINT	BENCH PRES 1RM (KG)	MEAN INCREASE (PERCENTAGE INCREASE)
Flexible group	Pre-Study	115.5±46.6	+9.5%
	Post-Study	126.5±48.2	
Fixed order group	Pre-Study	117.2±41.1	+9.4%
	Post-Study	128.2±45.2	

Data are Mean ± SD
From Walts et al. 2021 (1)

swered the daily question on the TeamBuildr app, which then provided the workout based on their choice. While this is a limitation, it's inherently not the researchers' fault. Since the study used Division III NCAA collegiate athletes, NCAA rules had to be followed, which meant that training workouts had to be self-selected. The researchers couldn't officially report training adherence or volume because that would amount to "tracking" an intercollegiate athlete's off-season training. Specific interset rest intervals were not listed; however, all workouts lasted approximately 60 minutes.

Outside of lifting, the athletes also participated in speed and agility sessions twice per week for 60 minutes each time, and one "conditioning" session, which was not otherwise described.

Findings

The findings were simple. All outcome measures tended to increase in both groups; however, there were no group differences. Vertical jump increased by 3.9% and 6.4% in the flexible and fixed groups, respectively. Agility performance improved by 0.8% and 1.6% in the flexible and fixed groups, respectively. Tables 4 and 5 show the findings for bench press and hex bar deadlift 1RM strength along with percentage changes.

Interpretation

The reviewed study from Walts et al (1) didn't show flexible training to augment strength gains, but that doesn't mean we should write off the concept. One could argue that similar strength gains but more autonomy over training decisions is a win for flexible templates, for starters. However, I think there's much more to discuss. We should also consider the readiness indicator used, how fatiguing the program is, and the degree of flexibility allowed (i.e., weekly, monthly, or all-time). Therefore, this interpretation will provide a nuanced discussion of the above considerations.

Current and Previous Research

Although the concept of flexible templates is well-known, there are only three resistance training studies directly tackling the idea. Two of those studies – the currently reviewed study from Walts (1) and a study from Colquhoun et al (3 - MASS Review) – failed to show a benefit for flexible training versus fixed order training. The Colquhoun study compared a group of trained lifters using a fixed weekly order of hypertrophy-focused (Monday), power-focused (Wednesday), and strength-focused (Friday) sessions for nine weeks to a flexible group. The flexible group performed hypertrophy, power, and strength sessions within the same week, but lifters could choose the order. Lifters used a five-point Likert scale before each session to assess motivation and readiness to train. Further, subjects performed the last set to failure on both the hypertrophy and strength sessions each week in Colquhoun's study. Weekly load changes were based on repetition performance, which allowed for between-group volume and intensity calculations. Colquhoun reported similar squat, bench press, and deadlift increases between groups, and no group differences for volume or percentage of 1RM used. Colquhoun did show a lower dropout rate in the flexible group (12.5%) versus the fixed group (31%), and fewer total missed sessions in the flexible (four) versus the fixed group (eight).

Walts' argument regarding autonomy seems to have some value, based on Colquhoun's adherence reporting. I'll return to autonomy in a bit, but in the short term, I don't think Colquhoun's flexible group experienced enhanced performance because the fixed group was already set up well. Specifically, the fixed order of hypertrophy, power, and strength allocates weekly volume appropriately. Higher volume training sessions (i.e., traditionally hypertrophy-focused) tend to result in the most muscle damage. Thus, inserting a lighter (i.e., power) session in the middle of the week considers that a lifter may be fatigued 48 hours after hypertrophy-type training. The lifter is then recovered for Friday's strength session and may even get a 48-hour priming effect from the power session to enhance Friday's strength performance (4 – MASS Review). Indeed, previous data have shown this hypertrophy, power, strength set-up to result in greater volume on the strength day than a hypertrophy, strength, power configuration (5). Other factors such as sleep, travel, stress, and early morning training can affect readiness and warrant a flexible template, which may have accounted for the greater adherence in Colquhoun's flexible group.

The other study to directly address this concept is from McNamara and Stearne (2), and was published over a decade ago. These researchers split 16 subjects (both men and women) with a little over one year of training experience into a fixed order and flexible groups and measured leg press and chest press strength before and after 12 weeks of

Table 6 Summary of Colquhoun et al and McNamara and Stearne	
COLQUHOUN ET AL SUMMARY	Flexible group using within-week flexibility vs. fixed group using hypertrophy, power, strength order for 9 weeks
	No difference in volume or intensity
	No difference in squat, bench press, or deadlift strength improvement
	Possibly improved adherence in flexible group
	Fixed group was already setup to account for readiness
MCNAMARA & STEARNE SUMMARY	Flexible group that could perform sessions in any order throughout a 12-week training block vs. fixed group using a 20, 15, and 10RM order rotation
	Only restrictions on flexible group, they had to perform same number of each training session type as fixed group
	7-15 sets to failure on various exercises in each session
	No difference in chest press strength increases between groups
	Significantly greater leg press strength improvement in flexible group

Main findings summarized from Colquhoun et al (3) and McNamara and Stearne (2).

training. The subjects trained only twice per week using one set of various exercises, but every set was to failure. The fixed order group rotated 20, 15, and 10RM sessions in that order, while the flexible group completed a 0-10 Likert scale to assess energy levels and then chose which session they wanted that day. The flexible group in this study had more autonomy than the flexible groups in the Walts or Colquhoun studies, in that flexibility was not restricted to within-week. Instead, lifters had to perform each session type eight times, but could do so in whatever order they chose. McNamara and Stearne reported no group differences for chest press increase, but leg press improvement in the flexible group roughly tripled (Figure 1 here) the fixed group's progress. Table 6 provides a summary of both the Colquhoun and McNamara studies.

Flexible templates are generally viewed positively. I mostly share that view; however, it's worth noting that only one strength measure (McNamara and Stearne leg press) out of seven strength tests from three studies improved more with a flexible versus a fixed training order. However, the McNamara and Stearne study may have been better designed to see group differences than the other two studies. Specifically, as noted above, both the Colquhoun and Walts studies had power-focused training sessions in the middle of the training week, which may have helped mitigate fatigue. Further, while I'm not entirely sure about proximity to failure in the Walts study, subjects in Colquhoun's study only went to failure on the last set of the hypertrophy and strength day (two sets per week for squats, two for bench, and one for deadlift). On the other hand, McNamara and Stearne's subjects did at least 14 sets to failure each week on various exercises and only had a little over a year's training experience, while Colquhoun's lifters had been training for three years on average. Therefore, fatigue may have been greater in the McNamara and Stearne study, which provides a stronger justification for a flexible program. McNamara and Stearne prescribed the same volume in each group, but subjects in the flexible group may have been able to progress loads more frequently than subjects in the fixed group, which would explain the flexible group's enhanced rate of strength gain. Although, even if volume or intensity was greater in the flexible group, I'm not entirely sure how to account for the roughly three times greater leg press strength increases in favor of the flexible training group in the McNamara and Stearne study. One possible explanation is that subjects in the flexible group chose mostly lighter sessions (20RM and 15RM) early in the program and thus, performed more of the heavier (10RM) sessions closer to post-testing than the fixed order group. However, that is purely speculative.

In general, the cornerstone of flexible templates is that lifters can match the day's session to their readiness. This flexibility is beneficial when training or life circumstances (or both) are *really* demanding. In other words, if a training program isn't that demanding (i.e., not high-volume or a lot of failure training) and life circumstances aren't extraordinary, is a flexible template vital to optimize progress? Even though a flexible template may not always shine without demanding life circumstances, that doesn't mean flexible templates still aren't a good idea for some individuals. The discussed studies, including the currently reviewed one, show similar performance changes between flexible and fixed programs; thus, individuals should choose whatever they prefer. Having autonomy in a program is indeed a good thing, but we should also be cautious of too much autonomy. The specific population may also matter in terms of autonomy. For example, the reviewed study (1) used Division III collegiate athletes during voluntary off-season workouts, which I'm intimately familiar with as both a former Division III NCAA athlete (i.e., average athletic adult human) and former Division III strength coach. In this specific case, autonomy is probably positive. First and foremost, these athletes must voluntarily choose to do the workouts, and a coach wants the athletes to buy into the program since NCAA rules do not allow coaches to monitor athletes in the off-season. Some athletes will train and do exactly as instructed; however, others will take a bit more convincing, so on the whole, flexibility is a positive for the Walts study population. In the context of team sport athletes, flexible training may also be helpful in-season, as some athletes play more minutes in a game or match than others. For instance, in NCAA soccer, there are typically two games per week. If an athlete is playing 90 minutes and another is barely touching the field, these athletes should have different workloads (both on the field and in the weight room) during the week, and a flexible template is a vehicle to get them there. On the other hand, some autonomy is a positive for the individual strength athlete, but others hire a coach because they want exact programming. Therefore, some lifters come to a coach precisely to avoid having to make training decisions. In other words, I don't think autonomy is the most salient defense of flexible templates for the strength athlete.

Flexibility Situations and Degrees of Flexibility

As previously stated, specific circumstances should be present to warrant use of a flexible template:

1. Extremely demanding training.
2. Currently exhaustive life (work/school/family) schedule.
3. Consistent travel with inconsistent gym access.

Although, I'd argue that extremely demanding training isn't necessarily a reason to utilize a fully flexible training program. If performing an overreaching block or sustained high volume hypertrophy-type training, coaches and lifters should organize programming within a week to account for training fatigue. For example, if you are training a muscle group three times per week (i.e., M, W, F) and there are high RPE, moderate RPE, and low RPE days, then the default program structure should be to do moderate RPE training on Monday, low RPE on Wednesday, and high RPE on Friday. Similarly, if thinking in terms of high-, low-, and moderate-volume days or hypertrophy-, power-, and strength-type training sessions, the weekly order should be: high-volume/hypertrophy (Monday), low-volume/power (Wednesday), and moderate-volume/strength (Friday). The point being, no matter what type of programming you prefer, each week should be programmed to allocate training volume appropriately. If you already do this, such as Colquhoun's fixed order group, the need for a flexible template is minimized. If you are constantly fatigued going into your next session, then a flexible template is not the solution. Instead, I'd recommend rearranging your training, or consider lowering your training volume or proximity to failure (i.e., training variables which elongate recovery).

Flexible programming may shine when life gets busy, such as a month-long work project, studying for that elusive D+, preparing for family holidays, or extended travel – in other words, situations in which you have consistently lower sleep and higher stress, which can impact performance along with inconsistent gym access. The next step is not just implementing a flexible model, but also considering the degree of necessary flexibility. Suppose all of the above situations last approximately one month, and your fatigue levels and gym access are entirely unknown. In that case, you might use within-month or within-block flexibility such as the Mc-

IF YOU ARE CONSTANTLY FATIGUED GOING INTO YOUR NEXT SESSION, THEN A FLEXIBLE TEMPLATE IS NOT THE SOLUTION CONSIDER LOWERING YOUR TRAINING VOLUME OR PROXIMITY TO FAILURE.

Table 7 Conceptual example of appropriate pre-determined order

EXERCISE	MONDAY	WEDNESDAY	FRIDAY
Squat	4 X 8 @5-8 RPE	3 X 5 @6-8RPE	4 X 3+ @85%
Deadlift	3X 4 @5-7 RPE		3 X 1 @7-9 RPE
Pullups	X50, stop each set @8 RPE	X30 stop each set at 6-8RPE	Weighted: 3 X max reps with 10kg added
Seated Row	4 X 10-15 @6-8 RPE	3 X 6-8 @6-8RPE	5 X 8-12 @8-10 RPE
Leg Curls / DB Curls	4 X 10-15 @6-8 RPE	3 X 6-8 @6-8RPE	4 sets with 15RM load and stop each set at 7-10 RPE

RPE = Rating of Perceived Exertion; DB = Dumbbell;
+ = Plus Set (as many reps as possible on last set)

Namara and Stearne study. For example, if you have six low RPE days, six high RPE days, and six moderate RPE days, then you would perform six of each session type anytime in the month in whatever order you choose. It may also be wise to scale back to four of each session type to ensure feasibility during stressful times. If someone doesn't want to scale back, they could still aim for 24 total sessions, but use a breakdown with more "easier" days such as 4 high RPE, 8 moderate RPE, and 12 low RPE sessions.

Another option is within-week flexibility, such as in the Walts (1) and Colquhoun (3) studies. For within-week flexibility, there are usually two or three different types of training sessions during the week (whatever is best for the specific individual), and the lifter completes each session type during the week, but in whatever order they choose. However, I'm not sure that within-week flexibility offers much benefit if the week's volume is already appropriately allocated so that fatigue from one session doesn't bleed into another. If you're already appropriately allocating volume within the week, within-week flexibility doesn't provide much benefit. While daily stress could still warrant flexing in easier sessions, this could present problems with a within-week model. For example, if stress levels are high on Monday in a Monday (hypertrophy), Wednesday (power), and Friday (strength) setup, then you may choose to perform the power session. Then, on Wednesday, you complete one of the two more fatiguing sessions (hypertrophy or strength). Still, now fatigue from Wednesday may bleed into the hypertrophy or strength session (whichever is left) on Friday. Ironically, an actual within-week model of flexibility could exacerbate the same issue it's trying to mitigate.

Instead of a true "within-week only" flexible model, I'd prefer a fixed order, but with an "all-time flexible option." For example purposes, let's assume we're training a muscle group three times per week. I'd set up training so that you are already allocating volume to the best of your ability. Table 7 shows a conceptual example of this setup where the heaviest training day (Friday) is positioned

Table 8 Pre-determined order with all-time flexible option

WEEK 1			
EXERCISE	**MONDAY**	**WEDNESDAY**	**FRIDAY**
Squat	4 X 8 @5-8 RPE	3 X 5 @6-8RPE	2 X 3 @60%
Deadlift	3X 4 @5-7 RPE		3 X 1 @60-70%
Pullups	X50, stop each set @8 RPE	X30 stop each set at 6-8RPE	X 20 stop each set at 5-7RPE
Seated Row	4 X 10-15 @6-8 RPE	3 X 6-8 @6-8RPE	2 X 8 @5-6 RPE
Leg Curls / DB Curls	4 X 10-15 @6-8 RPE	3 X 6-8 @6-8RPE	2 X 8 @5-6 RPE
WEEK 2			
EXERCISE	**MONDAY**	**WEDNESDAY**	**FRIDAY**
Squat	4 X 3+ @85%	4 X 8 @5-8 RPE	3 X 5 @6-8RPE
Deadlift	3 X 1 @7-9 RPE	3X 4 @5-7 RPE	
Pullups	Weighted: 3 X max reps with 10kg added	X50, stop each set @8 RPE	X30 stop each set at 6-8RPE
Seated Row	5 X 8-12 @8-10 RPE	4 X 10-15 @6-8 RPE	3 X 6-8 @6-8RPE
Leg Curls / DB Curls	4 sets with 15RM load and stop each set at 7-10 RPE	4 X 10-15 @6-8 RPE	3 X 6-8 @6-8RPE
WEEK 3			
EXERCISE	**MONDAY**	**WEDNESDAY**	**FRIDAY**
Squat	4 X 2+ @87.5%		4 X 8 @5-8 RPE
Leg Press		3 X 10-12 @5-7RPE	
Deadlift	3 X 1 @7-9 RPE		3X 4 @5-7 RPE
Pullups	Weighted: 3 X max reps with 10kg added	X30, stop each set @8 RPE	X50, stop each set @8 RPE
Seated Row	5 X 8-12 @8-10 RPE	2 X 10-15 @5 RPE	4 X 10-15 @6-8 RPE
Leg Curls / DB Curls	4 sets with 15RM load and stop each set at 7-10 RPE	2 X 10-15 @5 RPE	4 X 10-15 @6-8 RPE

Percentages are of one-repetition maximum. RPE = Rating of perceived Exertion.
[light blue shading] = A flexed in "easy day" (power or assistance work-focused).

the farthest from the high-volume day. Before looking at Table 7, just know that there are many other ways to configure training and many different exercises to include; this is solely intended for conceptual purposes.

Although the program in Table 7 isn't easy training, the predetermined order is sound, so training fatigue alone probably won't be an issue, assuming this is the appropriate magnitude of volume for a specific person. However, since life situations still pop up, you could have a few "easy days" in your back pocket to allow for all-time flexibility as needed. These easy days could be a low volume power session or a solely assistance work-focused session at a low RPE, or another option you prefer. In this design, you would perform the predetermined order, plug in one of the easy options when needed, and then continue with the next pre-planned day. Table 8 presents this option.

In Table 8, you can see a power day on the main lifts or a session focused on assistance work was flexed in when needed. Then, the lifter carried on with their next scheduled session-type after the flex day. This type of

> I WOULD ALMOST ALWAYS HAVE A FLEX OPTION IN A TRAINING PROGRAM.

model may not be best when traveling and having limited gym access; however, I think it works well when you are not planning for disruptions. In other words, I would almost always have a flex option in a training program to account for unforeseen circumstances. In addition to just inadequate sleep or elevated acute stress, a lifter may have to train early in the morning unexpectedly or may suddenly be short on time. In both of these situations, having flex options works well. If we understand this concept conceptually, we can create a whole host of flex options that serve a specific purpose. For example, this video provides flexible examples for an afternoon lifter who has to train in the early morning. Of course, even in a flexible template, there should also be the option not to train if fatigue and motivation are just too low; in that case, I'd just push everything back one day. If you have to miss two days, then I'd probably repeat the training week. Our video on program troubleshooting provides additional flexible options when traveling or completely missing training.

Determining Readiness

I've previously covered readiness indicators in great detail (one, two), so I'll just provide some brief considerations here. The three flexible studies (McNamara and Stearne, Colquhoun, and Walts) vary in their methods of determining pre-training readiness. McNamara and Stearne (2) used a 0-10 Likert scale, Colquhoun (3) used a 0-5 scale assessing readiness and motivation, and Walts (1) used a specific question (quoted earlier) asking about mindset and readiness. Importantly, if using a readiness indicator to influence training choice, that indicator should have some capacity to predict performance. Yet, many common readiness indicators lack empirical support to predict lifting performance. The perceived recovery status scale (0-10 Likert scale) has a strong inverse correlation with muscle damage following very damaging sprinting (6). A general Likert scale might pick up large magnitudes of fatigue; however, if you have extreme soreness when you go into the gym, then you should consider allocating your volume differently, as discussed earlier. Further, a scale such as the perceived recovery status scale doesn't assess well-being (anxiety and mood state), which may affect performance. While well-being scales may have merit in team sports (7), their ability to predict acute strength performance has not fleshed out (8). Even technological tools such as heart rate variability have also failed to show promise to relate to recovery of resistance training performance (9 - MASS Review) or enhance strength gains when used to guide flexible programming (10 - MASS Review). Perhaps the readiness indicator with the most empirical support to predict lower body lifting performance is vertical jump height. Watkins et al (11) assessed lifters' vertical jump height and performed four squat sets to failure at 80% of 1RM. 48 hours later, Watkins retested both measures and observed that decreased vertical jump height was correlated with reduced squat reps (r = 0.65). A lifter could perform a quick vertical jump before each training session and set a cutoff (e.g., 1.5 cm); if their vertical jump drops below that target, they choose an easier training session. Of course, vertical jump height wouldn't apply to upper body performance, but conceptually the Watkins study design is how researchers can determine if recovery of a particular metric is indicative of performance.

Since becoming interested in this topic about 12 years ago and writing this piece for Stronger by Science a few years back, I've started to wonder how much readiness indicators matter. In other words, how fatigued do you need to be to change training? Suppose you are training with a well-designed setup where volume is allocated appropriately, and you're probably not ever too fatigued going into the next session. In that case, you probably don't need to be 100% recovered to train effectively. Additionally, intra-session load can always be adjusted (up or down) to match performance using RPE or velocity, which mitigates the need to completely change the day's session if you're feeling just a touch fatigued. Let's use the perceived recovery status scale as a simple example. If a lifter plans a heavy session when their perceived recovery is between 8-10 on a 10-point scale, does that mean performance will be worse if they do a heavy session on a day where they'd rate their perceived recovery status a 7? Probably not. I think a lifter generally knows if he or she feels completely trashed or good enough to perform. If feeling good enough to perform, tools such as RPE and velocity are there for intra-session adjustments. If the lifter is feeling trashed, then perhaps a day off is warranted, or the athlete can insert a light/power day. If a specific circumstance (i.e., morning training or travel) arises, using one of the specific flexibility options noted above is a good idea.

Conclusions and Thoughts

Overall, there's merit in the idea of being able to flex in a different type of training session than was initially planned. Still, unless major circumstances are present (high fatigue, inadequate sleep, travel, etc.), I wouldn't expect a huge benefit from flexible templates. The presently reviewed study does have a high ecological validity for team sport athletes training in the offseason. It's often difficult to get those athletes to adhere to an off-season lifting program; given that a flexible approach did not hinder progress in this study, flexibility could be viewed as a potential approach to enhance adherence without sacrificing efficacy. However, for strength sports athletes, I'd be more likely to implement flexibility in specific circumstances, or always having a power/light day on hand in case it's needed. Lastly, training flexibility isn't limited to just session-type. A study (12) previously reviewed by Dr. Helms showed that allowing a lifter to choose from a pool of exercises each day may enhance strength. While a powerlifter needs to squat, bench press, and deadlift, a coach could give the athlete a choice

APPLICATION AND TAKEAWAYS

1. The reviewed study found that choosing each weekly session's volume or intensity did not enhance strength performance compared to a fixed weekly training schedule.
2. The concept of flexible training has been around for a while and has merit; however, it's probably most beneficial when training readiness is low due to extenuating life circumstances.
3. Ultimately, if life circumstances aren't extenuating, then I'd prefer a fixed order weekly configuration. However, I'd always keep a light or power training session on hand to flex in just in case readiness is low due to unexpected poor sleep, early morning training, or time restraints.

of what assistance exercises to perform. For instance, I often program "back assistance (your choice)" to provide athletes with autonomy. Of course, not everyone may want that autonomy, so this is not a blanket statement to always offer this choice; instead, this is just to say that there are other ways (more than listed here) to implement flexibility into your training program.

Next Steps

Although flexible templates are logical and should work, I still feel this area needs proof of concept for resistance training. When early studies are conducted, the intervention is often overly demanding to examine if the idea is worth continuing. For example, an early static stretching study from Fowles et al (13) had subjects hold stretches for >100 seconds and found decreased acute muscle stiffness and force production. We now know that if your stretches are pretty short (i.e., <10 seconds), the risk of a strength decrease is negligible. The point being, I'd like to see a longitudinal study that compares flexible versus fixed order training when training or life circumstances are really demanding, with my preference being the latter. Potentially, college students who report typically being stressed and sleeping less during the last month of a semester would be good candidates for this study. In that case, we'd see if flexible training could enhance volume and intensity when lifters chose the hard days in the flexible group and if that led to improved outcomes over a month.

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Study Reviewed: Overtraining Syndrome (OTS) and Relative Energy Deficiency in Sport (RED-S): Shared Pathways, Symptoms and Complexities. Stellingwerff et al. (2021)

The Link Between Overtraining and Low Energy Availability

BY ERIC HELMS

For decades, iron gamers have said, “There is no such thing as overtraining, only under-eating.” While this is an incorrect statement deserving of an eye-roll, it may carry an element of truth.

KEY POINTS

1. Overload is necessary, but if recovery is inadequate, fatigue can suppress performance in the short (overreaching) or long (Overtraining Syndrome) term, possibly accompanied by higher injury risk, disrupted sleep, mood, and immune function, and more. These overtraining symptoms are also Relative Energy Deficiency in Sport (RED-S) symptoms, caused by low energy availability (eating too little energy relative to lean mass for one's training).
2. Overtraining Syndrome diagnoses require isolating the cause to excessive training and excluding other causes, including low energy, macronutrient, or micronutrient intakes. If this isolation doesn't occur, RED-S can be mistaken for Overtraining Syndrome.
3. Authors of this review (1) analyzed 21 studies that attempted to induce overreaching or Overtraining Syndrome while reporting energy intake. They found that 18 of 21 studies were potentially confounded by lower energy availability (14 studies) or carbohydrate availability (4 studies) for participants in the overtraining group or condition. Thus, symptoms of overtraining in some cases may be due to insufficient energy intake.

I don't know who first said "There is no such thing as overtraining, only under-eating," but it's repeated so often it's now cemented as bro "wisdom." To be clear, it's an objectively false statement, but a recently published review (1) indicates there may be *some* element of truth to it. To understand where this element comes from, we must 1) define overtraining and 2) define under-eating. The most recent (2013) consensus definition from the European College of Sport Science and the American College of Sports Medicine is that overtraining syndrome is a decline in performance lasting months or longer, with or without secondary symptoms including hormonal, psychological, immune, or sleep dysregulation, and more (a related concept, overreaching, has the same definition as Overtraining Syndrome just delineated by a shorter time course and a potential rebound in performance; more details later in this article) (2). Under-eating in a training context was defined in 2014 and updated in 2018 in the International Olympic Committee's consensus statement as low energy availability: "A mismatch between an athlete's energy intake (diet) and the energy expended in exercise, leaving inadequate energy to support the functions required by the body to maintain optimal health and performance" (3). Chronic low energy availability can lead to what's called Relative Energy Deficiency in Sport (RED-S), a syndrome with nearly identical symptoms to Overtraining Syndrome. But, to diagnose an athlete with Overtraining Syndrome, other potential contributing factors, such as medical conditions or insufficient energy, macronutrient, or micronutrient intakes, must be ruled out to isolate the cause as excessive training stress (2). Further, the most recent overtraining consensus definition came out the year before RED-S was introduced, and unlike RED-S, overtraining is not a new concept and its definition hasn't changed *that* much over the years (4). Therefore, the authors of the present review wanted to explore if RED-S could be misdiagnosed as Overtraining Syndrome or overreaching. To do so, they reviewed 21 overtraining studies (in which the authors induced or attempted to induce overreaching or Overtraining Syndrome) where energy availability of the participants was calculable. In 14 studies, the participants in the overtraining group or condition consumed less energy or had lower energy availability than the comparator, and in four studies the participants didn't consume less energy but had lower carbohydrate availability. Meaning, in total, 18 of the 21 overtraining studies (86%) might have been confounded by nutritional factors. In this article I'll discuss the specific nuances of this review and the relevance and application of the findings to lifters.

Purpose and Hypotheses

Purpose

The purpose of this review was to highlight that many negative outcomes of excessive training load – whether or not it becomes overreaching (to be defined later in this article) or full-blown Overtraining Syndrome – can be caused by under-eating, and to highlight that RED-S can be mistaken for overreaching or Overtraining Syndrome.

Hypotheses

The authors hypothesized "that many of the negative outcomes of training-overload (with, or without an OTS [Overtraining Syndrome], NFOR [non-functional overreaching] or FOR [functional overreaching] diagnosis) may primarily be due to misdiagnosed under-recovery from under-fueling (LEA [low energy availability] leading to RED-S)."

Subjects and Methods

Subjects

In the present review, the authors assessed a few collections of studies for specific outcomes. First, the authors gathered studies where athletes experienced overreaching or Overtraining Syndrome symptoms (57 studies) and studies where athletes experienced RED-S symptoms (88 studies) to compare symptomatology. Interestingly, the RED-S literature is dominated by female participants (n = 7,400 females [78%]; n = 2,105 males [22%]), while overtraining studies are dominated by male participants (n = 210 females [19%]; n = 880 males [81%]). This is most likely because RED-S research began as female athlete triad research (the convergence of disordered eating, menstrual cycle disruption, and reductions in bone density), which is also caused by low energy availability and sits under the umbrella of RED-S. However, overtraining research, like most of sport science broadly, has had historically greater male representation (which is fortunately changing).

Additionally, the authors located and reviewed 21 studies in which the researchers attempted to induce a state of Overtraining Syndrome or overreaching, while also reporting sufficient nutritional and body composition data for the authors to calculate energy availability. Of the 21 studies, 9 used a within-group design (e.g., a crossover or time series analysis in a single cohort where one condition or period was an intended overtraining phase) and 12 used a between-group design (an overtraining group and a "normal training" comparator group). The participants in these studies primarily consisted of endurance athletes (cyclists, long distance runners, and triathletes), rowers, and swimmers, but there were also two studies that included middle distance runners, and one study on active men. Importantly, there were no studies on resistance training.

Methods

While this was not a formal meta-analysis with a systematic literature search, the authors did perform some analyses. For the 57 overtraining and 88 RED-S studies, they assessed what symptoms were reported for each condition and which symptoms overlapped. For the 21 studies in which energy availability was calculable in groups or conditions where researchers attempted to induce overreaching or Overtraining Syndrome, the researchers assessed energy and carbohydrate availability by estimating if these intakes increased commensurately as training energy expenditure increased (or if they actually decreased).

Findings

In Table 1, the symptoms observed in the RED-S/Female Athlete Triad research are compared to those observed in the "overtraining" research. As you can see, all symptoms except for bone health decrements overlap in the two lines of research. Notably, in the over-

Table 1 Symptoms observed in overtraining and low energy availability studies

SYMPTOM	OVERTRAINING SYMPTOM?	RED-S/TRIAD SYMPTOM?
Decreased endurance	Yes	Yes
Decreased strength, speed, or power	Yes	Yes
Injury or illness (higher risk or outcome)	Yes	Yes
Decreased glycogen or protein synthesis	Yes	Yes
Poorer judgement or reaction time	Yes	Yes
Negative impact on sex hormones	Yes	Yes
Negative impact on HPA or HPG axis	Yes	Yes
Negative impact on hematological or biochemistry markers	Yes	Yes
Negative impact on immune function	Yes	Yes
Negative impact on metabolic or cardiovascular markers (RMR, HRV, etc.)	Yes	Yes
Decreased bone health	No	Yes
Poorer mood, emotional state, sleep quality, perceived fatigue, appetite, etc.	Yes	Yes

RED-S = relative energy deficiency in sport; HPA axis = hypothalamic pituitary adrenal axis (associated hormones include cortisol, adrenocorticotropic hormone, prolactin, growth hormone and others), HPG axis = hypothalamic pituitary gonadal axis (associated hormones include luteinizing hormone, gonadotropin releasing hormone, follicle stimulating hormone, and others); RMR = resting metabolic rate, HRV: heart rate variability.

training research, Overtraining Syndrome (or even overreaching) is not always successfully induced (more on this in the interpretation), as a true Overtraining Syndrome diagnosis requires a reduction in performance. However, the high-volume, high-intensity protocols used to induce overtraining often produce secondary symptoms even when performance does not decrease. The authors actually used the terminology "training-overload" studies for this reason; however, I'm comfortable with calling a study an "overtraining study" (or referring to the "overtraining" group or condition) if the researchers *attempted* to induce overtraining, successfully or not.

In the analysis of energy and carbohydrate availability, the authors found that participants in 14 studies had lower energy availability in the overtraining group or condition, and that participants in four studies had lower carbohydrate intake, without lower energy availability. Thus, 18 out of 21 studies (86%) may have observed reductions in performance or secondary symptoms due to inadequate energy or carbohydrate intake, rather than excessive training load. The difference in energy availability between the overtraining and comparator groups or conditions in the 21 analyzed studies was ~10kcal/kg FFM/day (range: 6–18kcal/kg FFM/day). Notably, prior research has shown RED-S symptoms can occur with reductions in energy availability of just 7kcal/kg FFM/day (5).

If you haven't read or don't remember from our previous articles (refresher here), energy availability represents "left over" energy for physiological function after training energy expenditure is subtracted from energy intake. It is expressed relative to fat-free mass (FFM) and an example calculation is as follows: a 10% body fat, 100kg athlete (90kg of FFM) consuming 3,000kcal and expending 400kcal on average in training (2,600kcal "left over") has an energy availability of ~29kcal/kg FFM/day (2,600kcal divided by 90kg).

In all four studies where energy intake was similar between groups or conditions, but carbohydrate intake was lower, poorer performance was also observed. Further, all but one paper that reported lower energy availability in the overtraining condition or group also had a lower carbohydrate intake. These carbohydrate intake differences ranged from 1.4-6.0 g/kg/day, and at the high end, this difference amounted to as much as a two fold difference in total daily carbohydrate intake between groups or conditions (e.g., 4g/kg/day versus 8g/kg/day). These data highlight the importance of maintaining sufficient carbohydrate for athletes with very high endurance training volumes.

Interpretation

This paper targeted endurance athletes, so the findings as reported are only partially relevant to the majority of MASS readers. Thus, I'll briefly interpret them, then frame the interpretation through a lifter's lens. The main findings were that in more than three-quarters of studies where researchers exposed athletes to excessive training loads, energy and carbohydrate intake didn't commensurately increase with increased exercise energy expenditure. In some cases energy and carbohydrate intake actually *decreased* despite an increase in energy expenditure. These reductions in energy availability may have been the cause of observed decreases in performance or secondary symptoms rather than excessive training load. Thus, endurance athletes do not always increase ad libitum energy intake to match high training loads, and they may even fail to do so when intentionally trying to consume sufficiently high energy intakes, resulting in instances of inadvertent low energy or carbohydrate availability. Indeed, in addition to the logistical challenge of consuming very high volumes of food, some data suggest high-intensity training can acutely blunt appetite in a dose dependent manner (6). Further, the data on individuals taking up exercise programs broadly show there is often an initial loss of weight or fat before energy intakes compensate for increased expenditure (7), and this time-lag may be mirrored in athletes during training periods with particularly high energy expenditure.

However, energy expenditure during traditional resistance training isn't nearly as high as energy expenditure during high-volume, continuous, high-intensity endurance training. As such, the risk of inadvertently low energy or carbohydrate availability due to the energy cost of training is comparatively lower in lifters than endurance athletes. Nonetheless, this review is relevant to lifters for three reasons, which I'll address: 1) misconceptions around the concept of overtraining, 2) misconceptions about the role of sufficient energy intake for recovery (i.e., the bro wisdom that kicked this article off), and 3) a high occurrence of low energy availability among lifters due to competitive or non-competitive reasons for dieting.

Because people often talk about "overtraining" without actually referring to Overtraining Syndrome or overreaching, I need to spend a bit more time on terminology. Overtraining Syndrome exists on the far end of the spectrum of training overload, and like I stated in the introduction, it results in sustained decreases in performance for at least *months,* and may or may not accompany negative secondary physiological and psychological effects. On the opposite end of the spectrum is "normal" overload, which results in an acute performance impairment due to fatigue that resolves before the next training session (or the next session that trains similar qualities). There are also two points on the spectrum between normal overload and Overtraining Syndrome: functional and non-functional overreaching. The distinction between functional and non-functional overreaching is that functional overreaching results in a decline or stagnation in performance that lasts days to weeks and is followed by an *increase* in performance above baseline, while non-functional overreaching is *not* followed by an increase in performance, and lasts weeks to months. Like Overtraining Syndrome, either may be accompanied by negative secondary physiological or psychological effects (2).

To make the terminology even more complex, authors of the present review made the distinction between overreaching and Overtraining Syndrome and "mechanical overtraining." Mechanical overtraining specifically refers to sustained performance decrements due to mechanical forces, such as repeated collisions in contact sports, ground reaction forces in running, or high volumes of repetitive motor patterns (e.g., rowers performing 30,000–40,000 strokes/week) that stress specific joints or soft tissue structures past their capacity, without necessarily rising to the level of an injury, or surpassing the theoretical amount of training stress an athlete can systemically tolerate (8).

True Overtraining Syndrome is rare, even among endurance athletes. One study found only 15% of endurance athletes experiencing declines in performance, fatigue, and other secondary effects of excessive training actually met the diagnostic criteria for true Overtraining Syndrome (9). But as rare as these diagnoses are among endurance athletes, they are even rarer in lifters (as I discuss in this video). I'd go as far to say that they are *almost never* experienced by lifters. The volume of training that's logistically feasible with traditional weight training is far less than the volume of training (measured in total contractions or training time not including rest periods) that team sport or endurance athletes can accumulate. Grandou and colleagues (10) illustrated this in a 2020 systematic review of overtraining research in resistance training. In 10 of the 22 studies where researchers attempted to induce overreaching or Overtraining Syndrome, they failed, as no reduction in performance was observed. Of the 12 studies where a decrease in performance was observed, four didn't do a follow-up to see how long the decrease lasted (meaning the protocol may have just resulted in functional overreaching), and the remaining eight studies that did follow-ups were not long enough to detect Overtraining Syndrome (the longest was eight weeks). Thus, full blown Overtraining Syndrome has never been documented in lifters in peer-reviewed literature to my knowledge, despite some absolutely ludicrous protocols. For example, Fry and colleagues had participants test their 1RM on the squat, followed by 10 singles with their 1RM, or as close to it as possible, twice per week (11). Another example is the study by Margonis and colleagues, which had participants increase baseline training volume four-fold while also increasing frequency, load, and proximity to failure for three weeks, and then increase volume *seven-fold* from baseline while also increasing frequency and load again, and training even closer to failure, for yet another three weeks (12). This figure from the study shows the protocol.

I've expressed a number of times on podcasts or at seminars over the years, that "I've only observed overtraining in contest prep competitors and occasionally in CrossFit." This is where the present review comes in, as my anecdote likely misattributed many incidences of low energy availability to overtraining. In the case of contest prep, physique athletes maintain a similar training schedule, add cardio, and concurrently and progressively reduce energy intake. In the case of CrossFit (and to be fair, this is very dependent on the box), it's not uncommon (but also not universal) to adopt the "Paleo Diet" (or similar) which can result in a decreased energy and/or carbohydrate intake. Furthermore, CrossFit isn't a pure strength sport. You perform aerobic and anaerobic training as well, and success in most events is dictated by how much volume you can perform in as short a time period rather than absolute strength (to

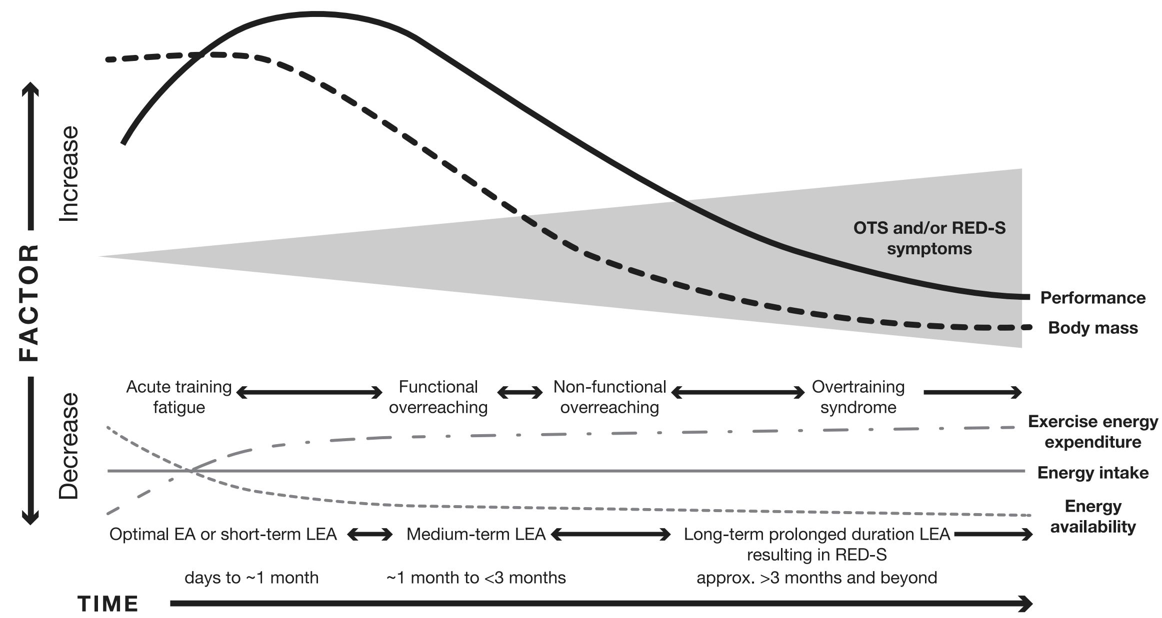

Figure 1 Interplay between low energy availability (LEA) overtaining syndrome (OTS) and RED-S

be clear, this is not an indictment of CrossFit; anyone doing high-volume concurrent training with insufficient energy or carbohydrate intake could experience RED-S). It's also relatively easy to confuse symptoms of low energy availability for excessive training load, because of how they can come about and because they are both related to under-recovery. RED-S symptoms are caused by low energy availability, a mismatch between exercise energy expenditure and energy intake. As shown in Figure 1, someone who drastically increases training volume (and thus energy expenditure), *but keeps energy intake the same*, is now in a state of low energy availability and may develop RED-S. However, it could be that even if they *had* commensurately increased their energy intake, the training load might have been too severe, and they'd also have experienced overreaching, and eventually developed Overtraining Syndrome. In a case like this, sure, you could just eat more (as the bros would suggest) to increase energy availability, but reducing training volume would take care of both low energy availability and excessive training stress.

If you think these findings only apply to endurance athletes, or imply that lifters should aim for their highest possible training volume with the intention of eating their way to satisfactory recovery, I'm here to set you straight. Just because you won't experience full blown Overtraining Syndrome doesn't mean there isn't such a thing as doing too much, or that just because you *can* do more, that you should. As I mentioned in my article on progression frameworks for hypertrophy, building the work capacity to perform a very high-volume protocol or being able to recover performance session-to-session while following a very high-volume protocol doesn't *necessarily* mean you are actually improving at a

JUST BECAUSE YOU WON'T EXPERIENCE FULL BLOWN OVERTRAINING SYNDROME DOESN'T MEAN THERE ISN'T SUCH A THING AS DOING TOO MUCH, OR THAT JUST BECAUSE YOU *CAN* DO MORE, THAT YOU SHOULD.

faster rate because of the high-volume training protocol. Work capacity and recuperability are different qualities than strength or hypertrophy, and strength is one of the qualities that is last and least negatively impacted by excessive training load. In many of the studies reviewed by Grandou, secondary signs of overtraining cropped up even when performance hadn't declined. Further, if a study participant experiences an injury or "mechanical overtraining," they drop out of the study and aren't included in the final analysis. In my anecdotal experiences, when lifters overdo their training dose, they stagnate (indicative of overreaching) and then either change their training because they get hurt (injury or mechanical overload) or because of a loss of motivation or mild depression (secondary symptoms of overtraining). So, no, doing far more volume than you'd benefit from, even while eating more, is probably not a good idea, even though you won't technically overtrain or experience RED-S.

We can also look at this from another angle. If you're experiencing an extended plateau or decline in performance (and/or secondary symptoms), Overtraining Syndrome is an unlikely diagnosis, so energy availability might be the issue. Whether it's the pressure to stay reasonably lean in the offseason so you aren't too far from stage condition as a physique athlete, the pressure to keep your bodyweight close to your weight class cutoff as a strength athlete, or the pressure from your damn Instagram feed to look good naked, undereating is a common occurrence. If you've been changing programs, trying supplements, or considering medical treatments or drugs, and nothing is working, it might be time to assess whether you're simply not eating enough.

Next Steps

I would love to see a very similar review on overtraining research using resistance train-

DOING FAR MORE VOLUME THAN YOU'D BENEFIT FROM, EVEN WHILE EATING MORE, IS PROBABLY NOT A GOOD IDEA, EVEN THOUGH YOU WON'T TECHNICALLY OVERTRAIN OR EXPERIENCE RED-S.

APPLICATION AND TAKEAWAYS

The old adage "there is no such thing as overtraining, only under-eating" isn't true, as you can certainly put yourself through an excessively challenging training protocol that won't get you faster gains, but might leave you depressed and injured, no matter how much you eat. However, it's also true that if you chronically under-eat, you can experience reductions in performance and negative mental and physical health effects, just like you would if you were overtraining, which can be alleviated by increasing your energy intake.

ing. With that said, I suspect it would be a very small review. In the present review, there were 57 studies on overtraining in non-resistance trained athletes, and only 21 of them (about a third) had sufficient information to calculate energy availability. The 2020 Grandou review on overtraining in resistance training only had 22 total studies in it, and I suspect an even smaller proportion reported data sufficient to calculate energy availability. Therefore, what might be a more realistic next step, would be to conduct observational research on lifters who are plateaued or experiencing a decline in performance, and then assess them for both Overtraining Syndrome as well as low energy availability. This would allow us to see how often these plateaus or performance declines might be related to insufficient energy availability.

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Extrapolating From Short-Term Adaptations and Proxy Measures: A Dangerous Game

BY ERIC TREXLER

Polyphenol supplements can acutely accelerate recovery, and protein supplementation can boost muscle protein synthesis. A new longitudinal study sought to determine if combined supplementation would pay off in the long run, but the results were underwhelming.

KEY POINTS

1. Over the course of a ~10.5 week resistance training program, 29 healthy adults were randomly assigned to consume a protein-polyphenol supplement after exercise (20g protein + 650mg pomegranate extract) and before bed (18g protein + 480mg tart cherry extract), or an isocaloric maltodextrin placebo at both time points.
2. The protein-polyphenol supplement increased 48-hour protein synthesis rates after the first training session and early gains in muscle function (total work over 30 leg extensions, measured after the 10th workout). However, there were no between-group differences in protein synthesis, muscle strength, muscle function, muscle volume, or muscle cross-sectional area at the end of the intervention.
3. Acute muscle protein synthesis isn't predictive of long-term hypertrophy in untrained people, chronic consumption of recovery-accelerating supplements doesn't make a ton of sense for typical training applications, and gains don't always plummet when you fall short of 1.6g/kg/day of protein.

As a proud member of the MASS Nutrition Department, I've covered a wide range of nutrition topics in previous articles. I've written at length about the fact that short-term muscle protein synthesis rates are not predictive of long-term hypertrophy, particularly in untrained individuals. I've written about optimal daily protein intake and distribution for the promotion of hypertrophy. I've written about the recovery-enhancing effects of tart cherry supplementation, while simultaneously questioning how relevant those effects are for typical training scenarios. I've also done quite a bit of writing outside of MASS over the last several years, including some peer-reviewed research on pomegranate extract supplementation (2), and a long Stronger By Science article that discusses whether or not polyphenols may enhance or hinder training adaptations. At this point, you might be wondering why I'm telling you about a series of unconnected topics I've written about over the last 5-8 years. The answer: because the presently reviewed study (1) somehow managed to tie all of them together.

In this study, 29 recreationally active participants completed 30 unilateral resistance training sessions over the course of about 10.5 weeks. 15 participants were randomly assigned to consumed a protein-polyphenol supplement after exercise (20g protein + 650mg pomegranate extract) and before bed (18g protein + 480mg tart cherry extract), with >1.6g/kg/day of total protein intake, while 14 participants were assigned to consume an isocaloric maltodextrin placebo at both time points (with <1.6g/kg/day of total protein intake). The researchers measured muscle protein synthesis over 48-hour time periods, along with several indices of hypertrophy and performance, at several different points throughout the study, which enabled them to distinguish between early-phase and late-phase training adaptations.

Supplementation increased 48-hour protein synthesis rates after the first training session and enhanced early improvements in muscle function, but there were no between-group differences in protein synthesis, muscle strength, muscle function, muscle volume, or muscle cross-sectional area at the end of the intervention. Muscle protein synthesis measured at the beginning of the study didn't correlate with any training adaptations from pre- to post-testing, whereas some training adaptations did correlate (somewhat weakly) with protein synthesis rates measured post-intervention. This study lends itself to some interesting discussions about drawing inferences from protein synthesis measurements, the utility of recovery-enhancing supplements, and the precision of protein intake recommendations, which will all be discussed in this article.

Purpose and Hypotheses

Purpose

The purpose of the presently reviewed study was to determine if protein-polyphenol supplementation would facilitate quicker adaptations across the early stage (first 10 sessions) of a training program and greater adaptations across the entire training program (30 sessions). An additional purpose was to evaluate relationships between pre-training protein synthesis, post-training protein synthesis, and adaptations to training.

Table 1 Participant characteristics

	PLACEBO N=14	PROTEIN-POLYPHENOL N=15
Sex (male:female)	7:7	7:8
Age (years)	25 ± 2	24 ± 1
Body mass (kg)	67.6 ± 2.5	65.5 ± 3.5
Height (cm)	168 ± 3	170 ± 3
BMI (kg·m^{-2})	23.9 ± 1.0	22.3 ± 0.7
Baseline function (J)	U: 2172 ± 180	U: 2413 ± 216
	T: 2204 ± 173	T: 2418 ± 232
Baseline peak isometric torque (n·m)	U: 185 ± 10	U: 211 ± 21
	T: 184 ± 13	T: 204 ± 21
Baseline peak isokinetic torque (n·m)	U: 139 ± 12	U: 153 ± 16
	T: 132 ± 12	T: 150 ± 15

Values represent mean ± SEM.
BMI = Body mass index, U = untrained leg, T = trained leg.

Hypotheses

The researchers hypothesized that protein-polyphenol supplementation "would accelerate improvements in muscle function during the early (10 sessions; ~3 weeks) training period." They also hypothesized that this early improvement "would be associated with greater post-training [myofibrillar protein synthesis] rates, and a greater increase in quadriceps muscle volume and fiber [cross-sectional area]."

Subjects and Methods

Subjects

The present study enrolled 32 recreationally active participants (16 male and 16 female). Participants were excluded if they consumed less than 0.8 or more than 1.6g/kg/day of protein, had any type of relevant musculoskeletal injury, metabolic or cardiovascular impairment, used any anti-inflammatory medications or nutritional supplements, or regularly engaged in structured resistance training (>2 times per week) or endurance training (>6 hours per week) programs within six months of study initiation. Three participants dropped out of the study prior to completion, so data were available for 14 participants from the placebo group and 15 participants from the supplement group; their characteristics are presented in Table 1.

Methods

Participants were randomly assigned to consume a protein-polyphenol supplement (n = 15) after exercise (20g protein + 650mg pomegranate extract) and before bed (18g protein + 480mg tart cherry extract), or an isocaloric maltodextrin placebo at both time points (n = 14). Interestingly, this protein supplementation bumped the supplement group into the commonly recommended protein range for lifters (1.6-2.2 g/kg/day), which corresponds to a meta-analysis by Morton et al (3), while the placebo group remained below this range. Before starting the intervention, participants completed two familiarization sessions to become acquainted with the leg extension exercise and testing procedures. Throughout the ~10.5 week intervention, participants completed 30 sessions of unilateral resistance exercise (leg extensions), with approximately 3 training sessions per week. Participants completed all of the leg extension workouts (5 sets of 30 maximal muscle actions, alternating between sets of concentric and eccentric muscle actions) with the same leg, while their other leg served as an untrained, within-subject control.

As mentioned previously, the researchers were interested in distinguishing between early-phase and late-phase training adaptations. As a result, a variety of measurements related to muscle protein synthesis, strength, and hypertrophy were taken at several time points. Muscle protein synthesis was measured over a 48-hour period on two occasions: once following the first workout, and once at the end of the study. In order to obtain valid estimates, diet was strictly controlled during these 48-hour periods. The researchers also obtained muscle biopsies and MRI scans of participants' thighs before and after the intervention to assess muscle hypertrophy. Peak isometric knee extension torque (maximal leg extension at a fixed knee angle), peak isokinetic knee extension torque (maximal leg extension at a fixed velocity), and muscle function (total work over a set of 30 maximal isokinetic leg extensions) were measured in the trained and untrained legs every 3 training sessions, and diet logs were collected every 6 training sessions. In addition, the researchers assessed subjective soreness at multiple time points using a 100mm visual analogue scale.

In terms of outcomes, the researchers were obviously interested in determining if supplementation significantly impacted training adaptations (changes in muscle size and function) across the entire training program. However, they were also interested in distinguishing between effects observed in the early phase of training (first 10 sessions; ~3 weeks) and late phase of training (sessions 11-30; weeks 4 to 10.5). In addition, the researchers were interested in exploring relationships between acute muscle protein synthesis measurements and training adaptations. As such, they did some correlation tests to see if acute muscle protein synthesis rates, measured at the beginning and end of the intervention, were predictive of changes in muscle size or function.

Findings

This study reported a lot of different outcomes at a lot of different time points, so I am going to focus on the most relevant findings.

Dietary Intakes

When expressed as raw units (grams per day), carb and fat intakes were not significantly different between groups. In the protein-polyphenol group, protein remained within the protein range commonly recommended for lifters (1.6-2.2g/kg/day), with values fluctuating between 1.7-1.8 g/kg/day. In the placebo group, protein remained below this range, with values fluctuating between 1.2-1.5 g/kg/day.

Training Sessions

Total work completed during training sessions increased by about 20% during the early phase of training, with no significant difference between groups. Total work further increased by about 5-10% during the late phase of training, which was a significantly slower rate of progress than the early phase. Once again, this was not impacted by supplementation. Muscle soreness was significantly elevated at the second training session (from ~3-4 mm at baseline to ~7-9mm at session 2), which was performed 48 hours after the first session. However, by the third session, soreness had returned to baseline, and soreness values were not significantly impacted by supplementation.

Muscle Function and Strength

Peak isometric torque increased significantly during the early phase of training, but did not increase significantly from session 10 (end of early phase) to session 30 (end of late phase). Peak isokinetic torque did not change significantly throughout the early phase or late phase of training, and neither isometric nor isokinetic torque values were significantly influenced by supplementation.

There was a significant interaction effect for muscle function (total work over a set of 30 isokinetic leg extensions) during the early phase of training. In the placebo group, muscle function in the trained leg, expressed as a percentage of the muscle function value for the same individual's untrained leg, decreased from 102.6 ± 3.9% (mean ± standard error) to 100.8 ± 2.4%, whereas an increase was observed in the supplement group (99.9 ± 1.8% to 107.2 ± 2.4%). Muscle function continued to generally improve during the late phase of training, but was not significantly impacted by supplementation. When simply comparing leg extension outcomes over the duration of the full 10.5-week intervention, training increased muscle function and peak isometric torque, but these improvements were not significantly impacted by supplementation. Effect sizes for each group's changes in muscle function during the early phase of training and the entire training program are presented in Table 2.

Muscle Hypertrophy

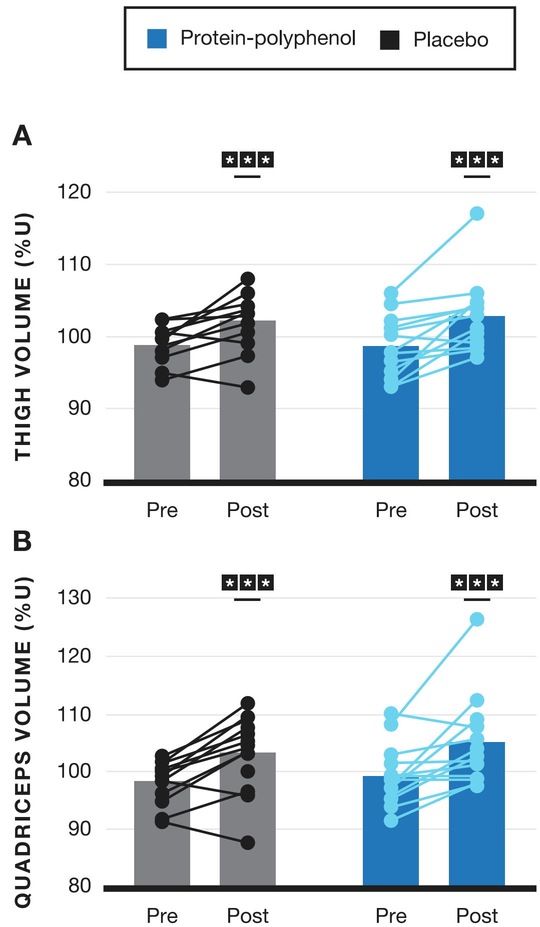
Fiber-level hypertrophy outcomes were assessed in only 9 participants from each group. Overall (combining type 1 and type 2 fibers),

Table 2 Change scores from pre-training

	CHANGE SCORES (MEAN ± SD)	
	PLACEBO	PROTEIN-POLYPHENOL
Function S10	-0.16 ± 1.27	0.63 ± 0.89
Function post-training	0.70 ± 1.57	1.17 ± 1.72
Quadriceps volume	1.05 ± 0.96	1.24 ± 1.32
Quadriceps CSA; proximal	0.85 ± 1.34	1.55 ± 1.50
Quadriceps CSA; central	0.82 ± 0.86	0.88 ± 0.97
Quadriceps CSA; distal	0.62 ± 0.66	0.86 ± 1.23
TI fCSA	-0.12 ± 0.98	0.61 ± 1.20
TII fCSA	-0.38 ± 0.96	0.34 ± 0.71

SD = standard deviation, S10 = session 10, CSA = cross-sectional area, TI fCSA = type 1 fiber cross-sectional area, TII fCSA = type 2 fiber cross-sectional area. Values presented as standardized (Cohen) units.

Figure 1 Whole thigh (A) and quadriceps (B) muscle volume measured using MRI pre and post 30 sessions of unilateral, maximal, isokinetic contractions, expressed relative to the untrained leg (%U)



*Post-exercise and pre-bed protein-polyphenol (PPB; n=15) or isocaloric maltodextrin placebo (PLA; n=14) nutritional interventions were ingested daily throughout the training period. Data are means ± standard error. Statistical analysis performed with separate two-way ANOVAs. *** = p < 0.001, significant main effect of training.*

there was a statistically significant interaction effect favoring the supplement group, but this seems related to a paradoxical change in the placebo group. Mean fiber cross-sectional area of the trained leg, expressed as a percentage of the cross-sectional area value for the same individual's untrained leg, dropped from 120.5 ± 7.4% to 109.5 ± 8.6% throughout the training program in the placebo group. In the supplement group, it increased from 91.5 ± 6.1% to 111.8 ± 10.7%. There was not a statistically significant effect for type 1 fiber area, but a small reduction was seen in the placebo group while a fairly noteworthy increase was seen in the supplement group. For type 2 fiber area, a significant interaction was observed, with a fairly pronounced reduction in the placebo group and a fairly pronounced increase in the supplement group.

I personally don't put a lot of stock into these fiber-level findings. The two groups started with very different baseline values in their trained legs (120.5% versus 91.5%), which is unexpected with this type of study design. In addition, the placebo group experienced favorable changes in whole-muscle indices of hypertrophy (muscle cross-sectional area and muscle volume), which were comparable in magnitude to the supplement group, despite the reported drop in fiber cross-sectional area. Both groups experienced statistically significant increases in thigh muscle volume, quadriceps muscle volume, thigh muscle cross-sectional area (at proximal, central, and distal regions), and quadriceps muscle

Table 3 Correlations between dependent variables measured pre-, during and post-training

	PRE-TESTING PROTEIN SYNTHESIS (%U)		POST-TESTING PROTEIN SYNTHESIS (%U)	
	r	P	r	P
Fucntion S10 (%U)	0.421	0.057	-0.140	0.579
Function post-training (%U)	-0.050	0.830	-0.313	0.206
Quadriceps volume (%U)	0.068	0.771	0.399	0.101
Quadriceps CSA; proximal (%U)	0.016	0.946	0.314	0.204
Quadriceps CSA; central (%U)	0.181	0.258	0.478	0.045
Quadriceps CSA; distal (%U)	0.249	0.276	0.557	0.016
TI fCSA (%U)	0.317	0.182	0.443	0.066
TII fCSA (%U)	0.299	0.229	0.439	0.069

%U = expressed relative to time-matched untrained control leg, S10 = session 10, CSA = cross-sectional area, TI fCSA = type I fiber cross-sectional area, TII fCSA = type II fiber cross-sectional area

cross-sectional area (at proximal, central, and distal regions), which were not significantly impacted by supplementation. Results for thigh muscle volume and quadriceps muscle volume are presented in Figure 1. Effect sizes for changes in quadriceps volume, quadriceps cross-sectional area, and fiber-specific cross-sectional area from pre-testing to post-testing are presented in Table 2.

Muscle Protein Synthesis

When protein synthesis was measured at pre-testing, supplementation led to significantly greater rates of 48-hour myofibrillar protein synthesis than placebo. However, the difference between trained and untrained legs was not statistically significant. As shown in Table 3, pre-testing protein synthesis measurements were not significantly correlated with any post-training outcome related to muscular performance or hypertrophy. When protein synthesis was measured at post-testing, supplementation did not have a significant impact ($p = 0.799$), but protein synthesis rates were significantly higher in the trained leg when compared to the untrained leg. As presented in Table 3, post-testing protein synthesis measurements were significantly correlated with post-training quadriceps cross-sectional area measured at the distal portion of the muscle ($r = 0.557$, $p = 0.016$) and the central portion of the muscle ($r = 0.478$, $p = 0.045$). In addition, correlations with post-training cross-sectional areas of type 1 ($r = 0.443$, $p = 0.066$) and type 2 ($r = 0.439$, $p = 0.069$) muscle fibers were fairly close to the statistical significance threshold.

Interpretation

In a nutshell, the results of this study are fairly simple and straightforward: the protein-polyphenol supplement facilitated muscle protein synthesis and improvements in muscle function during the early phase of a training program, but muscle protein synthesis rates at pre-testing weren't very helpful for predicting chronic training adaptations, and supplementation didn't have a statistically significant impact on changes in muscle cross-sectional area, muscle volume, or leg extension performance. I think this study reinforces three specific points, which will be discussed in order: 1) muscle protein synthesis is not hypertrophy, 2) polyphenols can facilitate short-term recovery, but might not matter much in the long run, and 3) evidence-based protein recommendations aren't at precise as you might think.

Muscle Protein Synthesis Is Not Hypertrophy

I've made this point before, so I'll be more concise the second time around. In a recent MASS article, I spent a lot of time highlighting the numerous issues with assuming that acute muscle protein synthesis is a reliable predictor of long-term hypertrophy (4). Many fitness professionals have grown comfortable using acute muscle protein synthesis as a "proxy measure" that is assumed to be fully interchangeable with hypertrophy, and the scientific evidence suggests that this is a very, very shaky assumption. The presently reviewed study, like others before it (4), found that muscle protein synthesis measured at the start of an intervention is not reliably predictive of chronic training adaptations over the course of a longitudinal training program. In this case, pre-test muscle protein synthesis did not significantly correlate with any outcome related to performance or hypertrophy.

In reviews by Witard et al (4) and Trommelen et al (5), researchers have identified some scenarios in which the predictive utility of acute protein synthesis measurements can be improved. When a sample of study participants is relatively well-trained, is completing a type of exercise that they're accustomed to, and is having their rate of protein synthesis measured over a longer period of time, protein synthesis measurements tend to be more predictive of hypertrophy outcomes. However, "more predictive" is not the same as "perfectly predictive," and even under ideal measurement conditions, we can't treat muscle protein synthesis and hypertrophy as interchangeable outcomes.

Table 3 presents correlations between post-test protein synthesis measurements and various indices of hypertrophy. By the time these post-test protein synthesis measurements were taken, the participants had been training for over 10 weeks and were extremely familiarized to the exercise bout. The measurements were also taken over the span of 48 hours, which is far longer than the typical protein synthesis study, which generally assesses protein synthesis over the span of <10 hours. Despite these methodological advantages bolstering the predictive utility of the post-test protein synthesis measurements in this study, the highest r value in Table 3 was r = 0.557, indicating that differences in post-test muscle protein synthesis predicted about 31% of the variance in distal quadriceps cross-sectional area.

That's not particularly high, and that's the best case observed in this study; of the six hypertrophy outcomes presented in Table 3, post-test protein synthesis rates predicted (on average) only about 19% of the variance in hypertrophy outcomes. In other words, post-test protein synthesis rates failed to explain 81% of the variance in hypertrophy outcomes. In summary, this study adds to the evidence suggesting that any hypertrophy-focused guidelines based exclusively on acute muscle protein synthesis measurements are resting on a shaky foundation, and should be viewed as relatively tentative and speculative in nature (pending more direct verification from longitudinal studies).

Polyphenols Can Facilitate Short-Term Recovery, but Might Not Matter Much in the Long Run

Back in 2020, I took a deep dive into the antioxidant literature for a Stronger By Science article. I took an interest in the topic because I noticed a lot of uncertainty surrounding antioxidants for lifters – antioxidant-rich fruits and vegetables are almost unanimously recognized as healthful and nutritious foods, and certain antioxidants are sometimes framed as performance-enhancing components of multi-ingredient supplement formulas, but some lifters have concerns that high antioxidant intakes could attenuate gains in strength and hypertrophy. The highlights of my conclusions were as follows: 1) there is some weak, fairly inconsistent evidence that high-dose vitamin C + vitamin E supplementation could modestly impair training adaptations, 2) even if vitamin C + E supplementation doesn't blunt training adaptations, there's not enough positive evidence to justify supplementing with them in the first place, 3) plant-derived phytonutrient antioxidant compounds, such as polyphenols, do not appear to blunt training adaptations due to mechanistic differences in reactive species scavenging (6), and 4) there is some modest evidence to suggest that phytonutrient antioxidant compounds (like polyphenols) can favorably impact recovery.

HYPERTROPHY-FOCUSED GUIDELINES BASED EXCLUSIVELY ON ACUTE MUSCLE PROTEIN SYNTHESIS MEASUREMENTS ARE RESTING ON A SHAKY FOUNDATION.

The results of the presently reviewed study are generally compatible with points #3 and #4, and are consistent with previous literature suggesting that a variety of polyphenol-rich extracts and juices from plants, including tart cherry, pomegranate, and watermelon, can acutely facilitate recovery. The presently reviewed study did not document significant reductions in soreness, which is slightly out-of-step with some of the polyphenol literature, but this training intervention didn't induce a lot of soreness to begin with; soreness briefly increased from ~3-4 (out of 100) to ~7-9, then returned to baseline by the third workout. When soreness never climbs above a 1 out of

10, there isn't much to attenuate, and statistically significant effects are extremely unlikely.

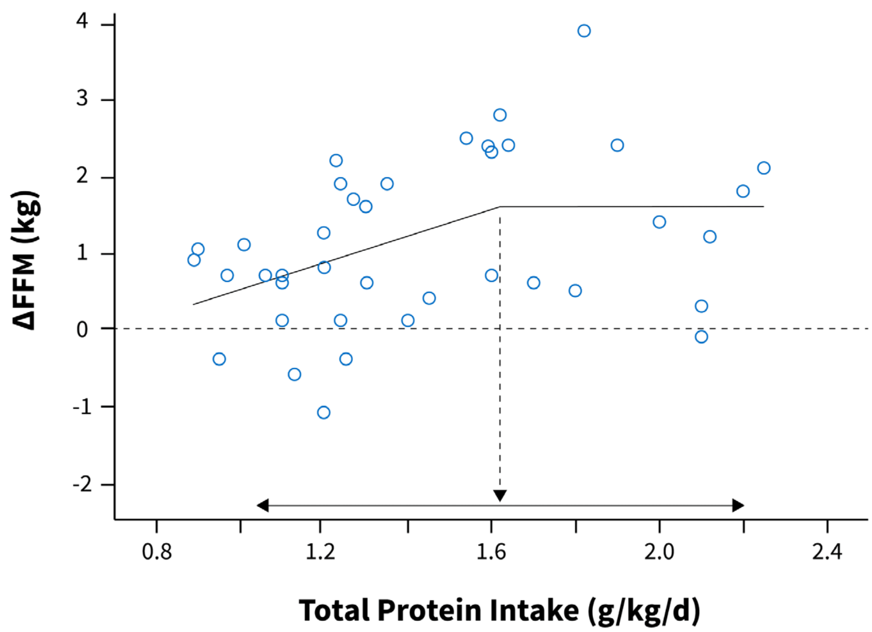
Having said all of that, the present findings also reinforce a caveat that I alluded to in a previous MASS article. Studies that report recovery-boosting effects from polyphenol supplements tend to introduce an intense, unaccustomed form of exercise that induces a great deal of muscle damage and a substantial recovery burden, and they tend to measure recovery over pretty short periods of time. In the context of normal training, it's uncommon to transiently introduce such a dramatic change in training variables, with the simultaneous need to be fully recovered within a day or two. Even if you do have a dramatic transition in your training approach, you're likely to adapt and accommodate the change quite effectively within the first few weeks, with or without supplementation. So, the literature to date suggests that phytonutrient antioxidant compounds like polyphenols can facilitate recovery, but the utility of this supplementation strategy is probably a bit limited. If you're making some big program changes, pushing through a particularly arduous phase of training, or trying to cope with an intense competition schedule that is testing your recovery capacity, polyphenol supplementation would make sense. However, if you're expecting daily polyphenol supplementation to substantially improve your training adaptations within the context of a normal, everyday training program, this study (and others) cast doubt on that expectation. Of course, many of us like to train pretty hard on a pretty consistent basis, so I would propose a nice middle ground: there are no downsides and plenty of upsides associated with consuming antioxidant-rich fruits and vegetables, so a well-rounded diet that intentionally aims to include plenty of antioxidants should effectively support recovery (along with plenty of additional benefits), without requiring extraneous supplementation.

POLYPHENOLS CAN FACILITATE RECOVERY, BUT THE UTILITY OF THIS SUPPLEMENTATION STRATEGY IS PROBABLY A BIT LIMITED.

Evidence-Based Protein Recommendations Aren't As Precise as You Might Think

In the evidence-based fitness world, the protein intake range I see most commonly recommended to lifters is 1.6-2.2 g/kg of body mass per day. This is a fine recommendation, and just about as good as it gets if you're scaling a protein recommendation to total body mass. The first time I saw this recommendation presented in the literature was in a review paper by Morton and colleagues (3), which derived this estimate from applied, longitudinal studies looking at training-induced changes in fat-free mass over time in response to varying levels of protein intake. This recommendation is also supported by more mechanistic

Figure 2 The relationship between protein intake and gains in fat-free mass



As demonstrated in this figure from Morton et al (3), consuming at least 1.6g/kg/day of protein is generally conducive to maximizing hypertrophy, but this is estimated threshold is far from a precise guideline, with a 95% confidence interval ranging from 1.03 to 2.20g/kg/day.

data from Bandegan and colleagues (7), who took an entirely different approach to assessing the protein needs of male bodybuilders, and still ended up calculating a very similar recommendation (around 1.7-2.2 g/kg/day).

In the presently reviewed study, the supplements provided 38 grams of extra protein per day. As a result, the supplement group consumed just above the common threshold of 1.6g/kg/day (1.7-1.8 g/kg/day), while the placebo group consumed just below this threshold (1.2-1.5 g/kg/day). In a recent MASS article, I mentioned that researchers have a tendency to latch on to p-value thresholds that place excessive emphasis on fairly arbitrary cutoffs. Some researchers are dazzled by a finding when p = 0.045, but quick to discard a finding as flatly unimportant when p = 0.055. Such a dichotomized perspective ignores the fact that these two scenarios are quantitatively very similar, and may lead to conclusions that lack nuance. I've noticed a similar trend when it comes to protein thresholds; an evidence-based fitness enthusiast may balk at the idea of eating 1.55g/kg/day of protein, while they consider 1.65g/kg/day to be comfortably within the optimal range.

In the presently reviewed study, there was nothing magic about the 1.6g/kg/day threshold. You might argue that there was a slight, non-significant advantage favoring the supplement group, but consuming below 1.6g/kg/day of protein did not lead to a substantial impairment of hypertrophy in the placebo group, no matter how ingrained the threshold has become in our minds. I suspect that widespread support for this common protein recommendation (1.6-2.2g/kg/day) has led some to believe that this "optimal range estimate" is more precise than it truly is. Figure 2 is re-created from the meta-analysis by Morton et al (3), from which this recommended protein range was originally derived. If you look at the individual data points, you can see that there is no abrupt drop off; being below 1.6g/kg/day did not guarantee poor results, and being above 1.6g/kg/day did not guarantee excellent results. The "breakpoint" of the regression line (that is, the estimated threshold for optimal protein intake) was 1.6g/kg/day, but the 95% confidence interval ranged all the way from 1.03 to 2.20 g/kg/day. The same general point is true for the other study by Bandegan et al (7), which yielded a similar protein recommendation; the estimated breakpoint was 1.7g/kg/day, but the 95% confidence interval spanned from 1.2 to 2.2 g/kg/day.

To be clear, I'm not suggesting that 1.6-2.2g/kg is an ineffective recommendation for protein intake. Over the last few years, I've developed a preference to recommend protein based on fat-free mass rather than total mass (with a general recommendation of around 2-2.75g/kg of fat-free mass, with values increasing as high as 3.1g/kg of fat-free mass in the context of aggressive fat loss phases). However, if I have to scale a protein recommendation by total body mass, 1.6-2.2g/kg is still the range I use. The important thing to keep in mind is that, despite the suitability and popularity of this recommendation, it's far from a precise recommendation, and you can make some pretty great gains with protein intakes below 1.6g/kg/day.

Next Steps

In the presently reviewed study, the little details didn't matter too much – bumping protein intake from 1.2-1.5g/kg/day to 1.7-1.8g/kg/day and adding some polyphenols to the mix didn't meaningfully impact gains over 10.5 weeks. However, we should always be cautious about placing too much confidence in a single study with 14-15 participants per group, and you could make the argument that this study wasn't optimally designed to reveal the beneficial effects of this supplementation strategy. The training program only targeted the quadriceps of a single leg, was static in terms of exercise selection and set volume, and failed to elicit substantial levels of soreness. As such, it's very possible that the program didn't introduce a particularly large recovery burden, even for untrained participants. I'd be interested to see if this supplementation strategy (twice-daily servings of protein, plus additional polyphenols) would favorably impact training adaptations in a more arduous, progressive, full-body training program that introduces a much larger recovery burden. It's theoretically possible that this type of supplementation would make sense within that context, but that approach to training might lack sustainability in the long run.

APPLICATION AND TAKEAWAYS

Eating plenty of protein is great, and aiming for around 1.6-2.2g/kg of body weight (or around 2-2.75g/kg of fat-free mass) is an excellent way to maximize your likelihood of optimizing training adaptations in most circumstances. However, the lower ends of these ranges are not precise cutoffs; you can make excellent progress on slightly lower protein intakes, and slipping from 1.7g/kg/day to 1.5g/kg/day is not going to grind your progress to a halt. Evidence suggests that supplementing with polyphenol-rich extracts and juices from plants, including tart cherry, pomegranate, and watermelon, can acutely facilitate recovery in the context of intense, novel exercise. However, this supplementation strategy may only be useful when weathering transient periods of training or competition in which your recovery burden is dramatically increased. In the context of normal, everyday training, eating a well-rounded diet with plenty of antioxidant-rich fruits and vegetables should provide all the antioxidants you need to support recovery, in addition to providing plenty of other unrelated benefits.

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Study Reviewed: Resistance Training with Different Velocity Loss Thresholds Induce Similar Changes in Strength and Hypertrophy. Andersen et al. (2021)

The Most Comprehensive Look at Proximity to Failure Yet

BY MICHAEL C. ZOURDOS

A new study with an excellent design shows that training to ~5 reps in reserve produces strength and hypertrophy outcomes that are comparable to those observed when training close to failure. This article provides the most comprehensive look at proximity to failure to date in the MASS catalog.

KEY POINTS

1. Seven women and three men trained the unilateral leg press and leg extension twice per week for nine weeks. Researchers instructed the subjects to stop sets on one leg after a 15% velocity loss, and on the other leg at a 30% velocity loss. I've estimated that the 15% velocity loss group trained sets to 5-10 RIR while the 30% loss group took sets to 1-4 RIR.
2. Researchers reported no statistically significant differences between conditions for the rate of increase in strength or muscle thickness, suggesting that training far from failure (≥5 RIR) may produce similar hypertrophy to training close to failure.
3. This article examines every longitudinal velocity loss study to date and reviews other proximity to failure studies to clarify how far from failure you should train to maximize strength and hypertrophy.

I recently made the case that we can comfortably recommend non-failure training for both hypertrophy and strength; however, the debate rages on how far from failure lifters can train and still maximize gains. Although researchers can use various methods to control for proximity to failure, velocity loss (despite my objections) has become prominent in recent years. Some of this recent research has shown that at moderate intensities (70-85% of 1RM), training with 20% (2 – MASS Review) and 25% (3 - MASS Review) velocity loss led to superior strength gains compared to a 40 and 50% velocity loss, respectively. Further, a 20% velocity loss elicited similar rates of muscle growth compared to a 40% velocity loss (2). In other words, as I've indicated before, training shy of failure likely provides larger 1RM strength gains than training to failure, and at least similar hypertrophy when compared to failure training. The presently reviewed study from Andersen et al (1) had 10 trained women (n = 7) and men (n = 3) perform the leg press and leg extension unilaterally for nine weeks. This study was a within-subjects design; thus, researchers terminated a set on one leg when a 15% velocity loss was achieved and terminated sets on the other leg when velocity loss exceeded 30%. Before and after the nine weeks, researchers assessed unilateral 1RM strength on both exercises, isometric strength, rate of force development, and quadriceps muscle thickness. Both legs increased strength and muscle thickness, and there were no group differences for any measure. These results suggest that training with ≥5 RIR per set may be sufficient to maximize strength and muscle growth. That notion may sound surprising, but training at ≥5 RIR has now been shown to be equal to or better than training closer to or at failure on various occasions (1, 4, 5) for muscle growth; thus, this finding should no longer be surprising. Therefore, this article will aim to:

1. Discuss the state of the proximity to failure literature.

2. Determine how far from failure lifters were in the longitudinal velocity loss studies.
3. Examine limitations in the longitudinal velocity loss literature.
4. Discuss the various program design considerations that may drive strength gains.

Purpose and Hypotheses

Purpose

The purpose of the presently reviewed study was to compare changes in leg press and leg extension strength, quad hypertrophy, and rate of force development when terminating each set after either a 15% or 30% velocity loss threshold.

Hypotheses

The researchers hypothesized that there would be greater strength gains in the 15% velocity loss condition but similar hypertrophy between training protocols.

Subjects and Methods

Subjects

Seven women and three men with at least two years of training experience participated. The available subject characteristics are presented in Table 1.

Study Overview

The presently reviewed study used a within-subjects design, with each participant serving as their own control. Specifically, the 10 subjects trained the leg press and leg extension twice per week on non-consecutive days. One leg terminated sets when subjects exceeded a 15% velocity loss, and the other leg terminated sets after achieving a 30% velocity loss. Before and after the training program, researchers assessed various outcome measures, including strength and muscle growth. These measures are listed, and additional descriptions are provided for unique measures in Table 2.

Training Protocol

The training protocol in this study was excellent. In week 1, subjects started training the leg press with 80% of 1RM and the leg extension with 75% of 1RM. Researchers intended for sets to be terminated after 5-7 reps in the 15% loss leg and after 12-14 reps in the 30% loss leg. Load increased 2.5-5 kg for the next set whenever subjects performed over the upper limit of the rep range, and subjects rested 2.5 minutes between each set. More on this

Table 1 Subject characteristics

SUBJECTS	AGE (YEARS)	BODY MASS (KG)	HEIGHT (CM)	TRAINING EXPERIENCE (YEARS)	AVERAGE PRE-STUDY TRAINING FREQUENCY EXPERIENCE (SESSIONS/WEEK)
10 (7 Women, 3 Men)	23.0 ± 4.3	68.1 ± 8.9	171 ± 8	4.5 ± 0.7	3.9 ± 1.2

Data are Mean ± SD.
Subject characteristics from Andersen et al. 2021 (1).

Table 2 Outcome measures

MEASURE	DESCRIPTION
1RM Strength	Maximal strength on only the dynamic unilateral leg press (not the leg extension).
Hypertrophy	Muscle thickness via ultrasonography.
Pennation Angle	Pennation angle for the vastus lateralis was measured via ultrasonagraphy. Pennation angle is the angle at which fibers attach to the tendon. An increased pennation angle is associated with greater single-fiber cross-sectional area and force production.
Fascicle Length	Fascicle length of the vastus lateralis was measured via ultrasonagraphy. Increases in fascicle length are a positive resistance training outcome and occur due to adding sarcomeres in a series (sarcomerogenesis).
Maximal Voluntary Contraction (MVC)	This isometric strength test was only performed on the leg press. The sled was fixed to a 90-degree knee angle and subjects pushed against it for 5 seconds. The average force over the strongest two seconds of the contraction was recorded. MVC tests were not conducted on the leg extension.
Load-Velocity and Power Profile	Velocity and power output were assessed at 30, 45, 60, and 75% of both the pre- and post-study 1RM to examine if these parameters changed over time at the same relative load.
Rate of Force Development	Δforce/Δtime during the 20-80% of MVC and during the first 50, 100, and 20ms of the MVC.

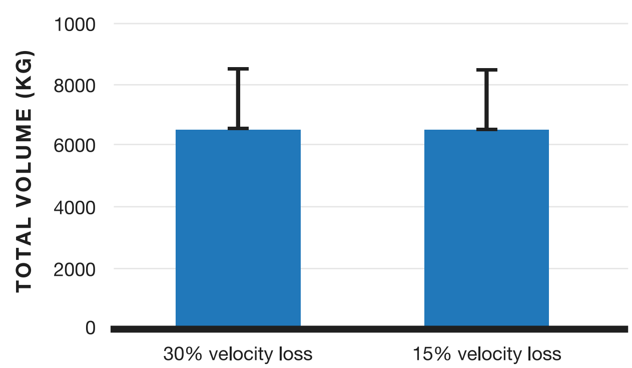
Outcomes from Andersen et al. 2021 (1).

Table 3 Training program set prescription

WEEKS	15% LOSS LEG	30% LOSS LEG
1-2	Leg press: 4 Leg extension: 4	Leg press: 2 Leg extension: 2
3-5	Leg press: 6 Leg extension: 4	Leg press: 3 Leg extension: 2
6-9	Leg press: 6 Leg extension: 6	Leg press: 3 Leg extension: 3

Protocol from Andersen et al. 2021 (1).

Figure 1 Total volume



Data from Anderson et al. (1).

in the interpretation, but I estimate that the 15% loss leg trained to a minimum of 5 RIR and probably ~8 RIR, while the 30% loss leg trained to a minimum of 2 RIR but more likely ~3-4 RIR.

The excellent part of this protocol is that the 15% and 30% conditions were volume-equated. Most velocity loss studies don't equate for volume, just for sets, and although sets may have merit for calculating volume for hypertrophy, this strategy often leads to large total volume differences. These volume differences may be meaningful, especially when the group performing the lower velocity loss percentage is often performing <5 reps per set. Researchers in the currently reviewed study did have a prescribed number of sets, but there was a little leeway. To equate volume, researchers calculated the total volume that each subject performed with whichever leg performed an exercise first. The next leg then performed the necessary number of sets and reps to equate for volume. The leg which started each exercise rotated each week, so as seen in Table 3, researchers doubled the number of prescribed sets in the 15% velocity loss leg to ensure equated volume.

Findings

Observations

Figure 1 displays that average training volume throughout the nine weeks was nearly identical. The legs assigned to the 15% loss protocol actually trained, on average, to a 20.2 ± 6.2% velocity loss, while in the 30% target condition legs trained to an average of 36.3 ± 3.3% velocity loss. Additionally, I estimated that the 15% VL group (actually ~20%) finished sets at ~5-10 RIR while the 30% group ended sets at ~1-4 RIR. Details of the RIR estimation are in the interpretation.

All Outcome Measures

The bottom line is that strength and muscle thickness increased in both groups, but there were no differences between the 15% and 30% legs for the rate of change in these measures. Further, there were no group differences for any other measure. In both groups, there was no change from pre- to post-study for rate of force development, velocity at the same percentage of 1RM, pennation angle or fascicle length. Power output significantly decreased at all loads tested, but with no group differences. Table 4 shows the findings for strength, muscle architecture, and velocity.

Statistical Criticisms and Musings

The authors hypothesized a similar rate of hypertrophy between groups, yet used an analysis of variance (ANOVA) to compare changes in muscle thickness between groups. However, when it is hypothesized that changes between groups will be similar (rather than different), then equivalence testing (6) should be used to analyze the data for the outcome measure. I'll refrain from a long write-up; that was done in this article. Instead, I'll simply state that when an ANOVA reveals a lack of a significant group by time interaction it's possible that an equivalence test may reveal that the rate of change between groups is not similar. The 0.20 ef-

Table 4 Most relevant outcome measures

MEASURE	30% VELOCITY LOSS CONDITION		15% VELOCITY LOSS CONDITION		
	Pre-study	Post-study (% change)	Pre-study	Post-study (% change)	Between condition ES (Condition favored)
1RM Leg press (kg)	84.2 ± 11.8	118.9 ± 15.2 (+42%)	86.7 ± 17.0	119.6 ± 20.5 (+40%)	0.10 (30% VL)
MVC Leg Press	886 ± 125	1,027 ± 184 (+15%)	904 ± 160	1,026 ± 244 (+12%)	0.10 (30% VL)
Vastus Lateralis (mm)	21.0 ± 2.9	22.1 ± 3.0 (+5%)	20.6 ± 2.6	21.9 ± 2.2 (+7%)	0.06 (15% VL)
Rectus Femoris (mm)	21.8 ± 2.7	22.6 ± 2.0 (+5%)	20.8 ± 2.0	22.2 ± 1.9 (+7%)	0.20 (15% VL)
ACV 30% of 1RM (m/s)	0.56 ± 0.06	0.52 ± 0.07 (-6%)	0.55 ± 0.08	0.48 ± 0.08 (-10%)	
ACV 45% of 1RM (m/s)	0.47 ± 0.04	0.42 ± 0.06 (-10%)	0.46 ± 0.05	0.40 ± 0.06 (-12%)	
ACV 60% of 1RM (m/s)	0.35 ± 0.04	0.33 ± 0.05 (-4%)	0.36 ± 0.04	0.31 ± 0.06 (-13%)	
ACV 75% of 1RM (m/s)	0.28 ± 0.04	0.23 ± 0.04 (-12%)	0.28 ± 0.05	0.22 ± 0.04 (-15%)	

Data are Mean ± SD from Andersen et al. 2021 (1).
1RM = One-Repetition Maximum; MVC = Maximal Voluntary (Isometric) Contraction; ACV = Average Concentric Velocity; ES = Effect Size (hedges g); VL = Velocity Loss.

fect size in favor of the 15% loss group for rectus femoris muscle thickness may not be a game changer, but it does suggest that further investigation is warranted. In brief, a minor comment on an otherwise excellently designed study is that the authors should have used equivalence testing for the muscle thickness measurements.

Interpretation

The reviewed study from Andersen et al (1) shows that there's no difference between strength and hypertrophy gains when velocity loss prescription keeps sets far (~5-10 RIR) or close to failure (~1-4 RIR) (although it is worth noting specifically for strength that a within-subject design always carries the limitation of the cross-education effect; thus, it's possible this limitation masked strength differences). You also may have noticed a 0.20 between-group effect size for rectus femoris muscle thickness favoring the 15% velocity loss group (Table 4). However, with a group × time interaction p-value of 0.421 in such a small sample size, we can't be confident that this finding is meaningful (Table 4). While we can use this study to determine a set's appropriate velocity loss percentage, velocity loss has a whole host of issues outlined here. Further, most of us don't use velocity in every single training session. So, it's more useful to attach an RIR to the velocity loss thresholds and figure out how this study fits into the proximity to the failure body of literature

This article is hardly the first time that MASS has discussed proximity to failure for strength and hypertrophy. Most recently, I reviewed a study in the article "Time to Reframe the Proximity to Failure Conversation," and I concluded the following:

1. Training shy of failure is probably better than training to failure for strength.
2. Training shy of failure is just as good as training to failure for hypertrophy (although my opinion is that non-failure training is more sustainable and probably better in the long-run).
3. We don't know how far from failure you can train, most of the time, and still maximize hypertrophy, although I believe this is farther than most people think (~5 RIR).

Although I covered most of the failure versus non-failure studies in the previous review, we've only touched on a few longitudinal velocity loss studies in MASS. A meta-analysis (7), out as a pre-print (8), concluded similar strength and hypertrophy between low (<15%), moderate (15-30%), and high (>30%) velocity loss thresholds. While the meta-analysis provides good information, the velocity loss thresholds alone are a bit esoteric without attaching an RIR value to the sets performed in studies. Further, the meta-analysis included some studies which only had one velocity loss threshold and did not compare different proximities to failure between groups. The meta also was too recent to include the presently reviewed study (1) and another just-released velocity loss study from Kilgallon et al (9).

Since MASS has not covered much of the longitudinal velocity loss literature and the meta-analysis didn't include some recent studies, I identified 13 studies that met the criteria below and have summarized them in Table 5.

- Longitudinal velocity loss study comparing at least two groups with different velocity loss thresholds or one velocity loss threshold and a failure group.
- Had at least one measure of dynamic strength (on the squat or bench press) or hypertrophy.
- If concurrent training was performed, it was the same in all groups.

To make the table practically useful, I've estimated the RIR associated with each group. 10 of the 12 studies in Table 5 were from the same research group and used a Smith machine squat. That research group also published a paper a few years ago, Rodriguez-Rosell et al (10 - MASS Review), which reported the number of reps performed in a set to failure on the Smith machine squat at 50, 60, 70, and 80% of 1RM, and the number of RIR at each 5% increment of velocity loss. Therefore, as an example, Pareja-Blanco et al 2016 (11) had subjects train to a 15% and 30% velocity loss at 50-70% of 1RM throughout the study. The subjects performed an average of 10.9 reps in that study in the 15% velocity loss group when training at 50% of 1RM. They also performed 4.1 reps, on average, when training at 70% of 1RM. The aforementioned Rodriguez-Rosell paper (10) reported 15.3 RIR after a 15% loss at 50% of 1RM; thus, I used 15 RIR as the upper range for this study. I did the same thing for 70% and came up with a range of 4-15. To verify these values, I also looked for the total reported reps performed in the reviewed studies. In the example study (11), the authors reported an average of 10.9 reps per set at 50% of 1RM in the 15% velocity loss group. A 15 RIR would put the lifters at 25.9 reps possible. The Rodriguez-Rosell (10) study reported 23.4 reps performed, on average, at 50% of 1RM, which is a bit under the estimation. However, subjects in the example study (11) got stronger over time and kept training at 50%; thus, it's likely they could perform more total reps, so I stuck with the 15 RIR. I could not follow that strategy for the non-Smith machine squat studies (1, 9). Kilgallon et al (9) used the floor press. One group went to failure, and the authors reported reps performed in the failure group and a 20% velocity loss group; thus, I was able to use the difference between reps in the failure group and reps in the 20% velocity loss group to estimate RIR. For the currently reviewed study (1), I used data from various studies that trained the unilateral leg press and leg extension to failure to estimate RIR (12, 13). These estimations are not exact, but I'm confident they're pretty close. There are some limitations with the studies I've compiled; for example, the velocity losses and proximities to failure may not apply to high intensities (i.e., >85% of 1RM), and 12 out of 13 studies in the table did not equate volume between groups. We'll expand on those limitations later, but for now, let's look at Table 5.

All 13 studies in Table 5 assessed strength, while only five measured hypertrophy. For hypertrophy, only one study (19) showed that

Table 5 Summary of all longitudinal velocity loss studies

STUDY	SUBJECTS	PROTOCOL	RESULTS	EQUATED VOLUME	ESTIMATED RIR RANGE THROUGHOUT ENTIRE PROTOCOL	OVERALL MESSAGE
Andersen et al. 2021 (1)	7 trained women and 3 trained men	**Duration** 9 wks **Design** Within-Subject **2 Groups** 15% vs. 30% VL Unilateral leg press/leg extension trained 2x/wk starting at 80 and 75%, respectively and progressed	**Strength,** **(Leg Press 1RM)** No significant group differences **Hypertrophy (quad muscle thickness)** No significant group differences.	Yes	15% VL: ~-5-10 30% VL: ~1-4	No difference for either strength or hypertrophy between VL thresholds.
Pareja-Blanco et al. 2017 (2)	24 trained men	**Duration** 8 wks **Design** Parallel group **2 Groups** 20% vs. 40% VL Both groups trained Smith machine squat 2x/wk. for 3 sets between 70-85% of 1RM	**Strength (Squat 1RM):** No significant group differences. But, 4.6% greater increase in 20% VL and ES of 0.31 in favor of 20%. **Hypertrophy (Quad CSA - biopsy):** No difference between groups for any quad muscle	No More volume in 40% loss groups	20% VL: ~3-5 40% VL: ~0-3	Strength gains leaned in favor of 20% group. No difference for hypertrophy.
Pareja-Blanco et al. 2020 (14)	55 trained men	**Duration** 8 wks **Design** Parallel group **4 Groups** 0%, 10%, 20%, and 40% VL All groups trained Smith machine squat 2x/wk for 3 sets with 70-85% of 1RM	**Strength (Squat 1RM):** All groups significantly increased strength, no group differences **Hypertrophy (Quad CSA - ultrasound):** No difference between groups, but only 20% (+7.0%) and 40% (+5.3%) had significant growth.	No Volume scaled with VL (i.e., more VL = more volume)	0% VL: ~4-10 10% VL: ~3-7 20% VL: ~2-5 40% VL: ~0-3	No difference for strength and staying shy of failure can maximize hypertrophy.
Pareja-Blanco et al. 2017 (11)*	16 pro male soccer players	**Duration** 8 wks **Design** Parallel group **2 Groups** 20% vs. 40% VL Both groups trained Smith machine squat 2x/wk. for 3 sets between 50-70% of 1RM	**Strength (Squat 1RM)** Both groups increased 1RM (15%: +8.9%; 30%: +6.2%) with no group difference.	No More volume in 40% loss groups	15% VL: ~4-15 30% VL: ~1-8	1RM strength was maximized training far from failure
Held et al. 2020 (15)*	21 trained rowers (4 women, 17 men)	**Duration** 8 wks **Design** Parallel group **2 Groups** 10% VL vs. Failure Both groups trained squat, bench press, deadlift, seal row 2x/wk for 4 sets at 80% of 1RM	**Strength (Squat, Bench, Deadlift, Seal Row 1RM)** Significantly greater strength increase for squat, bench press, and seal row in 10% VL group.	No More volume in failure group	10% VL: ~4-7 Failure: 0	1RM strength was maximized training far from failure versus training to failure
Sanchez-Moreno et al. 2020 (16)*	33 strength and endurance trained men	**Duration** 8 wks **Design** Parallel group **2 Groups** 15% VL vs. 45% VL Both groups trained Smith machine squat, 2x/wk for 3 sets at 60-80% of 1RM	**Strength (Squat 1RM):** Significantly greater strength increase in favor of 15% VL group	No More volume in failure group	15% VL: ~2-10 45% VL: ~0-2	1RM strength was maximized training far from failure versus training almost to failure
Sanchez-Moreno et al. 2020 (3)	29 trained men	**Duration** 8 wks **Design** Parallel group **2 Groups** 25% VL vs. 50% VL Both groups trained bodyweight pullups, 2x/wk for 2-4 sets	**Strength (Pullup 1RM and Max Reps):** Significantly greater strength increases in 1RM in favor of 25% (+5.6kg) VL vs. 50% (+0.8kg).. No significant difference in added reps, but 0.24 ES in favor of the 25% VL group.	No More volume in failure group	25% VL: ~1-3 50% VL: ~5-8	1RM strength was maximized training far from failure versus training almost to failure
Galiano et al. 2020 (17)	28 trained men	**Duration** 7 wks **Design** Parallel group **2 Groups** 5% VL vs. 20% VL Both groups trained Smith machine squat, 2x/wk for 3 sets at 50% of 1RM	**Strength (Squat 1RM): 1RM Squat** Both groups increased 1RM with no group difference. 5% VL: +10.7% 20% VL: +13.6%	No More volume in 20% VL group	5% VL: >15 20% VL: ~7-10	When training at a low intensity (i.e., 50%) the 5% and 20% VL resulted in similar strength gains
Rodriguez-Rosell et al. 2020 (18)	26 trained men	**Duration** 8 wks **Design** Parallel group **2 Groups** 10% VL vs. 30% VL Both groups trained Smith machine squat, 2x/wk for 3 sets at 70-85% of 1RM	**Strength (Squat 1RM)** 1RM Squat Both groups increased 1RM with no group difference. 10% VL: +17.9% 30% VL: +14.9%	No More volume in 30% VL group	10% VL: ~2-7 30% VL: ~1-4	When training between 70-85% of 1RM a 10% and 30% VL resulted in similar strength gains
Martinez-Canton et al. 2020 (19)	22 trained men	**Duration** 8 wks **Design** Parallel group **2 Groups** 20% vs. 40% VL Both groups trained Smith machine squat 2x/wk for 3 sets between 70-85% of 1RM	**Strength (Squat 1RM)** Both groups increased strength with no group differences **Hypertrophy (Quad CSA – MRI)** Significantly more hypertrophy in 40% VL (average of vastus lateralis and intermedius) 20% VL: +9% 40% VL +3.4%	No More volume in 40% loss groups	20% VL: ~3-5 40% VL: ~0-3	Similar strength between groups. More hypertrophy in 40% VL (closer to failure). ***These findings are different than the first study in the table (Pareja-Blanco et al. 2017) which had the same design.
Rodriguez-Rosell et al. 2021 (20)	33 trained men	**Duration** 8 wks **Design** Parallel group **3 Groups** 10%, 30%, and 45% VL All groups trained Smith machine squat 2x/wk for 3 sets between 55-70% of 1RM	**Strength (Squat 1RM)** All groups increased strength with no group differences, but ES of 0.40 and 0.35 In favor of 10% and 30%, respectively vs. 45% VL group 10% VL: +22.2% / 30% VL: +22.1% / 45% VL: +15.4%	No Volume scaled with velocity loss	20% VL: ~3-5 40% VL: ~0-3	Similar strength between groups, but leaned in favor of 10% and 30% versus 45% VL.
Killagon et al. 2021 (9)*	26 pro Australian football players	**Duration** 3 wks **Design** Parallel group **2 Groups** 20% VL vs. Failure All groups trained the barbell floor press 2x/wk for 2 sets at 85% of 1RM	**Strength** **(Barbell Floor Press 1RM)** Significantly greater increase in failure group. 20% VL: +1.6% Failure: +5.1%	No More volume in failure group	20% VL: ~1-2 Failure: 0	Significantly greater strength in failure versus 20% VL when training at 85% of 1RM on floor press.
Pareja-Blanco et al. 2020 (31)	64 trained men	**Duration** 8 wks **Design** Parallel group **2 Groups** 0%, 15%, 25%, and 50% VL All groups trained Smith machine bench press 2x/wk. for 3 sets with 70-85% of 1RM	**Strength (Bench Press 1RM)** All groups significantly increased strength, no group differences **Hypertrophy** **(Chest CSA - ultrasound)** Significantly greater muscle growth in 50% VL versus 0 and 15% VL. Similar muscle growth between 50% and 25% VL	No Volume scaled with VL (i.e., more VL = more volume)	0% VL: ~5-11 15% VL: ~3-9 25% VL: ~2-7 50% VL: ~0-3	No difference for strength and staying shy of failure can maximize hypertrophy

Summary table of all longitudinal velocity loss studies comparing at least two different velocity loss thresholds and having at least one strength or hypertrophy metric.
*1RM = One-Repetition Maximum; ES = Effect Size; VL = Velocity Loss; CSA = Cross-Sectional Area; * = Study included concurrent training.*

training to failure or close to it (0-3 RIR) led to more muscle growth than training farther from failure, on average (2-5 RIR). However, two other studies (2, 14) observed similar muscle growth when comparing 0-3 versus 2-5 RIR and one other study (31) found similar hypertrophy for chest hypertrophy when comparing 2-7 versus 0-3 RIR. The presently reviewed study reported no statistically significant differences between training at an estimated 4-10 RIR versus closer to failure (1-4 RIR). Finally, Pareja-Blanco et al 2020 (14) also showed that velocity losses of 0 and 10% led to less muscle growth than both 20 and 40%. The overall picture of these studies suggests that you can maximize hypertrophy while training at least a few reps shy of failure (probably farther). However, the comparison of 0, 10, 20, and 40% velocity loss brings to light our first discussion of these data's limitations – only one of five studies assessing hypertrophy equated for volume between the training groups. In fact, the higher velocity loss group in Pareja-Blanco et al 2017a (2) (40%: 310.5 ± 42.0; vs. 20%: 185.9 ± 22.2) and Pareja-Blanco et al 2020 (14) (40%: 305.6 ± 81.7; vs. 20%: 168.5 ± 47.4) performed nearly double the number of reps completed at the same percentage of 1RM over the same number of sets compared to half the velocity loss percentage. Additionally, in the 0, 10, 20, and 40% velocity loss study, the 40% loss group averaged 6.4 reps per set, with all other groups averaging <4 reps per set. On the other hand, the presently reviewed study from Andersen (1) equated for volume by adding sets to the low velocity loss group, and researchers designed the training prescription to elicit at least five reps per set in both groups. Previously, Greg reviewed a study that found that although longer rest intervals promote greater hypertrophy than short intervals when sets are equated (by adding sets to short rest interval training), the difference in muscle growth disappears (21). The benefit of adding sets to equate for volume seemed to hold in the present study. I estimated the 15% velocity loss group in the current study trained between 5-10 RIR, and I tried to be conservative in my estimate. Overall, among the five velocity loss studies evaluating muscle growth, only one (19) shows that training close to failure is superior for hypertrophy than training far from failure, while the other four (1, 2, 14, 30) show no difference between staying really far (≥5 RIR) from failure versus taking sets close to failure.

YOU CAN MAXIMIZE HYPERTROPHY WHILE TRAINING AT LEAST A FEW REPS SHY OF FAILURE.

It may sound surprising that training far from failure yields similar muscle growth compared to training close to failure; however, I don't think we can call this finding surprising anymore. In fact, when considering all recent proximity to failure studies in trained individuals, data have either shown no difference

TRAINING FAR FROM FAILURE YIELDS SIMILAR MUSCLE GROWTH COMPARED TO TRAINING CLOSE TO FAILURE.

between failure and non-failure training for hypertrophy (2, 22, 23), leaned in favor of training a few reps shy of failure (12, 24), or favored training far from failure (≥5 RIR; 4, 5). Therefore, on balance, it would be more surprising if a new study reported benefits for failure training versus training far from failure. Further, the presently reviewed study (1) used a within-subject design and was volume equated, which is strong evidence in favor of training to ≥5 RIR. Despite that evidence, there are a few noteworthy caveats to those conclusions, which I've mentioned before in this article:

- We cannot extrapolate the findings of a squat or bench press to other exercises. Therefore, someone may not be able to train curls to a 5 RIR and maximize adaptations.
- We also do not know the impact of training to different proximities to failure on synergist muscles since it is typical only to assess the prime movers. So, for example, just because training the bench press to a 5 RIR produces similar chest growth to training to 2 RIR does not mean that bench pressing at both of these proximities to failure has the same impact on triceps growth.
- Further, the fatigue from some assistance movements, particularly those which train throughout a short range of motion, does not persist for long. Thus, training to failure or close to it may have minor consequences on specific movements.
- I don't think you should always avoid failure. In fact, please see Table 3 here to integrate failure and non-failure training.

The strength findings in Table 5 support using a velocity loss range of 15-30% when training between 50-85% of 1RM. Specifically, training at 10% (15), 15% (16), 20% (2), and 25% (3) velocity loss led to greater strength gains than training at ≥40% velocity loss. This finding means staying primarily at ≥3-5 RIR is better than going to failure or close to it. However, a pretty serious limitation to always staying at 3-5 RIR is that this recommendation is only for moderate intensities. Peak intensity seems to be more critical than average intensity (25 - MASS Review) for strength, and all of the studies in Table 5 equated for percentage of 1RM between groups. Those percentages mainly were between 50-80% of 1RM. Therefore, if you perform lots of volume at say 70% of 1RM, then yes, training to 3-5 RIR is good advice; however, this advice quickly falls apart when training at high intensities. We know that strength scales with load (26), and on average a single at 90% of 1RM already puts most people at a 2 RIR. Therefore, I don't think strength can be maximized by *always* training to a 3-5 RIR. Instead, if you're a powerlifter, then performing your volume work a good bit from failure is a good idea. Save your 0-2 RIR sets for high-intensity (>85%) and low-volume training.

Another observation from Table 5 is that strength gains were robust even when training far from failure. Specifically, Galiano et al (17) reported that subjects improved squat 1RM by 10.7% when training to only a 10% velocity loss at 50% of 1RM (>15 RIR). At first glance, that strength increase seems unrealistic given the protocol, but I have to imagine training status played a prominent role in the response rate. The men in Galiano's study had trained for at least 1.5 years and squatted 1.3 times their bodyweight at pre-study, which isn't too terrible. However, it's possible subjects didn't squat frequently; thus, consistent squatting in a controlled laboratory setting produced a robust response regardless of velocity loss percentage. Furthermore, this large response at low velocity loss thresholds (high RIR) was consistent across all 10 Smith machine squat studies from the same lab group, so we can compare subjects between studies better than research from different lab groups. In other words, to dig deeper into the training status theory, Rodriguez-Rosell reported an enormous individual difference in strength gains at 10% (+6.4-58.6%), 30% (+4.5-66.2%), and 40% (+1.8-52.1%) velocity loss thresholds, and those groups had similar pre-study squat 1RMs to Galiano of 96.1kg, 97.4kg, and 96.8kg, respectively. In last month's video, we explored the individual training response, and Klemp et al (27) reported a range of *only* -3.5 to +18.6% (mean = +9.4 ± 5.3%) change in squat 1RM among individuals with an average pre-study 1RM of 142kg. Therefore, it's likely that some lifters in the relevant collection of velocity loss studies had a pretty low training status accounting for a robust response despite the little stimulus. This low training status may have been the case in the presently reviewed study, as the average change in strength was ~40%.

IF YOU'RE A POWERLIFTER, THEN PERFORMING YOUR VOLUME WORK A GOOD BIT FROM FAILURE IS A GOOD IDEA. SAVE YOUR 0-2 RIR SETS FOR HIGH-INTENSITY (>85%) AND LOW-VOLUME TRAINING.

The last study in Table 5, Kilgallon et al (9), was published too recently to be included in the velocity loss meta-analysis. The Kilgallon study bucked the strength trend and reported greater strength for failure training versus a 20% velocity loss using 85% of 1RM (i.e., 1-2 RIR), and there are a few interesting notes about this study. First, this study used the floor press, which trains the involved musculature through a short range of motion. As Zac Robinson recently theorized to me, it's possible that training at or close to failure might be more meaningful when training through a short range of motion. Further, the Kilgallon study, which was only three weeks long, had subjects train at 85% of 1RM in each session (six sessions over three weeks) and reported an average of 2.8 reps per set and 3.3 reps per set in the failure group in weeks one and three, respectively. On the other hand, the 20% velocity loss group performed an average of 1.1 and 1.3 reps per set, respectively, in weeks one and three. Thus, although both groups performed low reps, the failure group performed roughly 2.5 times more reps than the non-failure group. As noted above, training at such a low velocity loss threshold may not be advisable if only using higher intensities. Additionally, Kilgallon instructed subjects to use a normal lifting velocity and not perform each rep at maximal intended velocity, which is the opposite of the recommendations in all other studies in Table 5. If the goal is to perform as many reps as possible during a set to failure, then I don't think it's best to use maximal intended velocity on each rep. However, the reverse may be true if performing a few sub-max reps and attempting to optimize strength gains. Further, since this study only lasted three weeks, the failure group could have gained more strength simply due to more practice (i.e., 2.5 times more reps) in the short time frame.

Final Notes

Four studies in Table 5 employed concurrent training in the form of soccer practice (11), rowing (15), Australian football practice (9), or endurance running (16). I chose to include them because all groups in each study performed the same endurance or sports training. In this case, running was separated from lifting by 24 hours (28), which minimizes the negative effect of concurrent training. Further, the results of these studies were consistent with the non-concurrent training studies that used the same 1RM measure (Smith machine squat 1RM); thus, I saw no reason to exclude them.

As an aside, I don't think velocity loss is the best prescription strategy. I will give an abbreviated version of my arguments since I previously threw a hissy fit about my gripe for an entire interpretation section. First, similar velocity loss thresholds are often used between exercises, despite velocity loss being exercise-dependent (10). Secondly, the first rep (or fastest rep) velocity may change from set-to-set, especially when training close to failure. If a lifter continues to use the same velocity loss percentage from set-to-set when the first rep velocity changes, then that will lead to a different proximity to failure. For example, if squatting to 1-2 RIR at 70% of 1RM set, one's first rep velocity might be 0.70 m/s, in which case a 30% velocity loss would terminate the set at ≤0.42 m/s. If using the same load on the fourth set, the first rep velocity may now be 0.60 m/s, and when applying a 30% velocity loss, the lifter now terminates the set at 0.42 m/s. The difference in 0.42 and 0.36 m/s is about 2-3 RIR, now putting the lifter close to failure. It has been established that the velocity associated with a specific RIR is stable across different percentages of 1RM (29). Therefore, as recent

Table 6 Key points on proximity to failure

TRAINING FOR STRENGTH	• When training at moderate intensities, keep RIR ≥3. • When training at high intensities, ≥85% of 1RM sets can be taken to 0-2 RIR and volume should be kept reasonably low. • Overall, consistently training to failure with high volume seems to be an inferior approach to maximize 1RM strength gains.
TRAINING FOR HYPERTROPHY	• When training at moderate intensities, most sets on compound movements can be kept shy of failure (≥2 RIR). • There is enough evidence to suggest that performing sets at a moderate intensity far from failure (≥5 RIR) can maximize muscle growth. • Ultimately, both failure and non-failure training can be used and the value of failure training may depend upon the exercise used. Training some sets to failure on any exercise is fine, provided it's not done too frequently and any fatigue associated with failure doesn't compromise the next training session.

research has suggested (30), a lifter can perform one set to failure at a moderate intensity (i.e., 75% of 1RM) and establish a RIR/velocity relationship. Then, a lifter can stop each set at a specific velocity rather than using velocity loss.

Overall, the proximity to failure in which you train does seem to matter for adaptations. Although not the focus of this review, it seems clear training to ≤20% velocity loss is ideal for explosive adaptations (i.e., vertical jump, rate of force development, etc.). With that in mind, Table 6 summarizes my thoughts on proximity to failure in training.

Next Steps

Last time we covered this topic, I called for a longitudinal study that included groups training to four different proximities to failure: 1) failure, 2) 1-3 RIR, 3) 4-6 RIR, and 4) 7-10 RIR. I'll keep that same proposal and add that the study should be relative volume equated. Researchers could carry it out on both the squat and a floor press to see if the effects of proximity to failure are indeed exercise-specific. Of course, the study could also use a biceps curl instead of the floor press, but if asking subjects to refrain from other upper body exercises such as the bench press during the study, then a floor press may be more feasible than a biceps curl. But, the point is that what holds for one exercise may not be the case for another.

APPLICATION AND TAKEAWAYS

1. Andersen et al (1) found that subjects who trained the leg press and leg extension far from failure for moderate repetitions (5-7 reps at 5-10 RIR) or close to failure with high repetitions (12-14 reps at 1-4 RIR) increased strength and muscle growth with no statistically significant difference between training conditions. Overall, the evidence continues to mount that training at a minimum a few reps shy of failure is sufficient, if not superior, to training to failure for both strength and hypertrophy.

2. Ultimately, non-failure training, especially on highly fatiguing movements, can be recommended for most of someone's training volume. However, at moderate intensities, it seems that training sets to a 5 RIR and perhaps even farther from failure is a viable strategy to maximize strength and hypertrophy. Therefore, rather than being used as a standalone method, lifters should use failure training in conjunction with non-failure training, and the amount of failure training and exercises used for failure should be selected carefully.

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Study Reviewed: Energy Deficiency Impairs Resistance Training Gains in Lean Mass but Not Strength: A Meta-Analysis and Meta-Regression. Murphy et al. (2021)

Building Muscle in a Caloric Deficit: Context is Key

BY ERIC TREXLER

Trainees with body composition goals often want to lose fat and build muscle. Unfortunately, these goals generally lead to contradictory recommendations for caloric intake. Read on to learn when and how both goals can be achieved simultaneously.

KEY POINTS

1. The presently reviewed meta analysis (1) quantified the impact of an energy deficit on strength and lean mass gains in response to resistance training.
2. Energy deficits led to significant impairment of lean mass gains (effect size [ES] = -0.57, p = 0.02) and non-significant impairment of strength gains (ES = -0.31, p = 0.28). As the energy deficit grew by 100kcals/day, lean mass effect size tended to drop by 0.031 units; a deficit of ~500kcals/day was predicted to fully blunt lean mass gains (ES = 0).
3. "Recomposition" (simultaneous fat loss and muscle gain) is possible in certain scenarios, but a sizable calorie deficit typically makes lean mass accretion an uphill battle.

Three of the most common goals among lifters are to lose fat, gain muscle, and get stronger. This presents a noteworthy challenge, as these goals can lead to contradictory recommendations for total energy intake. Lifters with fat loss goals are virtually always advised to establish a caloric deficit (2), whereas a caloric surplus is typically recommended to support recovery and anabolic processes for lifters aiming to get stronger and more muscular (3). If similar hypertrophy could occur in the presence of a calorie deficit, then this apparent dilemma would be resolved.

That brings us to the presently reviewed meta-analysis (1), which sought to determine if calorie deficits impair gains in strength and lean mass in response to resistance training. Compared to a control diet, energy deficits led to significantly smaller gains in lean mass (effect size [ES] = -0.57, p = 0.02). Energy deficits also led to smaller gains in strength, but the effect size was smaller, and the effect was not statistically significant (ES = -0.31, p = 0.28). Impairment of lean mass gains became more pronounced as the caloric deficit got larger, and a deficit of ~500kcals/day was predicted to fully blunt lean mass gains (ES = 0). Meta-analyses are great for identifying a general, overall effect, but the feasibility of body recomposition (simultaneous fat loss and muscle gain) is impacted by a number of nuanced contextual factors. Read on to learn more about who might be able to achieve substantial lean mass gains during a calorie deficit, and how to maximize the likelihood of success when pursuing fat loss, hypertrophy, strength, or recomposition goals.

Purpose and Hypotheses

Purpose

The primary purpose of the presently reviewed meta-analysis (1) was "to quantify the discrepancy in lean mass accretion between interventions prescribing resistance training in an energy deficit and interventions prescribing resistance training without an energy deficit." The secondary purpose was to investigate the same question, but with a focus on strength gains rather than lean mass gains. The researchers also conducted additional analyses to determine if effects were meaningfully impacted by potentially important variables including age, sex, BMI, and study duration.

Hypotheses

The researchers hypothesized that "lean mass gains, but not strength gains, would be significantly attenuated in interventions conducted in an energy deficit compared to those without."

Methods

Search and Study Selection

These researchers wanted to do a meta-analysis comparing resistance training in a caloric deficit to resistance training with a control diet. However, they knew ahead of time that there would be a limited number of studies directly comparing both types of diets in longitudinal research designs. So, they cast a broad net with their literature search and committed to doing two separate analyses. The search strategy aimed to identify English-language studies evaluating relevant resistance training adaptations (lean mass or fat-free mass measured via DXA or hydrostatic weighing, and strength measured via low-repetition strength tests [e.g., 1RM or 3RM] or maximal voluntary contraction). In order to be considered for inclusion, studies needed to implement resistance training protocols that were at least three weeks long, utilized a training frequency of at least two sessions per week, and did not involve aerobic training.

Analysis A

Analysis A involved only studies that directly compared two groups within the same longitudinal resistance training study, with one group consuming a calorie deficit, and another group consuming a control diet. Seven such studies were identified; six involved female participants only, while the seventh involved a mixed-sex sample of males and females. A total of 282 study participants were represented across 16 treatment groups, with an average age of 60 ± 11 years old. Participants were generally sedentary or physically inactive prior to study participation, but one of the studies did not specify activity level. In terms of study characteristics, the researchers described that the studies in analysis A included full-body resistance training programs that "lasted between 8 and 20 weeks (13.3 ± 4.4 weeks) and involved 2-3 sessions per week (2.9 ± 0.3 sessions) with 4-13 exercises per session (8.3 ± 2.4 exercises), 2-4 sets per exercise (2.7 ± 0.4 sets), and 8-20 repetitions per set (11.3 ± 4.1 repetitions)." The researchers used standard meta-analytic techniques to separately compare the effects of calorie deficits and control diets on strength gains and lean mass gains.

Analysis B

In order to expand the pool of studies, analysis B included studies with participants completing resistance training in an energy deficit *or* completing resistance training without an energy deficit. It's easy to do a meta-analysis when you've got two different diets tested within the same study, because the two diet groups are effectively matched in terms of key subject characteristics and training programs. However, it's not quite as easy when you're analyzing separate studies that involve one type of diet or the other. In order to ensure that results from studies with and without energy deficits were being compared on approximately equal footing, the researchers began by identifying studies that assessed the effects of resistance training *with* an energy deficit and met the previously listed inclusion criteria (they found 31). Then, they scoured the much, much larger body of research assessing the effects of resistance training *without* an energy deficit. The purpose of this expanded search was to find suitable "matches" for the 31 energy deficit studies based on age, sex, BMI, and characteristics of the resistance training interventions completed.

They weren't able to find perfect matches for every study, but they ended up with 52 total studies that were effectively matched for age, sex, study duration, and resistance training characteristics (but not BMI). One study included resistance-trained participants, one study did not specify the training status of their participants, and the rest of them included participants that were sedentary or physically inactive prior to study participation. This collection of 52 studies included 10 with male subjects, 24 with female subjects, and 18 with mixed-sex samples, for a total of 57 treatment groups and 1,213 participants with an average age of 51 ± 16 years. The researchers described that the studies in analysis B included full-body resistance training programs that "lasted between 3 and 28 weeks (15.8 ± 6.0 weeks) and involved 2-4 sessions per week (2.9 ± 0.5 sessions) with 4-14 exercises per session (8.2 ± 2.6 exercises), 1-4 sets per exercise (2.7 ± 0.6 sets), and 1-16 repetitions per set (10.1 ± 1.9 repetitions)."

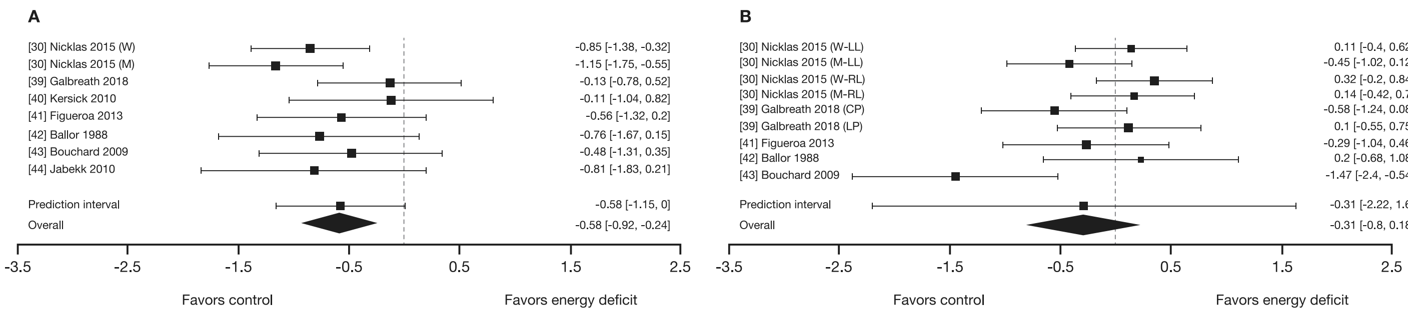
Analysis B began with a visual comparison of changes in lean mass and strength. For each treatment group among the included studies, an effect size was calculated, and the effect sizes from each group were plotted in a "waterfall plot." This type of plot arranges the effect sizes from smallest (or most negative) to largest (or most positive), which allows for some surface-level inferences based on visual assessment. Analysis B also included a meta-regression component, in which the energy deficit in each treatment group was calculated based on the assumption that each kilogram of fat lost in the study represented a cumulative calorie deficit of ~9,441kcals (4). As such, the daily energy deficit was back-calculated based on the cumulative energy deficit and the length of the trial, and meta-regression was used to assess the relationship between daily energy deficits and changes in lean mass, while controlling for age, sex, study duration, and BMI.

Findings

In analysis A, energy deficits led to significantly smaller gains in lean mass when compared to a control diet (effect size [ES] = -0.57, p = 0.02). Energy deficits also led to smaller gains in strength, but the effect size was smaller, and the effect was not statistically significant (ES = -0.31, p = 0.28). Forest plots for both analyses are presented in Figure 1.

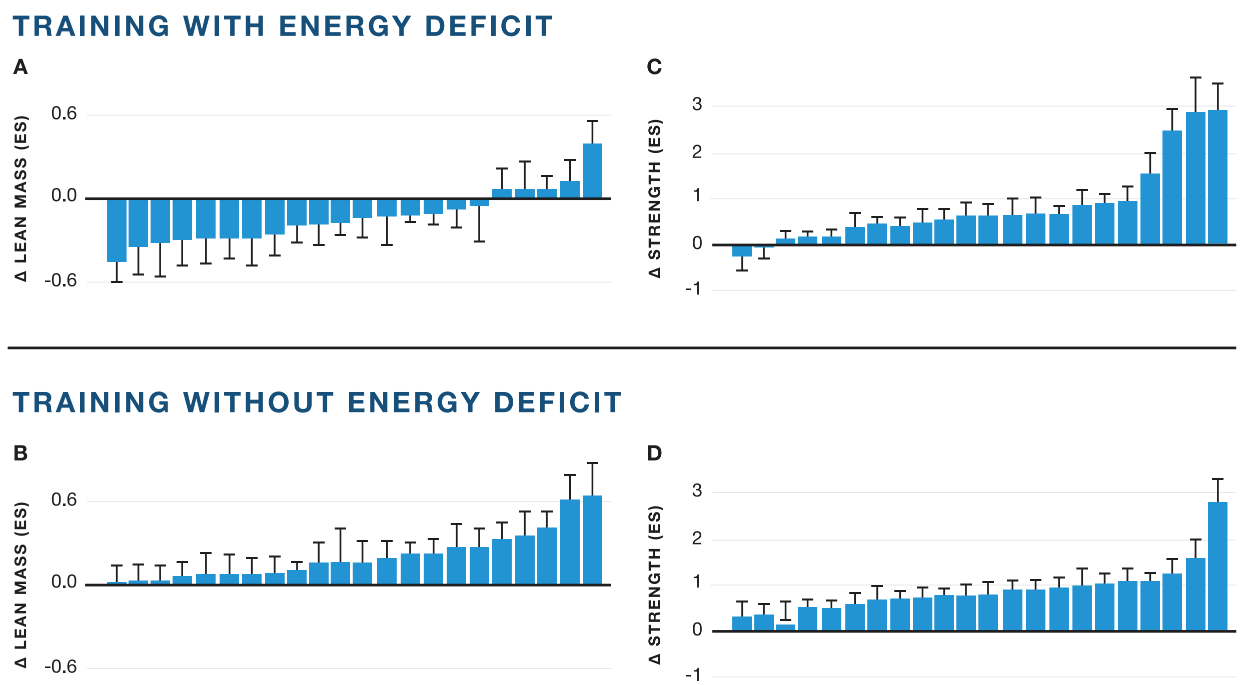
The waterfall plots for analysis B are presented in Figure 2. For studies involving an energy deficit, the pooled effect size for lean mass

Figure 1 Forest plots of Analysis A for the effect on lean mass (A) and strength (B)



A positive effect favors resistance training in an energy deficit while a negative effect favors resistance training without an energy deficit. Each box represents the effect size for that group and the lines around the box represent the 95% confidence interval.
CP = chest press; LL = left leg extension; LP = leg press; M = men; RL = right leg extension; W = women.

Figure 2 Waterfall plots of Analysis B for the effect of resistance training in an energy deficit on lean mass (A) and strength (C) and for resistance training without an energy deficit on lean mass (B) and strength (D)

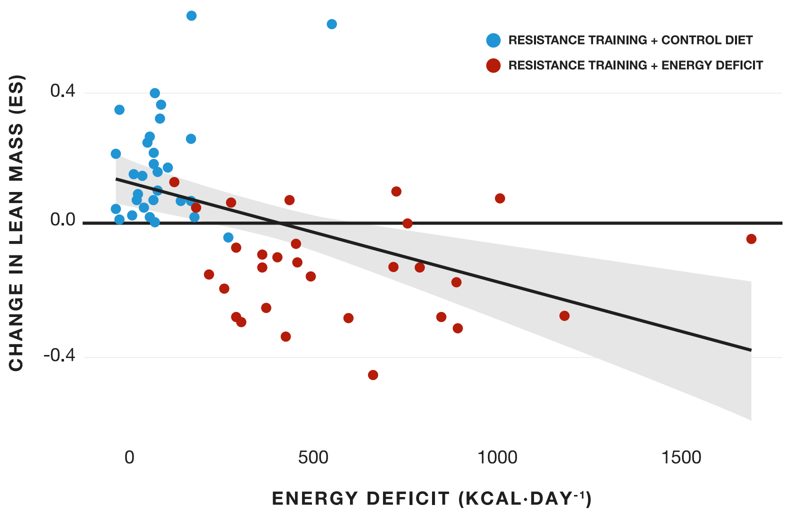


Each bar represents an effect size from a different study. The lines around each bar represent the 95% confidence interval for the effect size.

was negative (ES = -0.11, p = 0.03), while it was positive for studies that did not involve an energy deficit (ES = 0.20, p < 0.001). For strength gains, effect sizes were positive and similar in magnitude whether studies did (ES = 0.84, p <0.001) or did not (ES = 0.81, p < 0.001) involve an energy deficit.

As for the meta-regression component of analysis B, the relationship between energy deficits and changes in lean mass (when controlling for age, sex, study duration, and BMI) is presented in Figure 3. The slope of the line was -0.00031 (p = 0.02), which means there was a statistically significant

Figure 3 Relationship between estimated energy deficit and change in lean mass



The shaded area on either side of the regression line represents the 95% confidence interval for the regression.

negative relationship between the size of the energy deficit and the magnitude of changes in lean mass. As the energy deficit grew by 100kcals/day, the effect size for lean mass tended to drop by 0.031 units. By extension, a deficit of ~500kcals/day was predicted to fully blunt lean mass gains (ES = 0), and estimated changes in lean mass became negative for energy deficits beyond ~500kcals/day.

Criticisms and Statistical Musings

I wouldn't call these "criticisms," but there are a few important limitations and contextual factors to keep in mind when interpreting these results. The first point pertains to the pool of participants for this meta-analysis. In analysis A, the majority of participants were untrained individuals in their 50s, 60s, or 70s. Compared to a young, healthy, resistance-trained "control" subject, their untrained status boosts their propensity for short-term hypertrophy, while their age (specifically combined with their untrained status) might limit their propensity for short-term hypertrophy. The participant pool for analysis B is a little more heterogeneous in terms of age, but the untrained status is still a factor to consider when generalizing these findings to well-trained people. More advanced lifters tend to require greater optimization of training and nutrition variables to promote further training adaptations, so the untrained participants in this meta-analysis might theoretically be able to achieve better growth in suboptimal conditions (in this case, a caloric deficit). On the other hand, this analysis did not account for protein intake and did not require included studies to achieve any particular threshold for minimum protein intake. Insufficient protein consumption would impair hypertrophy and make recomposition less feasible, which could potentially exaggerate the impact of caloric deficits on lean mass accretion.

The next points pertain to analysis B. This analysis was a bit unconventional when compared to the typical meta-analysis, but I really like it and feel that it strengthens the paper. It's important to recognize that the energy deficit quantified in analysis B is estimated based on the energy value of changes in fat mass. While this analysis did not incorporate the energy value of changes in lean mass, the researchers provided an excellent explanation for this choice, and confirmed that the choice did not meaningfully impact outcomes of the analysis. As noted previously, analysis B included a pool of 52 studies that were effectively matched for age, sex, study duration, and resistance training characteristics, but the researchers were unable to match the studies based on BMI. The studies involving an energy deficit reported an average BMI of 32.7 ± 3.0, while the studies without an energy deficit reported an average BMI of 27.5 ± 3.6. The meta-regression analysis did identify a relationship between BMI and changes in lean mass, but I am neglecting to interpret that as a meaningful relationship due to the confounding effect of this study matching discrepancy.

Finally, a general note on meta-analyses. They sit atop our hierarchy of evidence, which means we consider them to be the most robust type of evidence available (when done correctly). However, we still have to apply their findings carefully and judiciously. For example, if a meta-analysis finds no benefit of micronutrient supplementation but virtually all of the studies recruited participants with adequate baseline levels of the nutrient in question, we can't use that evidence to conclude that supplementation would be ineffective for individuals with a deficiency. For many research questions, context is critically important; some meta-analyses are well suited to sort through those contextual factors, while others are not. A lot of people will scan the presently reviewed study, see that predicted lean mass gains reached zero at a deficit of 500kcals/day, and will interpret that cutoff point as a widely generalizable "rule." We should resist that temptation, and hesitate before applying a literal interpretation of these results for individuals who are substantially leaner or substantially more trained than the participants included in this meta-analysis.

Interpretation

A surface-level interpretation of analysis A is pretty straightforward: if gaining lean mass is your priority, you should avoid a calorie deficit. This general concept is easy to digest; low energy status leads to increased activation of 5'-adenosine monophosphate-activated protein kinase (AMPK), which generally promotes catabolic processes and impedes anabolic processes (5). Further, as reviewed by Slater and colleagues (3), maximizing hypertrophy is an energy-intensive process. The process of building muscle involves the energy cost of resistance training, the energy cost of post-exercise elevations in energy expenditure, the energy cost of increased protein turnover (which includes both degradation and synthesis), and several other aspects of increased expenditure that result from gaining more metabolically active tissue and consuming more calories to fuel training. As such, muscle hypertrophy is an energy-intensive process that is optimally supported by a state of sufficient energy availability. Having said that, a deeper interpretation of analysis B suggests that our conclusions probably require a little more nuance regarding how much energy is "enough."

Figure 3 shows the relationship between estimated energy deficits and gains in lean mass. The regression line crosses zero at about 500kcals/day, which is informative. It tells us that, in a sample of people who are mostly untrained and have BMIs in the overweight-to-obese categories, a daily energy deficit of ~500kcals/day is predicted to fully attenuate gains in lean mass. However, Figure 3 includes individual data points from studies, which adds further depth and nuance to our interpretation. With exactly one exception, all of the studies reporting fairly substantial gains in lean mass involved an estimated deficit of no more than 200-300 kcals/day. Furthermore, every study reporting an effect size clearly below zero (that is, a loss of lean mass) involved an estimated deficit larger than 200-300 kcals/day. As such, we should acknowledge and understand that the ~500kcals/day number is not a rigid cutoff; the relationship between energy deficits and lean mass changes is continuous in nature, and there appears to be (for example) a substantive difference between 100 and 400 kcals/day.

Since we can't treat every deficit below 500kcals/day as being functionally equivalent, a dieter with ambitions related to re-

HYPERTROPHY IS AN ENERGY-INTENSIVE PROCESS THAT IS OPTIMALLY SUPPORTED BY A STATE OF SUFFICIENT ENERGY AVAILABILITY.

composition will have to decide exactly how large of a deficit they can manage without meaningfully impairing hypertrophy potential. As Slater and colleagues have noted (3), simultaneous fat loss and skeletal muscle hypertrophy is "more likely among resistance training naive, overweight, or obese individuals." Along those lines, readers who are well-trained or substantially leaner than the participants in this meta-analysis might need to adjust their interpretation and expectations, erring toward a smaller daily energy deficit if they wish to accomplish appreciable hypertrophy along the way. While an untrained individual with a BMI over 30 is an obvious candidate for successful recomposition, it would be inaccurate to suggest that body recomposition is completely unattainable for individuals with leaner physiques or more training experience.

As reviewed by Barakat and colleagues (6), there are several published examples of resistance-trained individuals achieving simultaneous fat loss and lean mass accretion in the absence of obesity. Nonetheless, these researchers also acknowledged that the feasibility and magnitude of recomposition are impacted by training status and baseline body composition, and that trained individuals have an increased need to optimize training variables, nutrition variables, and other tertiary variables (such as sleep quality and quantity) in order to achieve practically meaningful recomposition. While having some resistance training experience or a BMI below 30 does not automatically render recomposition impossible, it's also important to acknowledge that significant recomposition might not be attainable for people who have already optimized (more or less) their approach to training and nutrition and are absolutely shredded or near their genetic ceiling for muscularity.

I think this meta-analysis was conducted very effectively, and its results are quite informative for setting energy intake guidelines that are suitable for a wide range of goals. So, to wrap up this article, I want to concisely review how to adjust energy intake for lifters with strength goals, recomposition goals, hypertrophy goals, and fat loss goals. Please note that these recommended targets for rates of weight loss and weight gain throughout the following section are admittedly approximate and imprecise, as hypertrophic responses to training can be quite variable. There are innumerable "edge cases" and circumstances in which these recommendations start to become less advisable; unfortunately, I can't (at this time) think of a way to provide a totally robust set of concise recommendations without an individualized assessment of body composition, diet history, training experience, and responsiveness to training.

Practical Guidance for Adjusting Energy Intake For Strength Goals

The results of the presently reviewed meta-analysis could be perceived as suggesting that energy restriction does not meaningfully impair strength gains. However, the analysis generally included untrained participants in relatively short-term trials. As we know, much of the early strength adaptations experienced by novice lifters can be attributed to factors that are entirely unrelated to hypertrophy, such as neural adaptations and skill acquisition (7). When it comes to long-term capacity for strength, creating an environment suitable for hypertrophy plays an important role in maximizing muscle mass, and creating an environment suitable for rigorous training and recovery plays an important role in maximizing longitudinal training adaptations. In both cases, a state of chronic energy insufficiency counters these goals, so lifters should generally aim to spend the majority of their training career in a state that reflects adequate energy status. Energy status is reflected by both short-term energy availability and long-term energy stores (i.e., fat mass), so lifters with higher body-fat levels can probably make considerable strength gains while losing fat, as long as the acute deficit isn't large enough to threaten hypertrophy, training performance, or recovery capacity. This is particularly true for lifters who are relatively new to training or have a lot of room for additional strength gains.

So, lifters with relatively high body-fat levels should not feel like they're unable to cut to their ideal weight if it happens to be lower than their current weight. I would expect that many lifters can maintain a satisfactory rate of progress while losing up to (roughly) 0.5% of body mass per week. However, as one gets leaner and leaner, stored body energy is reduced, and the acute presence of an energy deficit probably has a larger impact on the body's perceived energy status. Once a strength-focused lifter is at their ideal body-fat level, they'll want to shift their focus away from fat loss and toward hypertrophy, training capacity, and recovery. In this context, they'll generally want to minimize their time spent in an energy deficit and set their calorie target at a level that allows for weight maintenance or modest weight gain over time (for example, ~0.1% of body mass per week for relatively experienced lifters, or ~0.25% of body mass per week for relatively inexperienced lifters). As they get closer to their genetic limits for strength and muscularity, they might find it difficult to make continued progress at approximately neutral energy balance, and then might shift toward oscillating phases of bulking (a caloric surplus) and cutting (a modest caloric deficit). This approach is also suitable for less experienced lifters who simply prefer to see more rapid increases in strength and hypertrophy during their bulking phases, and are comfortable with the tradeoff of requiring occasional cutting phases. It's also important to note that strength-focused lifters don't *always* need to be in neutral or positive energy balance; in fact, short-term energy restriction is commonly implemented in order to make the weight class that offers the lifter their greatest competitive advantage. Fortunately, these transient periods of energy restriction don't tend to have a huge impact on strength performance (8), provided that the lifter is adequately refueled and recovered in time for competition.

For Recomposition Goals

I'd like to mention two caveats before providing recommendations for recomposition. First, you should assess the feasibility of recomping before you set up a recomposition diet. If you've got plenty of body-fat to lose and are untrained, your recomp potential is very high. If you're shredded and near your genetic ceiling for muscularity, your recomp potential is extremely low. Everyone else will find themselves somewhere in the middle, but the general idea is that you can get away with a larger energy deficit during recomposition if you have higher body-fat or less advanced training status. Second, these recommendations are going to seem a bit superficial. The presently reviewed meta-analysis discussed the specific caloric value of energy deficits, but I will focus on the rate of body weight changes. This is because the recommendations are intended to be practical in nature; few people will have the ability to perform serial DXA scans to allow for up-to-date energy deficit calculations based on changes in total body energy stored as lean mass and fat mass. Plus, and even if they could, the margin of error for DXA (and other accessible body composition measurement devices) is so large as to render this calculation functionally unreliable at the individual level.

One factor that could guide your approach to recomposition is hypertrophy potential. If you've got plenty of body-fat to lose and you're relatively untrained, you should be able to recomp very effectively with an energy intake that allows for a slow rate of weight loss (up to 0.5% of body mass per week), weight maintenance, or even a slow rate of weight gain (up to 0.1% of body mass per week). I know it seems paradoxical to suggest that you could be gaining weight while in a caloric deficit, but the math works out. If, for example, you gain 1.5kg of lean mass while losing 1kg of fat mass, the estimated cumulative change in body energy would be in the ballpark of around -6,700 kcals (so, body weight increased, but the total metabolizable energy content of the body decreased, thereby representing a caloric deficit). For lifters with lower body-fat levels or more advanced training status, it becomes increasingly critical to optimize diet and training variables in order to promote hypertrophy. Even when these variables are optimized, the anticipated rate of hypertrophy shrinks. As a result, the "energy window" for recomposition most likely tightens; even a moderate energy deficit has potential to threaten hypertrophy, and the anticipated rate of hypertrophy becomes too low to suggest that rapidly trading a few pounds of fat for several pounds of muscle is a realistic goal. So, for these individuals, I would advise keeping body weight as steady as is feasible.

A separate factor that could guide your approach to recomposition is the degree to which you prioritize fat loss versus hypertrophy. In many cases, a lifter interested in recomposition might have goals that are a bit skewed. In other words, some lifters might feel that recomposition would be fantastic if possible, but they're particularly adamant about losing fat, even if it comes at the expense of optimizing hypertrophy along the way. Conversely, others will be particularly adamant about making some big strides toward lean mass accretion, even if it comes at the expense of losing fat along the way. For a lifter who wishes to recomp but prioritizes fat loss, aiming for a relatively slow rate of weight loss would be a sensible approach (for example, losing somewhere between 0.1% and 0.5% of body mass per week).

For a lifter who wishes to recomp but prioritizes hypertrophy, aiming for a relatively slow rate of weight gain would be advisable (for example, gaining somewhere between 0.05% and 0.1% of body mass per week). It's obviously difficult to track some small changes in weekly intervals without using some method of data smoothing, but just to contextualize those numbers, a 180lb lifter would gain between 4.32-8.64 pounds over the course of a year if gaining between 0.05% and 0.1% of body mass per week. Within this set of recommendations, a lifter with lower perceived potential for recomping would be advised to aim for the lower ends of the weight gain and weight loss ranges, or to simply aim for approximate weight stability.

For Hypertrophy Goals (Bulking)

Finally, moving on to simpler stuff. For hypertrophy-focused lifters who are relatively experienced and comparatively closer to their genetic limit for muscularity, aiming to gain around 0.1% of body mass per week is a decent starting point. For hypertrophy-focused lifters who are relatively inexperienced and pretty far from their genetic limit for muscularity, aiming to gain around 0.25% of body mass per week is a good place to start. Obviously, if one were adamant about avoiding unnecessary fat gain, they could go a little below these recommended rates. You'll notice that the guidelines for a hypertrophy-focused recomp and a very conservative bulk are not mutually exclusive. Sometimes, people will embark on a conservative bulking phase and find that they ended up losing a little fat along the way (as Bob Ross would call it, a happy accident). Conversely, a lifter who was eager to maximize their rate of hypertrophy and unconcerned about fat gain could push their rate of weight gain a little higher. There are probably diminishing returns for the hypertrophy-supporting effects of a caloric surplus as the surplus grows larger and larger, but to my knowledge, the "ideal surplus" for hypertrophy has not yet been conclusively identified (3).

For Fat Loss Goals (Cutting)

Choosing a rate of fat loss involves striking a balance; as mentioned in a previous MASS article, favoring a slower rate of weight loss confers plenty of benefits. However, going too slow with the process can delay goal completion, threaten motivation, and lead to unnecessary time spent in a deficit. If maintaining strength, lean mass, and training capacity is of utmost importance, losing up to 0.5% of body mass per week would be advisable. Once again, the guidelines for a recomp that prioritizes fat loss and a very conservative cut are not mutually exclusive, and some individuals will embark on a conservative fat loss phase and be pleasantly surprised to find that they gained a little bit of muscle along the way. If you're in a bit of a hurry, you could bump your rate of weight loss closer to 1% of body mass per week. However, it's important to note that the higher this rate gets, the higher the potential to negatively impact strength, lean mass, and training capacity, especially for lifters with less fat mass to lose. From a practical perspective, it might not be a bad idea to cap weight loss at around a kilogram or so per week, even if that ends up being <1% of body mass. Losing a kilogram of fat requires establishing a cumulative energy deficit of ~9,441kcals, which would equate to a daily energy deficit of ~1350kcals/day. As such, when lifters who weigh over 100kg or so aim for 1% of body mass loss per week, they can often find themselves in a scenario that demands daily calorie intakes that might be considered unsustainably low relative to their body size.

Next Steps

Rates of weight gain and weight loss appear to be quite impactful, and they're topics of considerable interest in the fitness world. As a result, the dearth of studies directly comparing different rates of weight gain and weight loss in resistance-trained participants is a bit surprising. In the short term, we could probably gain some useful insight related to this question if researchers took an approach like the meta-regression component of "analysis B" in the presently reviewed study, but restricted the search to studies with resistance-trained samples and included studies assessing caloric surpluses and caloric deficits of varying magnitudes. An even better way to address this topic would involve a series of well controlled trials directly comparing different rates of weight loss and gain

APPLICATION AND TAKEAWAYS

The most direct path to fat loss is a caloric deficit, and a caloric surplus offers the smoothest path to gains in strength and lean mass. Nonetheless, we want the best of both worlds from time to time. Large energy deficits threaten lean mass accretion, and extended periods of excessive energy restriction can impair strength gains as well. However, these issues can largely be circumvented by utilizing a caloric deficit that is appropriately scaled to the individual's goal, training status, and body-fat level. Simultaneous fat loss and muscle gain is indeed possible, although it becomes less feasible as an individual's body-fat level decreases and training status increases. "Recomping" can theoretically be achieved in the context of weight loss, gain, or maintenance, but the dietary approach should be individualized based on the lifter's body composition, training status, and priorities.

within the same study. These types of studies would yield more robust results, but it would take a while to run enough of these studies to develop nuanced conclusions with a high level of confidence.

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VIDEO: Time-Efficient Programming Strategies Part I

BY MICHAEL C. ZOURDOS

Unfortunately, life gets in the way of training, sometimes leaving less time to train. In these cases, lifters can use various time-efficient programming strategies to maintain the appropriate configuration and dosage of training variables. This video discusses those time-efficient strategies and provides specific examples of putting them into practice.

Click to watch Michael's presentation.

Relevant MASS Videos and Articles

1. Rest-Pause Training is a Viable Strategy to Maximize Hypertrophy. Volume 1 Issue 3.
2. Back-to-Back Champs: The Agonist-Antagonist Superset. Volume 4 Issue 3.
3. Minimum Effective Dose Training Part 2. Volume 5 Issue 9.

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VIDEO: Periodizing Singles in Powerlifting Training

BY ERIC HELMS

Heavy singles are often used in powerlifting, but equally as often they are misunderstood or misapplied. In this video, Dr. Helms discusses the feasibility, rationale, pros and cons, and utility of heavy singles. Then, he presents a model of how to periodize singles into powerlifting training as an example you can use to integrate into your training.

Click to watch Eric's presentation.

Relevant MASS Videos and Articles

1. VIDEO: Daily 1RM Training. Volume 1, Issue 8.
2. VIDEO: Postactivation Potentiation. Volume 4, Issue 3.
3. What is Postactivation Potentiation, and Does it Work for Lifting? Volume 3, Issue 1.
4. Simplified Strength Tests Reveal the True Importance of Muscle Size for Force Output. Volume 4, Issue 2.
5. You Want to Get Better at Something? Do it First. Volume 4, Issue 4.
6. New Postactivation Potentiation Data is Less Promising. Volume 4, Issue 6.
7. A New Strategy for Postactivation Potentiation. Volume 5, Issue 9.
8. What's the Least a Powerlifter Can Do and Still Get Meaningfully Stronger? Volume 5, Issue 9.

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Research Briefs

BY GREG NUCKOLS & ERIC TREXLER

In the Research Briefs section, Greg Nuckols and Eric Trexler share quick summaries of recent studies. Briefs are short and sweet, skimmable, and focused on the need-to-know information from each study.

Study Reviewed: Acute Behavior of Oxygen Consumption, Lactate Concentrations, and Energy Expenditure During Resistance Training: Comparisons Among Three Intensities. João et al. (2021)

A Heuristic For Estimating Energy Expenditure During Resistance Training

BY GREG NUCKOLS

Back in Issue 3, I reviewed a study that examined the energy cost of resistance training (2). It was an informative study, but the data were presented in a way that made it challenging to provide many actionable takeaways. However, a recent study provides us with data that are a bit more useful for generating a ballpark estimate of the calories burned in a typical training session (1).

João and colleagues recruited 15 trained men for a crossover study investigating the impact of training intensity on energy expenditure during resistance training. After assessing 1RMs, the subjects performed three different sessions of eight exercises (chest press, pec deck, squat, pull-down, biceps curl, triceps extension, hamstrings curl, and machine crunch). The low-intensity session consisted of 2 sets of 15 reps of each exercise at 60% of 1RM, the moderate-intensity session involved 3 sets of 10 reps at 75% of 1RM, and the high-intensity session required 6 sets of 5 reps at 90% of 1RM (Figure 1). Subjects rested two minutes between sets. During each session, subjects wore a portable spirometer (to measure gas exchange) as a means to estimate energy expenditure.

Overall, energy expenditure was higher during the moderate-intensity session compared to the low-intensity session, and higher during the high-intensity session compared to the moderate-intensity session. That said, due to the number of sets performed in each condition, the high-intensity session was the longest and the low-intensity session was the shortest. So, when energy expenditure was expressed in terms of kilocalories per minute, it was actually slightly (though significantly; $p < 0.05$) greater in the low-intensity session than the high-intensity session (Figure 2). However, the average energy expenditure was approximately 6kcal/min in all three conditions, and the variability between subjects was reasonably low – almost all of the subjects burned between 4kcal/min and 8kcal/min in all conditions.

There aren't any great generalized equations for estimating energy expenditure during resistance training. However, I think this study leaves us with a decent heuristic: total energy expenditure during resistance training is probably about 6kcal/min (including rest intervals). Of course this won't be a com-

Figure 1 Experimental design

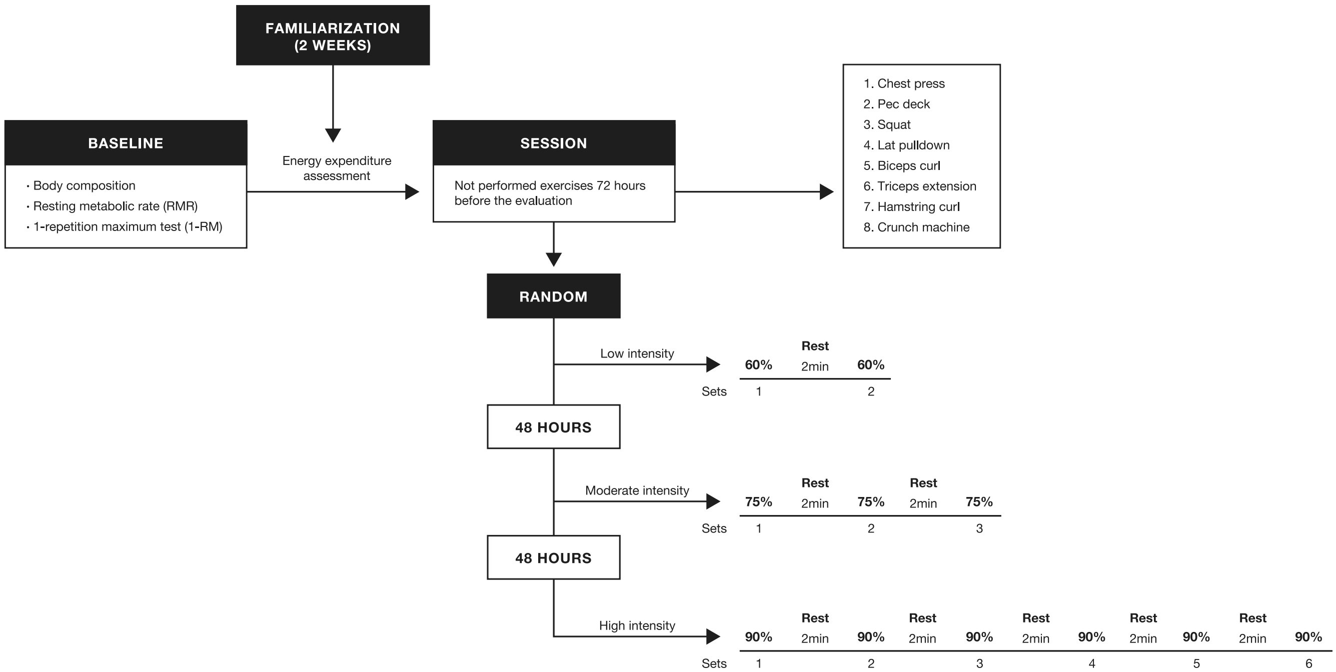
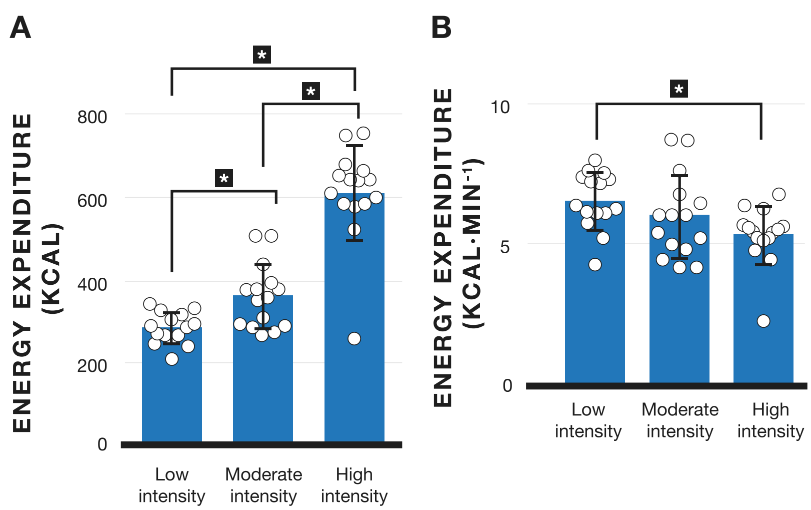


Figure 2 (A) Total energy expenditure and (B) energy expenditure per minute during different experimental sessions at low (60% 1RM, moderate (75% 1RM), and high (90% 1RM) training intensities



** = significant difference between conditions ($p < 0.05$)*

pletely accurate estimate in all circumstances. If two individuals with different strength levels perform identical workouts with the same relative intensity, energy expenditure will likely be greater in the stronger individual, since their training session will require more overall work (in physics terms). Furthermore, a session with shorter rest intervals will result in greater energy expenditure per minute compared to a session with longer rest intervals, all else equal. However, in practical terms, I think those considerations more-or-less work themselves out. Stronger lifters generally require longer rest intervals, because each set is more energy-intensive. Furthermore, rest intervals during training are generally influenced by the overall work being performed during each set, because people typically rest more between more energy-intensive sets (in other words, your rest periods for squats are probably longer than your rest intervals for curls).

Just to sanity-check the estimate that resistance training burns about 6kcal/min, let's compare it to the energy expenditure of locomotion. In general, an average-weight person burns about 100kcal per mile while walking or jogging (3). So, burning 6kcal/min is equivalent to traversing a mile in approximately 16 minutes and 40 seconds (100kcal ÷ 6kcal/min). That would correspond with a speed of about 3.6 miles per hour, which is a pretty brisk walking pace. All in all, that seems pretty plausible.

Keep in mind, 6kcal/min is the estimate of *total* energy expenditure, including basal metabolism. Using the Cunningham equation, basal metabolic rate for a day can be estimated using this equation: BMR = 500 + fat-free mass (in kilos) × 22 (4). This value divided by 1440 (the number of minutes in a day) estimates the approximate basal metabolic rate per minute. So, putting it all together, we can estimate the *additive* energy expenditure for a training session (i.e. the energy expenditure resulting from the actual exercise being performed) using this generalized equation:

Additive energy expenditure = training duration in minutes × (6kcal/min - (500 + (1 - body fat percentage) × body mass × 22) ÷ 1440).

I've also made a handy calculator to do all of the math for you. The calculator will also tell you the upper- and lower-end estimates for a training session, assuming your energy expenditure was below average (closer to 4kcal/min) or above average (closer to 8kcal/min).

Keep in mind that burning more energy during a training session may not scale perfectly with increases in total energy expenditure throughout the day. If you burn 400kcal in a training session, but you're tired after the session and don't move as much for the rest of the day, it's entirely possible that your total daily energy expenditure would only be 200kcal greater than that of a rest day. However, if you'd simply like to get an estimate of the number of calories you burn during a training session, I think the calculator in this research brief should put you in the right ballpark.

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Study Reviewed: Replacing dietary animal-source proteins with plant-source proteins changes dietary intake and status of vitamins and minerals in healthy adults: a 12-week randomized controlled trial. Pellinen et al. (2021)

Replacing Animal Proteins With Plant Proteins: Are There Any Downsides?

BY ERIC TREXLER

Plant-based diets have received a pretty substantial amount of attention in MASS over the last year or two, and for good reason – recent studies have prompted a fairly significant re-evaluation of how plant-based protein sources might impact our aspirations to build strength and muscle mass (one, two, three). Of course, "plant-based" can be viewed in relative terms; while some might choose to exclude all animal products from their diet, others might adopt an ovo-vegetarian, lacto-vegetarian, pescatarian, or flexitarian diet, or simply aim to replace some animal foods in their diet with plant-based options. Recent reviews in MASS have suggested that even fully vegan diets can adequately support muscle protein synthesis (2), strength (3), and hypertrophy (3) outcomes under the right conditions, but there's (arguably) more to life than getting bigger and stronger. Protein-rich foods contain not only protein, but also a wide variety of micronutrients; as such, swapping one protein source for another is likely to influence your daily micronutrient intakes. So, will replacing animal-based protein sources with plant-based protein sources meaningfully influence your micronutrient status? That's exactly what the presently reviewed study (1) sought to find out.

136 adults (107 female, 29 male) aged 20-69 years volunteered for this study, which randomly assigned participants to one of three groups. The animal protein group was instructed to consume 70% of their protein from animal sources, the 50/50 group was instructed to consume 50% of their protein from animal sources, and the plant group was instructed to consume 30% of their protein from animal sources. Animal protein (red meat, poultry, dairy, etc.) in the 50/50 and plant diets were partially replaced by plant-based protein sources (such as cereal products, peas, lentils, chickpeas, tofu, fava beans, nuts, almonds, seeds, and plant-based dairy substitutes). The researchers provided food items that made up about 80% of the daily energy intake; the other 20% or so was obtained from self-selected food sources. All diets were designed to provide about 17% of total energy intake from protein, and four-day food records were completed prior to the start and during the final week of the 12-week intervention. The researchers were

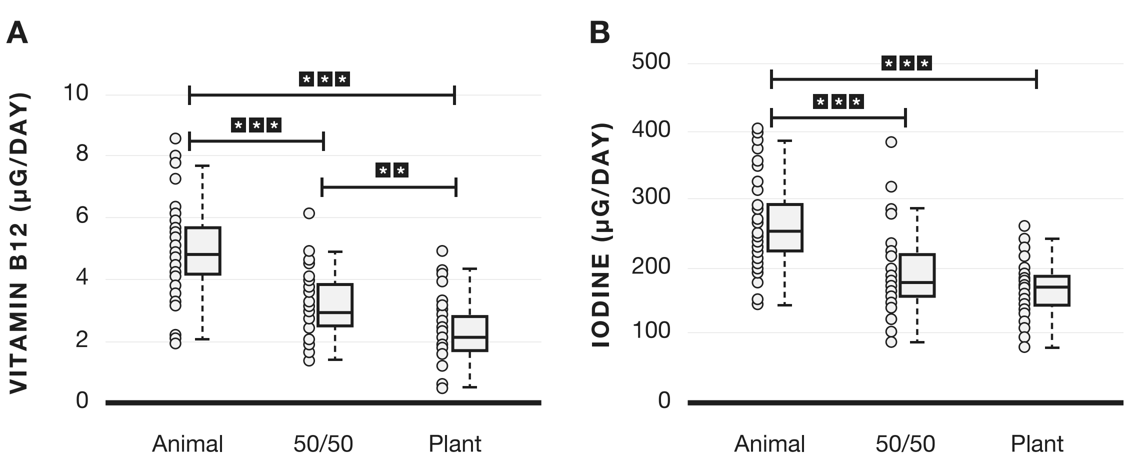
primarily interested in assessing intakes of vitamin B12, iodine, iron, folate, and zinc, along with several closely related blood or urine biomarkers representing nutrient status.

Results indicated that the groups did not consume significantly different amounts of total energy, carbohydrate, or fat. The plant group ended up eating significantly less protein (15.2% of energy) than the 50/50 and animal groups (16.9% and 18.2% of energy, respectively), but also ended up eating significantly more fiber than both. There were significant differences among groups for vitamin B12 intake (plant < 50/50 < animal), iodine intake (plant and 50/50 < animal), folate intake (animal < plant), zinc intake (plant < animal), total iron intake (animal < plant), plant-derived iron intake (animal < 50/50 < plant), and animal-derived iron intake (plant < 50/50 < animal). Intakes of vitamin B12 and iodine are presented in Figure 1.

Despite this relatively large number of between-group differences for dietary intakes, levels of only two biomarkers were significantly different among groups at the end of the intervention. Serum holotranscobalamin II (representative of vitamin B12 levels) was significantly lower in the plant group compared to the 50/50 and animal groups, with three participants (all in the plant or 50/50 groups) dropping below the threshold for vitamin B12 deficiency. In addition, urinary iodine was significantly lower in the plant and 50/50 groups compared to the animal group. Group averages were all within the recommended ranges for adults who are not pregnant or nursing, but there were more instances of iodine deficiency observed in the 50/50 and plant groups than in the animal group.

In summary, it would appear that there are some key micronutrients of elevated interest if you're transitioning to a more plant-based

Figure 1 Intakes of vitamin B-12 (A) and iodine (B) in healthy adults (n=136) who consumed intervention diets differing in animal and plant protein levels for 12 weeks



*Differences between the diet groups analysed by ANOVA with Bonferroni correction: ** = p < 0.01; *** = p < 0.001*
Animal = 70% animal and 30% plant proteins (n=46); 50/50 = equal proportions (50:50) of animal and plant proteins (n=46);
Plant = 30% animal and 70% plant proteins (n=44)
Two values were omitted from this figure by the authors: one observed vitamin B-12 intake (16.6 µg) in the 50/50 group, and one iodine intake (732.8 µg) in the plant group.

diet (of course, you already knew that from Dr. Helms' two-part video series on "Perfecting a Plant-Based Diet for Bodybuilding"). It's also worth noting that these findings were observed with diets consisting of only 50-70% of protein coming from plants, so these results might underestimate the impact of adopting a fully vegan diet. The presently reviewed study provided direct support for the idea that vegans, vegetarians, and even flexitarians might want to proactively seek out additional vitamin B12 and iodine, which shouldn't be hard to do – vitamin B12 is widely available in supplements and fortified foods and beverages, and iodine can readily be found in many multivitamin formulations and in iodized salt (or iodized salt substitutes). Other micronutrients of interest that Helms listed include vitamin D, iron, zinc, and calcium.

The presently reviewed study did not focus on vitamin D, but a previously reviewed study found that vegans had significantly lower vitamin D levels than omnivores at the time of enrollment. Iron levels weren't significantly impacted in the presently reviewed study, but it's also possible that the study was too short to reveal notable differences among groups; in the previously mentioned study comparing vegans and omnivores, blood ferritin levels were non-significantly lower in vegans (140 ± 83 196 ± 121; $p = 0.10$). The presently reviewed study noted that zinc intake was lowest in the plant group, but they were unable to measure a valid biomarker to compare nutrient status among groups. This could potentially be important, as the authors note that strict vegetarians might have a higher daily requirement for dietary zinc due to bioavailability considerations. Finally, eliminating dairy obviously takes some great calcium sources off the table, but there are plenty of vegan calcium sources with adequate bioavailability (4), and plant-based diets appear to be fine for bone health as long as some pretty feasible steps are taken to ensure adequate calcium and vitamin D levels (5).

I always encourage people to seek out micronutrients from whole food sources when it's feasible to do so. This recommendation isn't driven by the old appeal to nature fallacy, but rather by the awareness that, in addition to micronutrients, whole foods provide various combinations of essential amino acids, essential fatty acids, macronutrients, and several bioactive compounds that we're only beginning to understand. For example, we might think of coffee as nature's caffeine supplement, but it contains hundreds of potentially bioactive phytochemicals that make it so much more.

Having said all that, I do believe that multivitamin supplementation can be a viable and feasible strategy to provide some supplementary micronutrient coverage (rather than replacing the need to seek out nutrient-dense foods). Of course, targeted supplementation with singular micronutrients would also be a viable approach, but it's not my go-to recommendation; on the whole, it doesn't seem to be substantially more cost-effective than a broad-spectrum multivitamin approach, and it won't actually be a more targeted and precise intervention without repeated (and potentially costly) blood testing to inform dosing. People also have a tendency to go a bit overboard with singular micronutrient supplementation strategies, which may lead to excessive dosages with the potential for acute or chronic toxicity risk.

The most common arguments against multivitamin supplementation usually center around two points: 1) the literature reports few clear, clinically relevant benefits of multivitamin supplementation, and 2) multivitamins are a *huge* waste of money. As for point number one, that's true, and it's a good thing. There are many studies reporting null effects of multivitamin supplementation in populations in which micronutrient deficiencies are uncommon, which is exactly what you'd anticipate – most people in these studies don't actually need a multivitamin, so adding a multivitamin to the mix isn't a huge, statistically significant game changer in terms of clinical outcomes or mortality. However, multivitamin trials conducted in populations with fairly common micronutrient deficiencies often report quite positive, clinically relevant effects of supplementation. As such, in 2018 an expert panel (6) concluded that, "Given the relatively low cost and established safety of [multivitamin/multimineral supplements], as well as the essentiality of adequate micronutrient status for human biology and good health, [health care professionals] should assess their patients' dietary needs and risk of micronutrient inadequacies and consider intervening with [multivitamin/multimineral supplements] for their at-risk patients."

Now, when it comes to point number two (that multivitamins are a huge waste of money), that's ultimately a judgment call. Scientists can't (and, in my opinion, shouldn't) universally agree on what a "large" effect size is, so there's no chance of settling on a monetary value for a given effect. I was a college student for ten straight years, so I'm generally sensitive to the costs of any exercise or nutrition strategy, and not prone to downplay the financial impact of adding new costs to the mix. However, as of writing this article, I currently pay less than four cents per day for my multivitamin supplement, which offers pretty comprehensive micronutrient coverage. That's like paying $14.40 USD for an annual "micronutrient insurance plan," which isn't too bad.

One might suggest that you should just order some micronutrient testing to check your blood levels before supplementation. I don't necessarily disagree, as more information tends to be better than less information. However, when you consider an intervention that costs four cents per day and has an extremely low risk of adverse events, it seems kind of counterintuitive to pay for testing that might (depending on your healthcare situation) cost the equivalent of several years worth of multivitamins. Imagine you could spend several hundred dollars to test if you're a responder (or non-responder) to creatine. It would be cool to know, but it'd be way cheaper to just try creatine for a year and see if you like it, not to mention it's an extremely low-risk experiment for a healthy person with no underlying medical conditions.

In conclusion, a 12-week stint of replacing animal-based proteins with plant-based proteins won't necessarily yield a long list of clinically significant micronutrient deficiencies, but there are some key micronutrients to keep an eye on if you're transitioning to a more plant-based diet. The most noteworthy micronutrients of interest are iron, vitamin B12, vitamin D, iodine, zinc, and calcium. In many cases, adequate intakes can be achieved with a mixture of carefully selected conventional and fortified foods, but supplementation is also a viable option. You could pursue a targeted supplementation approach with individual micronutrients, but my personal preference is to lean on a basic multivitamin supplement. Plant-based diets with adequate micronutrient coverage, sufficient total protein intake (and comprehensive essential amino acids) can support the goals of lifters and athletes to the same extent as omnivorous diets with a higher proportion of animal-based products.

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Study Reviewed: Understanding Bench Press Biomechanics – Training Expertise and Sex Affect Lifting Technique and Net Joint Moments. Mausehund and Krosshaug (2021)

The Bench Press May Target Different Muscles in Male and Female Lifters

BY GREG NUCKOLS

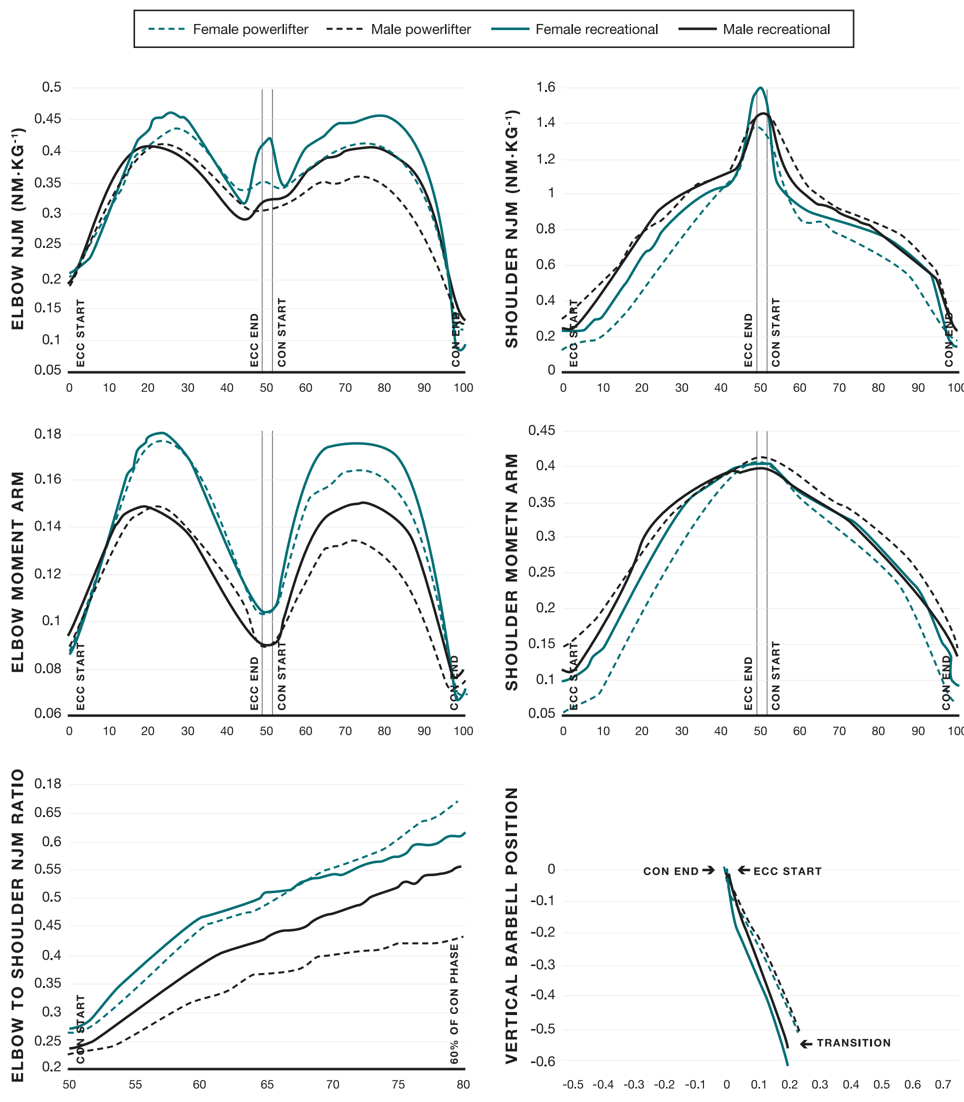
In Volume 2 of MASS, I reviewed a study by Gołaś and colleagues investigating sex differences in pec, triceps, and front delt electromyographic (EMG) amplitudes in the bench press, with loads ranging from 55% to 100% of 1RM (2). It was a valuable contribution to the literature, because the vast majority of prior bench press EMG studies had used exclusively male subjects, and the studies with mixed-sex cohorts didn't perform separate statistical analyses for the male and female subjects (3). However, the Gołaś study had a couple notable drawbacks. First, it had a very small sample – just five male and five female subjects. Second, it used an EMG normalization procedure that was sufficient for analyzing how EMG changed as loads increased, but didn't allow for an actual apples-to-apples comparison between the sexes. However, even with those drawbacks, the results of this study were interesting: it found that, as loads increased, pec EMG increased to a greater extent in the female subjects, while triceps EMG increased to a greater extent in the male subjects (2). That led me to tentatively conclude that bench press may be a slightly more pec-dominant lift for female lifters than male lifters, and a slightly more triceps-dominant lift for male lifters than female lifters, on average. At first glance, the study reviewed in the present research brief (1) would seem to contradict that conclusion. However, the results of these two studies can actually coexist nicely.

In this study by Mausehund and Krosshaug (1), 22 recreationally trained lifters (13 males and 9 females) and 12 competitive powerlifters (6 males and 6 females) completed a 6-8 RM set of bench press. All subjects used a medium grip width (approximately 160% of biacromial breadth). During the set, joint and limb positions were tracked in three dimensions using a camera system in order to calculate net joint moments, and EMG amplitudes of the pecs (sternal and clavicular heads), triceps (long head and lateral head), and anterior deltoids were recorded using surface electrodes. EMG amplitudes obtained during the bench press were normalized against maximal EMG amplitudes obtained during single-joint maximum voluntary contraction (MVC) testing. The MVCs were performed on an isokinetic dynamometer at a low angular velocity (60° per second); triceps MVC

EMG was assessed during isolated elbow extensions, and pec and anterior deltoid MVC EMG was assessed during isolated shoulder horizontal adduction.

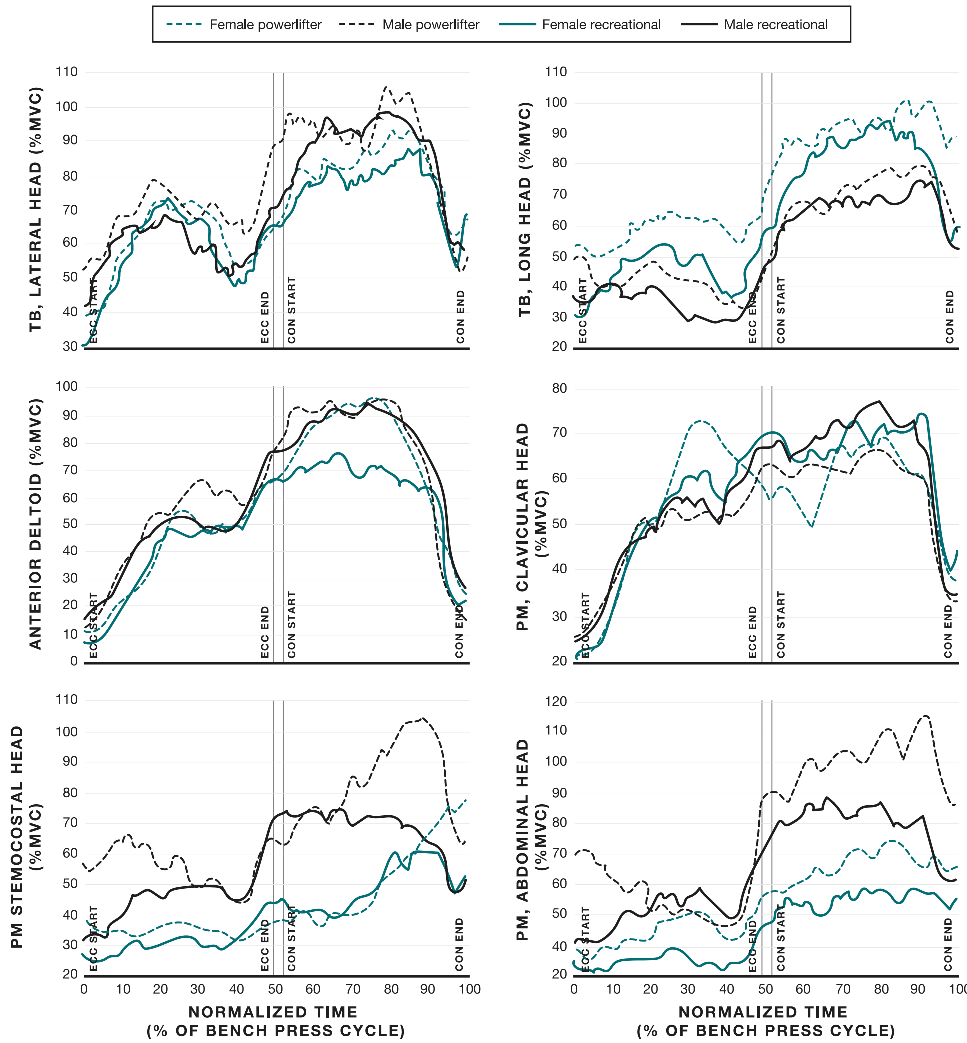
The powerlifters and recreationally trained lifters adopted different bar paths; the vertical range of motion was longer for the recreationally trained lifters, while the horizontal range of motion was greater for the powerlifters (i.e. the powerlifters touched the barbell lower on their chests). Shoulder moment arms were pretty similar between sexes for the recreationally trained lifters, but tended to be longer for the male powerlifters than the female powerlifters. Conversely, elbow moment arms were longer for female recreational lifters and powerlifters than for male

Figure 1 Normalized net joint moments (NJM) (top), normalized moment arms (middle), and NJM ratios and barbell paths (bottom) in the bench press



Data are time normalized to the eccentric and concentric phases and displayed as ensemble average curves. Vertical lines represent the start and end of the eccentric and concentric phases. NJM = normalized NJM; elbow NJM = external elbow flexion NJM; shoulder NJM = external shoulder extension/horizontal abduction NJM.
The moment arms and barbell position data are normalized to the subjects' arm length. The NJMs are normalized to the subjects' estimated 6RM load.

Figure 2 Electromyographic (EMG) activity of upper extremity muscles in the bench press



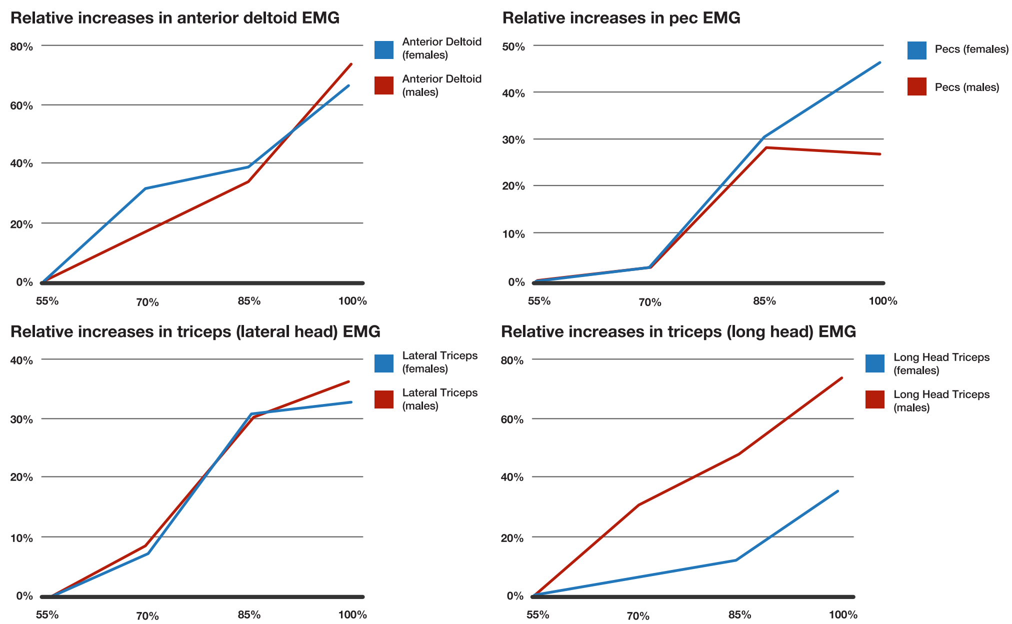
Data are time normalized to the eccentric and concentric phases and displayed as ensemble average curves. EMG activity is normalized to maximum voluntary isokinetic contractions (MVC). Vertical lines represent the start and end of the eccentric and concentric phases. TB = triceps brachii; PM = pectoralis major.

recreational lifters and powerlifters. Accordingly, the ratio of elbow net joint moments to shoulder net joint moments diverged between sexes – it was larger for female recreational lifters than male recreational lifters, and for female powerlifters than male powerlifters. In fact, the difference between the male and female powerlifters was larger than the difference between the male and female recreational lifters (Figure 1).

Normalized EMG for both heads of the pecs was greater for the male lifters than the female lifters (for both recreational lifters and powerlifters). Conversely, normalized EMG of the long head of the triceps was greater for the female lifters than the male lifters (Figure 2). These EMG results match up nicely with the reported moment arms and net joint moments.

As I mentioned previously, these results initially appear to conflict with those of the previous study we reviewed in MASS investigating sex differences in bench press EMG

Figure 3 Relative increases in normalized peak EMG above the EMG values observed with 55% 1RM loads



From Glas et al. (2). This figure originally appeared in Volume 2, Issue 7 of MASS.

(2). However, these two studies asked slightly different research questions. The prior study investigated differences in EMG as loads increased, while the present study investigated differences in EMG at a fixed load (1). In the present study, the bench press appears to be a more triceps-dominant lift for female lifters, and a more pec-dominant lift for the male lifters with heavy (but submaximal) loads. In the prior study, pec EMG increased to a greater extent in female lifters as they approached 1RM loads, while triceps EMG increased to a greater extent in male lifters as they approached 1RM loads (Figure 3).

Thus, when taken together, these studies suggest that the bench press may be a bit more triceps-dominant for female lifters with submaximal loads, but that female lifters are still capable of ramping up pec recruitment as they approach 1RM loads. Conversely, the bench press may be a bit more pec-dominant for male lifters with submaximal loads, but male lifters are still capable of ramping up triceps recruitment as they approach 1RM loads. In other words, there are slight differences in the muscles primarily used for "normal" efforts, versus the muscles that function as a "strength reserve" as lifters approach maximal effort.

Now, this was an EMG study, so all standard caveats apply. Namely, we don't know whether acute EMG differences are predictive of long-term differences in training adaptations (4). However, we don't need to solely rely on the EMG results. The joint moment results of this study suggest that female lifters may actually experience relatively larger increases in triceps strength with training, while male lifters experience relatively larger increases in pec strength. The ratio of elbow to shoulder net joint moments diverged to a greater extent in the powerlifters than in the recreationally trained subjects, which may be suggestive of different adaptations resulting from training. In other words, female lifters may utilize their triceps more when benching, build more triceps strength, and thus adopt a more triceps-dominant bench technique as training status increases, resulting in a larger ratio of elbow to shoulder net joint moments. Conversely, male lifters may utilize their pecs more when benching, build more pec strength, and thus adopt a more pec-dominant bench technique as training status increases, resulting in a smaller ratio of elbow to shoulder net joint moments. Of course, since this was a cross-sectional study, we can't rule out the possibility that these results were influenced by body segment length (i.e. humerus-to-forearm length ratios) differences between groups, unrelated to training adaptations.

If I were to offer a very tentative takeaway, I would suggest that, on average, female lifters may benefit a bit more from pec-focused accessory work than male lifters, while male lifters may benefit a bit more from triceps-focused accessory work than female lifters. This tentative takeaway is predicated on the assumption that female lifters are truly (slightly) under-utilizing their pecs during submaximal bench press training, and male lifters are truly (slightly) under-utilizing their triceps during submaximal bench press training. Of course, more work is needed to understand if and why this specific neuromuscular difference exists, if similar differences exist for other exercises, and whether or not these differences functionally influence bench press performance or training adaptations.

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Study Reviewed: Whey Protein Supplementation Is Superior to Leucine-Matched Collagen Peptides to Increase Muscle Thickness During a 10-Week Resistance Training Program in Untrained Young Adults. Jacinto et al. (2022)

Collagen Protein Isn't Great for Promoting Muscle Hypertrophy

BY ERIC TREXLER

Protein quality has received a lot of attention in recent issues of MASS, and for good reason – a number of applied studies have challenged some mechanistically driven assumptions about how a protein source's amino acid profile and overall quality score might impact its ability to support hypertrophy. This conversation often involves comparing a lower-quality plant-based protein to a higher-quality animal-based protein, and recent studies have suggested that plant-based proteins can effectively support hypertrophy when total protein intake is ≥1.6g/kg/day (2). As I noted in one of my articles this month, this is not because 1.6 is a magic number and ensures optimal gains. Rather, we see that lower-quality proteins tend to be somewhat "inefficient" protein sources but often have complementary amino acid coverage, so their suitability (in terms of maximally supporting hypertrophy) depends on total protein intake. When total protein intake is high, the efficiency of each individual protein source becomes less relevant, but when total protein intake gets lower and lower, efficiency becomes increasingly important.

It's important to recognize, however, that the protein quality conversation isn't always about comparing plant sources to animal sources. Collagen is a fairly popular animal-based protein, but it has a very low protein quality score (zero, in fact). Collagen has a very atypical amino acid profile; it lacks tryptophan entirely (hence the protein quality score of zero) and several other essential amino acids, but has very high amounts of glycine, proline, hydroxyproline, and hydroxylysine. Its amino acid profile is very conducive to collagen synthesis, which could theoretically be good for bones, tendons, and other connective tissues. In contrast, its amino acid profile is pretty awful for supporting hypertrophy, with relatively low amounts of important essential amino acids such as leucine, isoleucine, valine, lysine, methionine, and threonine.

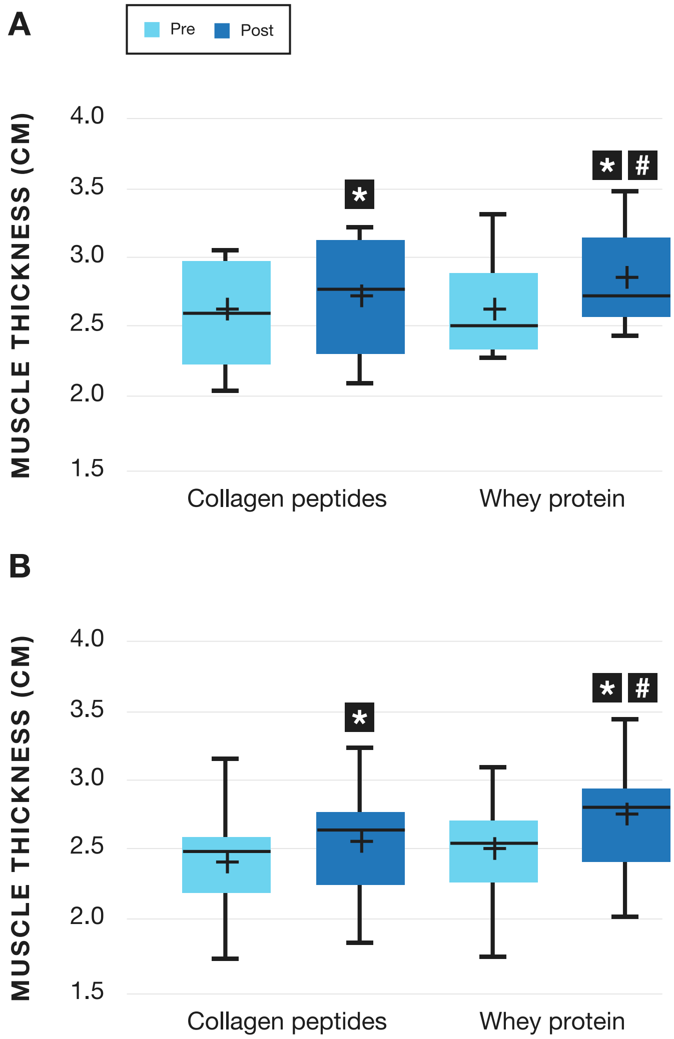
The amino acid shortcomings of collagen are quite a bit different than the amino acid situation for most plant-based proteins. If you check out this open-access review by Van Vliet and colleagues (3), you can compare amino acid quantities of various plant-based and animal-based proteins. You'll find that plant-based options tend to be a little lower in leucine (but not outrageously so), and will tend to lack one or two essential amino acids, with a relative abundance of others. For example, you can match a protein like lentils (low methionine, high lysine) with a protein like rice (high methionine, low lysine), and end up with a pretty comprehensive overall amino acid profile. In contrast, the widespread amino acid shortcomings of collagen could potentially be a little more difficult to rectify. Despite those numerous amino acid shortfalls, the research assessing collagen's impact on longitudinal changes in fat-free mass is mixed, with a surprising number of studies reporting increases (4).

To further explore collagen's potential for supporting hypertrophy and gains in fat-free mass, the presently reviewed study (1) compared post-workout supplementation with 35 grams of whey protein to 35 grams of leucine-enriched collagen over the course of a 10-week resistance training program. Both supplements contained 35 grams of total protein and 3 grams of leucine, which required that an extra 2 grams of leucine be added to the collagen supplement. The protein supplements provided about 0.5g/kg/day of protein, which was consumed on top of participants' habitual protein intake (which was around 1.1-1.5 g/kg/day, on average). Supervised training sessions occurred three days per week, and supplements were consumed in the evening on non-training days. The program consisted of full-body workouts with multiple sets per exercise and repetitions in the 8-12 per set range, and loads were adjusted weekly to ensure that the program was progressive in nature. 18 healthy young adults (aged 18 to 35) were randomly assigned to each group, but only 11 participants (8 men and 3 women) from each group were able to finish the entire study with suitable adherence.

In terms of study outcomes, the researchers were primarily interested in assessing changes in training load, isokinetic elbow flexor strength and power, lower-body peak power (measured via countermovement jump), and muscle thickness of the vastus lateralis and biceps brachii (measured via ultrasound). There were no statistically significant differences between groups in terms of training load, lower-body peak power, or isokinetic elbow flexor strength or power. However, the whey group experienced significantly larger increases in vastus lateralis and biceps brachii muscle thickness than the collagen group (Figure 1). The whey group experienced Cohen's d effect sizes of 0.68 and 0.61 for increases in vastus lateralis and biceps brachii thickness, whereas the collagen group experienced effect sizes of only 0.38 and 0.35, respectively.

Overall, these results aren't entirely surprising. As discussed by the authors of the present study (1), there are some studies reporting increases in fat-free mass following collagen supplementation, but the only study that directly measured muscle hypertrophy found no significant effect of collagen supplementation on muscle growth. Additionally, although we shouldn't assume that acute muscle protein synthesis rates are perfectly indicative of hypertrophic potential, there is direct research showing that that collagen has

Figure 1 Muscle thickness of the (A) vastus lateralis and (B) biceps brachii in the whey protein (n=11) and collagen peptide (n=11) groups before and after the 10-week resistance training program



The box plot shows the median (line) and mean (+), interquartile range (box), and the maximum and minimum values (whiskers).
** = p < 0.05 compared with pre-training values for both groups (ANOVA; time effect),*
 # = p < 0.05 compared with collagen peptide group (ANOVA; Group x Time interaction).
ANOVA = analysis of variance.

underwhelming effects on acute muscle protein synthesis (5), thereby linking the acute, mechanistic findings to the longitudinal, applied findings.

An interesting observation in the presently reviewed study is that non-supplement protein intake fell over time in the collagen group, and was a bit lower than the whey group. Diet logs were analyzed at baseline, along with weeks 3, 7, and 10. The collagen group started around 1.5g/kg/day, and steadily dropped to 1.2g/kg/day in week 7, and eventually to 1.1g/kg/day in week 10. In contrast, the whey group consumed 1.4g/kg/day at all time points except for week 3 (1.1g/kg/day). A reasonably consistent finding in the literature comparing plant and animal proteins is that plant-based proteins tend to do fine, as long as total protein intake is ≥1.6g/kg/day. In the present study, the leucine-enriched collagen should have pushed the collagen group to or above that threshold (1.1-1.5 g/kg/day of protein from food, plus 0.5g/kg/day of protein from the collagen supplement). So, it would appear that this general rule tends to hold true for diets composed of typical plant proteins (which tend to have reasonably adequate and complementary amino acid profiles), but collagen's amino acid profile is too flawed for this guideline to apply (even after leucine fortification). Again, this shouldn't be a total surprise, given that collagen's amino acid problems extend far beyond leucine alone.

So, if you're focused on hypertrophy and thinking about replacing some moderate- or high-quality dietary proteins with collagen supplements, you'll want to rethink that strategy. I generally don't advocate for convoluted protein-counting strategies (for example, counting only high-quality protein sources toward your daily protein total, or counting low- or moderate-quality proteins in a fractional manner), and I won't start now. However, I would advise hypertrophy-focused readers against consuming a considerable portion of daily protein from collagen, and if a significant dose of collagen (for example, >15g/day) is part of your daily routine, you might want to double check to ensure that your total daily protein intake is at least in the range of 1.7-1.8 g/kg/day. I've previously described some plant-based proteins as being "inefficient" for promoting hypertrophy (when scaled relative to caloric content or total protein content), but this becomes less important when total protein intake meets or exceeds 1.6g/kg/day. Collagen happens to be very, very inefficient, so you'll probably want to be at or above the 1.7-1.8 g/kg/day range to ensure that this inefficiency isn't hindering muscle growth. To be clear, that range is not empirically derived, and is a bit speculative. You could argue about the exact total protein number that needs to be reached, but the general point is that you don't want to be replacing a lot of high-quality or moderate-quality proteins with collagen if you're near the lower end of the optimal protein range.

You might be wondering why people would bother with collagen supplementation in the first place. As I reviewed in a previous MASS article, there is some evidence to suggest that collagen supplementation can facilitate collagen synthesis and may be beneficial for individuals with joint pain or other issues related to connective tissues. This body of research is small, and it's not universally embraced by sports nutrition experts, but there is at least *some* evidence linking collagen supplementation to increased rates of collagen synthesis, increased fat-free mass (presumably via increased connective tissue mass), and attenuation of joint pain.

I'm not a connective tissue expert, so take this with a grain of salt, but I'm personally not sure that collagen supplementation would be my first course of action if I was dealing with a connective tissue injury that needed some nutritional support. I think you can make a strong argument that the glycine content is most likely driving the effects of collagen supplementation (6), and as a fringe benefit, there's also evidence linking glycine to better sleep (7). Kidney stones don't seem to be a notable issue in the longitudinal studies on collagen supplementation, but it's worth noting that collagen is rich in hydroxyproline, which could theoretically increase the likelihood of kidney stones (8). As such, aiming for 3-5g of glycine might be a suitable alternative to taking 10-15g of collagen. So, in summary, there is some evidence linking collagen supplementation to modest benefits related to connective tissues and joints, but it's quite possible that a little bit of glycine would do the trick. Either way, you don't want to rely heavily on collagen for the promotion of muscle hypertrophy, and if you happen to consume a substantial amount of collagen, you'll want to make sure you're taking necessary steps to achieve adequate and comprehensive essential amino acid intake.

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Study Reviewed: Acute and Long-Term Effects of Attentional Focus Strategies on Muscular Strength: A Meta-Analysis. Grgic et al. (2021)

Attentional Focus May Influence Strength Development

BY GREG NUCKOLS

We've written about attentional focus a few times in MASS, discussing how an external focus (focusing on the outcome of a task) can lead to improved acute performance, and an internal focus (focusing on bodily movements or sensations) may improve muscle growth (one, two, three). However, when it comes to strength development, we can't necessarily assume that promising acute measures (increased strength performance when adopting an external attentional focus) will necessarily lead to improved long-term outcomes (greater strength development). With that in mind, the present meta-analysis (1) sought to analyze the research investigating the impact of attentional focus on both acute strength performance and longitudinal strength development.

The researchers identified seven studies investigating the impact of attentional focus on acute strength measures and three studies investigating the impact of attentional focus on longitudinal strength development that met their inclusion criteria. The study needed to 1) be written in English, 2) investigate the acute or longitudinal impact of an internal versus an external attentional focus on strength, 3) employ a crossover design or between-groups design, and 4) report enough statistical information for the results to be useable in a meta-analysis. Details about the included studies can be seen in Table 1.

The meta-analysis on acute strength measures found that an external attentional focus significantly enhanced strength performance (Figure 1A; Standardized Mean Difference [SMD] = 0.34; $p < 0.001$). Furthermore, it's worth noting that the effect wasn't solely driven by the studies assessing the effect of attentional focus on strength measures like handgrip strength or index finger flexion strength (2, 3). Studies assessing strength using isometric mid-thigh pull (4) or squat and deadlift (5) also found positive effects in favor of an external attentional focus.

For longitudinal strength development, there was an overall positive effect in favor of an external attentional focus. This effect size was quite similar to the effect size for acute strength performance, but it failed to meet the traditional standard for statistical significance (SMD = 0.32; $p = 0.11$). However, the authors

Table 1 Summary of the included studies

REFERENCE	PARTICIPANTS	EXTERNAL FOCUS INSTRUCTIONS	INTERNAL FOCUS INSTRUCTIONS	EXERCISE TEST	TRAINING INTERVENTION
Bredin et al. (2013)	8 young men and 8 young women	Concentrate on the wall marker during the test.	Concentrate specifically on the fingers.	Handgrip strength	n/a
Halperin et al. (2016a)	18 trained athletes (10 men and 8 women)	Focus on pushing the ground as hard and as fast as you possibly can.	Focus on contracting your leg muscles as hard and as fast as you possibly can.	Isometric mid-thigh pull	n/a
Halperin et al. (2016b)	28 resistance-trained participants (14 men and 14 women)	Attempt to produce as much force as you possibly can while focusing on pulling the strap as hard and fast as you can.	Attempt to produce as much force as you possibly can while focusing on contracting your arm muscles as hard and as fast as you can.	Elbow flexion MVC	n/a
Kuhn et al. (2018)	14 participants (11 men and 3 women)	Exert pressure on the force transducer so that the moving line increases as fast as possible to the maximum after the tone.	Contract your finger flexor muscles so that the moving line increases as fast as possible to the maximum after the tone.	Index finger flexion MVC	n/a
Marchant et al. (2017)	20 resistance-trained participants (16 men and 4 women)	Try to exert maximal effort during the movement whilst focusing on pushing against the pad.	Contract the vastus medialis oblique whilst generating maximal effort.	Isokinetic leg extension	n/a
Nadzalan et al. (2019)	20 resistance-trained men	**Deadlift:** Focus your attention on pulling the bar up. **Squat:** Focus on moving and exerting force through and against the barbell.	**Deadlift:** Focus your attention on extending your knees and hips. **Squat:** Focus on moving and exerting force with your legs.	Squat and deadlift 1RM	6 weeks
Nadzalan et al. (2020)	30 resistance-trained men	**Deadlift:** Focus your attention on pulling the bar up. **Squat:** Focus on moving and exerting force through and against the barbell.	**Deadlift:** Focus your attention on extending your knees and hips. **Squat:** Focus on moving and exerting force with your legs.	Squat and deadlift 10RM	n/a
Schoenfeld et al. (2018)	27 untrained men	Get the weight up!	Squeeze the muscle!	Knee extension and elbow flexion MVC	8 weeks
Taylor (2017)	44 male university team sport athletes	**Deadlift:** Focus on pushing the ground away as fast as possible. **Squat:** Focus on driving the bar to the ceiling as explosively as possible.	**Deadlift:** Focus on extending your hips as fast as possible. **Squat:** Focus on extending at your knees as rapidly as possible.	Squat and deadlift 1RM	12 weeks
Wiseman et al. (2020)	11 resistance-trained men	Focus on pulling up on the handle as hard and as quickly as you possibly can.	Focus on contracting your biceps as hard and as quickly as you possibly can.	Elbow flexion MVC	n/a

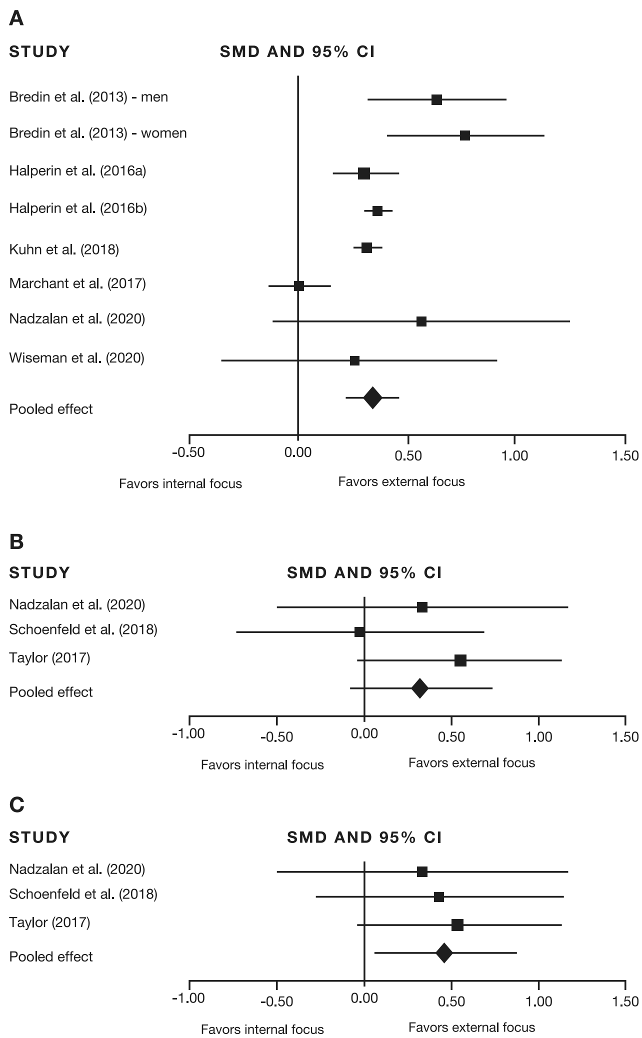
MVC = maximal voluntary contraction; RM = repetition maximum; n/a = not applicable.

also performed a sub-analysis on measures of lower body strength development, finding a small significant effect in favor of an external attentional focus (SMD = 0.47; p = 0.02).

This meta-analysis was useful for two reasons. First, while it's well-established that an external attentional focus improves acute motor learning and performance in a general sense (6), most of the research in the area has focused on tasks that are more dependent on coordination (for example, throwing darts or tossing bean bags) than force output. I was aware that several individual studies had identified positive impacts of an external focus on strength performance, but it's good to have those findings confirmed by a meta-analysis.

Second, and more importantly, this meta-analysis provides *some* evidence that an external attentional focus during training can improve longitudinal strength development. I'm not particularly concerned that the general analysis of strength measures failed to find a significant effect, and I'm also not particularly impressed that the subanalysis of lower body strength measures *did* find a significant effect. In both cases, the meta-analyses on longitudinal outcomes only included three studies, so it's still far too early to make any definitive statements. However, the re-

Figure 1 Results from the meta-analysis that explored the effects of internal focus. vs. external focus



A = acute effects of internal focus vs. external focus on muscular strength;
B = long-term effects on an internal focus vs. external focus on muscular strength;
C = long-term effects of an internal focus vs. external focus on lower-body muscular strength.
The data are presented as squares, which represent standardized mean differences (SMD) and whiskers, which are 95% confidence intervals (CIs). The diamond represents the pooled effect.

sults were generally positive, suggesting that adopting an external attentional focus during resistance training *may* not only enhance strength performance acutely, but may also improve rates of strength development over time. Of course, more research is needed to confirm these initial tentative findings.

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Study Reviewed: Physical Activity and Total Daily Energy Expenditure in Older US Adults: Constrained versus Additive Models. Willis et al. (2022)

Adding Another Layer to the Energy Compensation Discussion

BY ERIC TREXLER

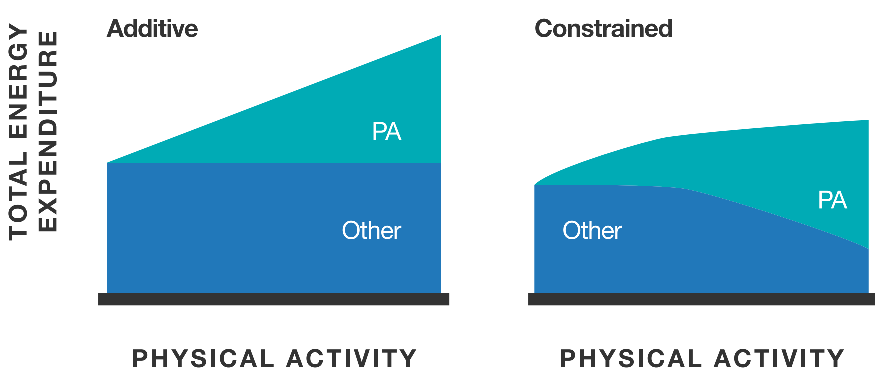
The constrained total energy expenditure model isn't new, but it's definitely a hot topic at the moment. Pontzer et al published a very thorough overview of the concept back in 2016 (2), but a few newer papers have made quite a splash over the past year or so. A paper by Careau et al (3) reported (in a huge sample of free-living individuals) that people tend to compensate for increased physical activity by reducing basal energy expenditure. There was also the paper by Broskey et al (4), which Dr. Helms reviewed in MASS, that also identified compensatory reductions in non-exercise components of energy expenditure, ultimately resulting in lower-than-predicted weight loss over the course of an exercise intervention. More recently, Dr. Kevin Hall revisited the data from the Biggest Loser Study (reviewed here) to present an updated perspective, suggesting that the observation of large, sustained, unexpected suppression of resting metabolic rate could be related to compensatory adjustments in response to high levels of physical activity (5).

As the constrained energy expenditure model picks up steam, it's informative to frame (and assess) it relative to the alternative model – the additive energy expenditure model. The additive model is certainly the most parsimonious; it contends that when we add 100kcals worth of exercise to our daily routine, total daily energy expenditure increases by roughly 100kcals. The constrained model argues that things are a bit more complicated – when baseline physical activity level is on the lower end of the spectrum, the constrained model and additive model essentially agree that total daily energy expenditure increases fairly proportionally to the amount of extra exercise that is added to the mix. However, the models diverge at higher levels of physical activity; the additive model assumes that the increases in energy expenditure keep ramping up, whereas the constrained model assumes that our bodies make adaptive adjustments to constrain total daily energy expenditure within a working range. In other words, as we start pushing total daily energy expenditure up to potentially unsustainable levels by engaging in extremely high levels of physical activity, our body aims to become more energy efficient, cutting unnecessary energy expenditure from other processes taking place at rest. These models are concisely described in the following figure, adapted from a paper by Pontzer et al (2).

One important aspect of Figure 1 is that energy compensation in the constrained model is incomplete. In other words, as you move from low physical activity levels to high levels, there is still a general increase in total energy expenditure. Physical activity increases total energy expenditure, but not quite as much as you'd expect, particularly at higher levels of activity. Many people misinterpret the constrained model and suggest that exercise is totally useless for increasing total energy expenditure. However, based on the assumption of partial energy compensation, a more accurate interpretation of the proposed model is that exercise causes smaller increases in total energy expenditure than you would mathematically anticipate.

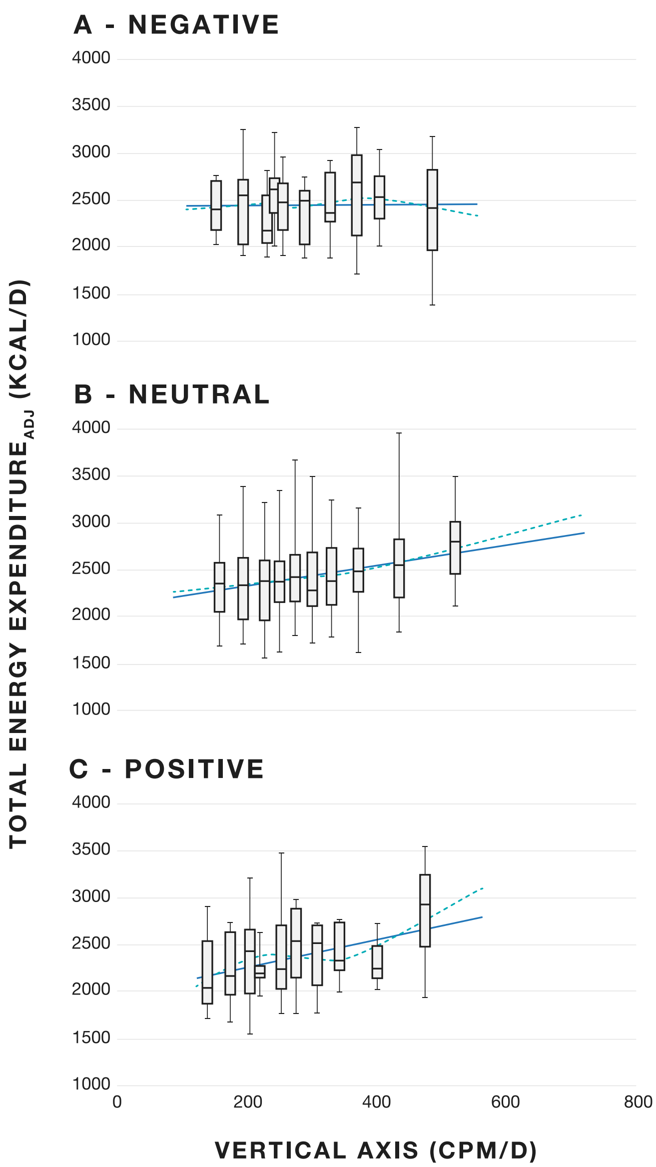
The presently reviewed study (1) put the constrained model to the test by directly comparing it to the additive model. In 584 free-living American adults (between the ages of 50-74 years, with BMI values between 18.5-40 kg/m2), total energy expenditure was measured using doubly labeled water, and physical activity was measured using accelerometry. The 12-month study timeline included a complicated staggering of assessments, but the important highlights are that total energy expenditure was measured over a 14-day period, physical activity was measured over a 7-day period, and energy status was categorized based on average weight change over a six-month period. Positive energy balance was defined as gaining more than 3% of body weight, negative energy balance was defined as losing more than 3% of body weight, and neutral energy balance was defined as staying within ±3% of baseline weight. The simplified version of the results is very straightforward: for people in neutral or positive energy balance, the additive model did just fine – as physical activity went up, total energy expenditure went up to a fairly proportional degree. However, the constrained model held true for

Figure 1 Schematics of additive total energy expenditure and constrained total energy expenditure models



PA = physical activity

Figure 2 Relationship between TEE and physical activity by energy balance status



TEE = total energy expenditure.
TEE$_{ADJ}$ (kcal·d^{-1}) and physical activity (CPM·d^{-1}). Boxplots indicate medians, quartlies, and range of TEE$_{ADJ}$ for each decile of CPM·d^{-1} and are centered on the median (CPM·d^{-1} value for each decile. Restricted cubic splines (dash) and linear (solid) regression lines are shown.

people in negative energy balance; total energy expenditure was fairly stable across the full range of activity levels. These relationships are presented in Figure 2.

This is pretty cool. In a recent MASS article, we saw how the constrained model can help us understand the adaptations commonly attributed to negative energy balance. In this paper, we see how negative energy balance can help us understand the constrained model. As a result, we have even more evidence supporting the idea that these two topics (metabolic adaptation and the constrained model) are inherently linked under the umbrella of topics related to energy availability. Of course, we should always hesitate to get overly excited about a singular research finding (pending further verification and replication), but these results might fill a pretty important gap in our understanding of energy compensation. Overly simplistic interpretations of the constrained energy expenditure concept have always bothered me, because they don't seem to pass some very superficial, unscientific sanity checks. We never want to get too attached to our anecdotal observations (as they are susceptible to considerable subjectivity and misinterpretation), but we also don't want to ignore our experience and observations. Overly simplistic interpretations of the constrained model just don't seem to match up with reality.

When people suggest that energy expenditure is maintained within an extremely tight range to compensate for physical activity, they often lean on studies showing surprisingly similar total daily energy expenditure in people with sedentary lifestyles in more industrialized areas compared to people who perform energy-intensive physical work in less industrialized areas (2). However, it is difficult to reconcile this with the research reporting that energy expenditure fluctuations across the adult lifespan seem mostly tied to changes in physical activity or the research (6) indicating that total daily energy expenditure in free-living athletes tends to be markedly higher than in free-living non-athletes.

Beyond that, I tend to be pretty curious about physiology, and I've spent most of my life hanging around a mixture of people with athletic goals and body composition goals. I've long been frustrated by an apparent discrepancy: I've known plenty of endurance athletes who seem to perpetually achieve astonishingly high caloric intakes to fuel their training, but I've simultaneously known plenty of chronic dieters who seem to require surprisingly low caloric intakes to promote further weight loss, despite pretty eye-popping amounts of daily cardio. I've never really resisted the concept of energy compensation, but I've long suspected that compensation is relatively incomplete in the majority of contexts, and that the relationship between physical activity level and the degree of compensation contains multiple layers of complexity.

Thanks to the hard work of many researchers, we are continuing to develop a more nuanced understanding of those layers of complexity. For starters, the relative degree of physical activity should influence the magnitude of compensation – it's literally built into the model (see Figure 1), which assumes that more severe compensation doesn't kick in until physical activity levels get pretty high. In addition, there appears to be considerable variability between individuals; in the study by Careau et al (3), higher fat mass was predictive of greater energy compensation. To quantify this relationship in practical terms, they reported that leaner individuals at the 10th BMI percentile compensated for 29.7% of the calories burned during physical activity, whereas individuals at the 90th BMI percentile compensated for 45.7%. It's unclear if compensation leads to greater BMI or if greater BMI leads to more compensation (or if a more complicated relationship explains the link between BMI and compensation), but there appears to be significant inter-individual variability that correlates with BMI (and more specifically, fat mass).

To add to the complexity, the presently reviewed study suggests that compensation is also impacted by the energy status of the individual. This may help us understand why total energy expenditure could be similar when we compare people in more active, less industrialized areas (where excess energy consumption is less likely) to people in less active, more industrialized areas (where excess energy consumption is more likely). It may also help us understand why the chronic dieter appears to experience so much energy expenditure compensation for their countless hours on the treadmill, while we observe consistently high energy expenditure values in endurance athletes who are actively striving to adequately fuel their training efforts.

As this line of research pushes forward at an impressive pace, it has delivered some pretty useful observations. We can't treat cardio as a one-size-fits-all method for increasing energy expenditure, and we should be open to the idea that some individuals will experience more or less compensation, depending on the circumstances. Aside from variability that is inherent to the individual (which may correlate with higher fat mass), individuals might experience greater degrees of compensation as they reach fairly high levels of physical activity or achieve fairly low levels of energy availability. So, exercise can absolutely be part of a well-constructed weight loss program (in addition to countless other benefits), but the relative efficiency with which exercise boosts total daily energy expenditure is context-dependent.

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Study Reviewed: Compatibility of Concurrent Aerobic and Strength Training for Skeletal Muscle Size and Function: An Updated Systematic Review and Meta-Analysis. Schumann et al. (2021)

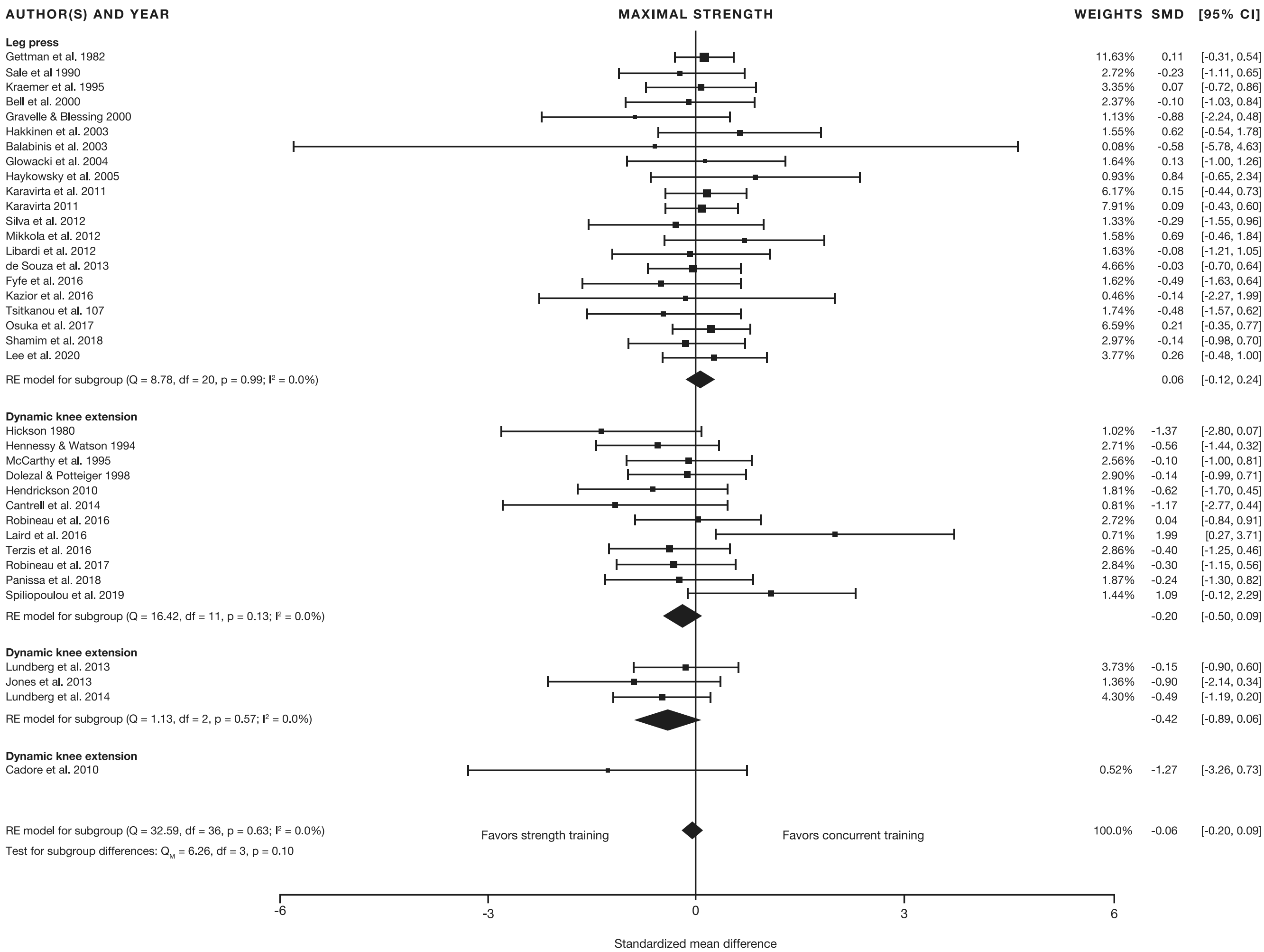
The Interference Effect is Getting Less Scary by the Day

BY GREG NUCKOLS

Long-time readers of MASS will know that concurrent training (performing both resistance and endurance training) is a popular topic around these parts; you can find all of our articles on concurrent training here. With concurrent training, you're always trying to balance and manipulate your strength training and endurance training to mitigate the impact of the dreaded interference effect (a reduction in the rate of strength gains, power/velocity gains, and hypertrophy observed when adding endurance training to a resistance training program). However, the research regarding concurrent training and the interference effect has been shifting over time.

The first study in the area by Hickson in 1980 (2) found that concurrent training led to considerably smaller strength gains than resistance training alone. By 2012, there was enough research to warrant a meta-analysis (3); this meta-analysis suggested that concurrent training led to smaller strength gains, less muscle growth, and smaller improvements in power output and explosive strength than resistance training alone. More recently, a 2021 meta-analysis (reviewed here) broke things down further, separating studies by the training status of the subjects and the timing of the resistance training and endurance training sessions (trained versus untrained subjects, and studies where endurance and resistance training were performed in the same training session versus different training sessions). That meta-analysis suggested that, at least for strength development, there's no significant interference effect for untrained subjects, nor is there any interference effect when trained subjects split their endurance and resistance training into separate training sessions (4). Thus, in the intervening years since 1980, the balance of evidence has shifted considerably – we used to be concerned that the interference effect would have a fairly large, fairly consistent negative effect for virtually anyone who wanted to gain strength and build muscle while also doing some endurance training. Now, it appears that the interference effect should only be a small concern for some people, some of the time (and only in situations where they have to perform their endurance and resistance training in the same session). But will this trend continue?

Figure 1 Forest plot of studies comparing differences in maximal strength



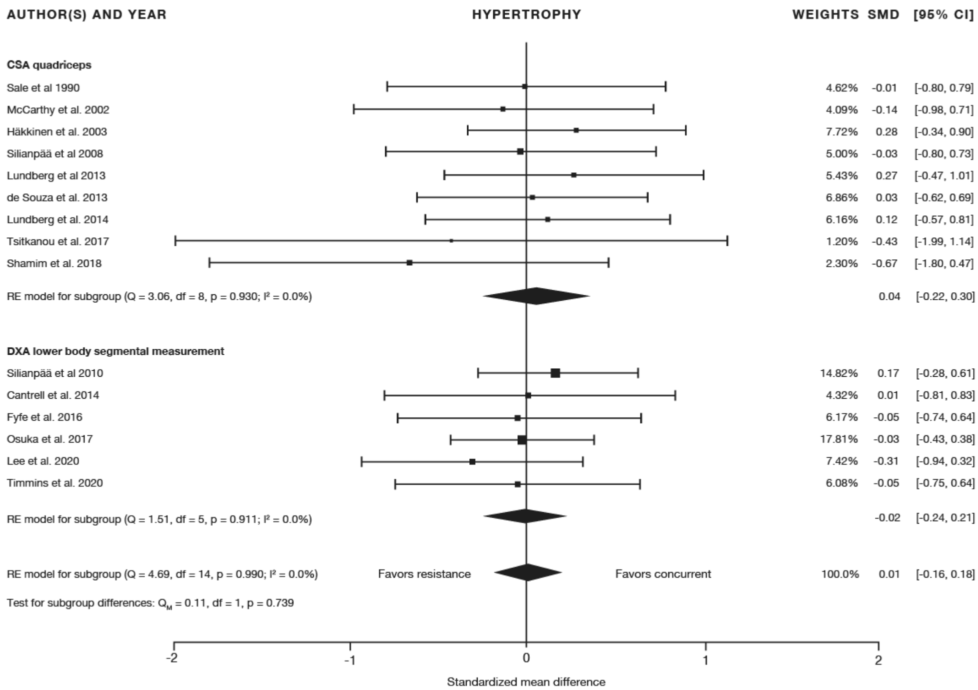
CI = confidence interval; RE = random effects; SMD = standardized mean difference.

Well, if you're a fan of concurrent training, a brand new meta-analysis should give you even less reason to be concerned about the interference effect (1). Schumann and colleagues started by identifying all of the studies that met the following inclusion criteria:

1. The studies needed to include a training intervention lasting at least four weeks.
2. The studies needed to include groups completing identical resistance training programs, with one group performing only resistance training, and at least one group performing additional aerobic training.
3. The studies needed to include measures of maximal strength, explosive strength, and/or muscle hypertrophy.
4. The exercises used to assess performance needed to be specific to the resistance training the subjects performed.

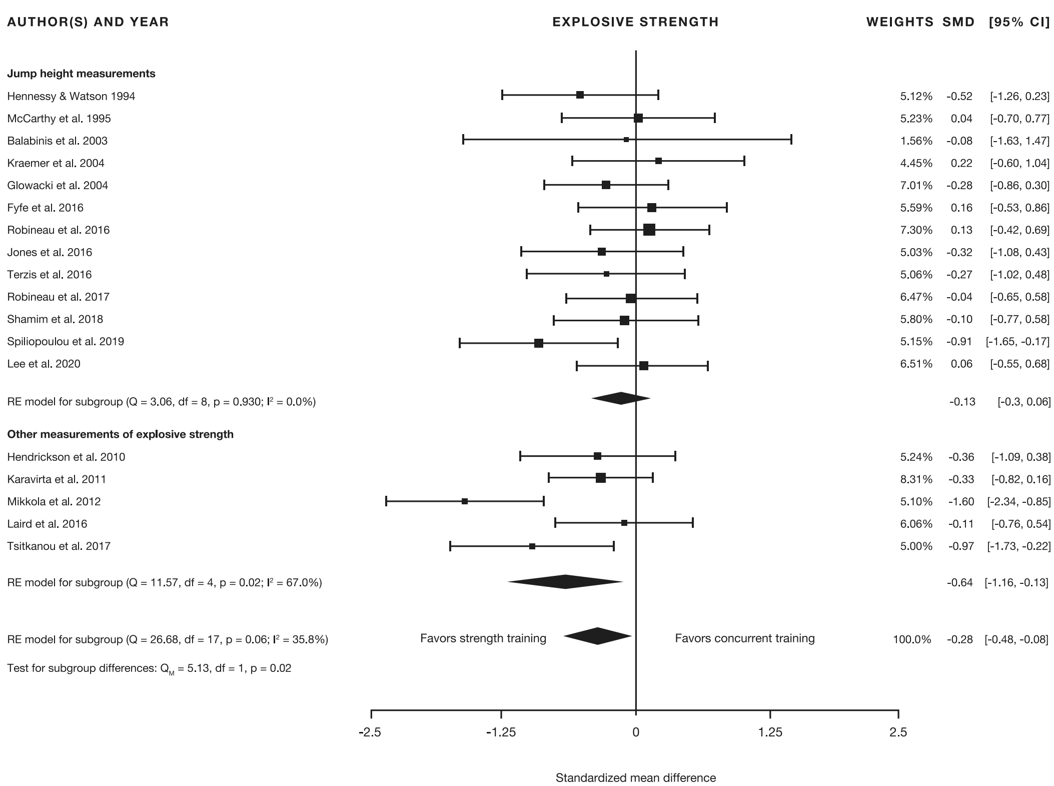
The researchers identified 43 studies with a total of 1,090 subjects that met their inclu-

Figure 2 Forest plot of studies comparing differences in hypertrophy



CI = confidence interval; RE = random effects; SMD = standardized mean difference; DXA = dual-energy X-ray absorptiometry.

Figure 3 Forest plot of studies comparing differences in explosive strength



CI = confidence interval; RE = random effects; SMD = standardized mean difference.

sion criteria, including 37 studies measuring maximal strength, 18 studies measuring explosive strength, and 15 studies assessing hypertrophy.

They found that concurrent training did not lead to significantly smaller strength gains than resistance training alone (Figure 1; Standardized Mean Difference [SMD] = -0.06; p = 0.45), nor did it lead to significantly less hypertrophy (Figure 3; SMD = -0.01; p = 0.92). However, concurrent training did lead to significantly smaller improvements in explosive strength than resistance training alone (Figure 3; SMD = -0.28; p = 0.007).

The researchers also performed a series of subanalyses that can be found here. For strength, they found that the modality of endurance training (running versus cycling), the weekly frequency of endurance training, the training status of the subjects ("active" versus untrained; they didn't run a subgroup analysis on specifically resistance-trained subjects), the age of the subjects (18-40 years old versus >40 years old), and the timing of resistance and endurance training sessions (performing both in the same training session versus different sessions) all failed to significantly modify the effect. Of note, however, the researchers didn't run a subanalysis investigating the impact of total endurance training duration. For hypertrophy, it's a similar story: endurance training frequency, training status, and the timing of resistance and endurance training sessions all failed to significantly modify the effect. In other words, this meta-analysis suggests that the interference effect doesn't really exist in any generalizable sense for strength and hypertrophy outcomes – it's only "real" and noteworthy for measures of power output and explosive strength.

Overall, this meta-analysis doesn't necessarily affect my recommendations regarding concurrent training to any large extent, but I do think it recontextualizes this body of research. Previously, the default assumption was that the interference effect generally mattered quite a bit, and that it was the goal of a coach to find the exact right mix of training variables to mitigate the interference effect to the greatest extent possible. However, I think the overall balance of evidence now suggests that the interference effect isn't *that* big of a deal, and you probably don't need to be *that* concerned about it most of the time.

To be clear, I don't necessarily endorse the position that would be implied by a literal and expansive interpretation of this study's findings: I absolutely think that if your endurance training volume, frequency, and/or intensity is high enough, it can have a negative impact on your muscle growth and strength development. It's always important to keep context in mind when research findings seem to contradict common sense. Most concurrent training studies don't involve resistance training protocols that push subjects to their absolute limits in an effort to maximize rates of hypertrophy and strength gains, nor do they put subjects through an endurance training protocol that might be typical of a runner attempting to qualify for the Boston marathon. Your capacity to recover from training is finite, so the introduction of a non-trivial amount of endurance training will necessitate some level of resistance training volume below the maximal amount you could theoretically tolerate (and possibly/probably below the amount of training volume that would theoretically maximize your rate of muscle growth and/or strength gains). However, I also think that, in general, "we" (referring to myself and the "evidence-based" fitness community in general) may have previously been a bit too concerned about the interference effect.

As more and more research on the subject is published, I'm becoming more and more convinced that the interference effect shouldn't be a major concern for most people, most of the time. However, there are a few groups of people who probably need to be a bit more careful:

1. If your capacity to recover from training is significantly diminished (due to poor sleep, high levels of psychogenic stress, or a large calorie deficit), you may not be able to handle a substantial amount of simultaneous endurance and resistance training.
2. If you're already stressing your capacity to recover from a given volume of endurance training, you may struggle to add in a significant amount of resistance training (and benefit from it).
3. If you're already stressing your capacity to recover from a given volume of resistance training, you should be careful about adding in a large amount of endurance training, or ramping up endurance training volume too quickly.
4. Most importantly, if you have major goals related to explosive strength or power output (for example, improving your jumping ability), endurance training will likely reduce your rate of progress.

Now, I realize that a lot of MASS readers probably fall into the third group above. However, I also suspect that >80% of people who do some sort of endurance or resistance training *can* combine both without compromising their strength and hypertrophy results. And that's really my main point: Rather than framing the interference effect (for strength and hypertrophy) as the likely outcome of concurrent training that is challenging to mitigate, it may be more appropriate to frame it as a relatively uncommon phenomenon that is unlikely to impact training outcomes unless someone is already really pushing their limits (or attempting to push their limits) in multiple capacities at once.

Finally, I'd just like to acknowledge that most of this article has been written with strength and hypertrophy-related goals in mind (since this *is* MASS, after all). However, it's worth reiterating that endurance training *does* seem to consistently and significantly affect explosive performance. So, for example, a powerlifter may not notice any negative effects from jogging a few times per week, but a thrower or high jumper probably would. Or, in the context of team sports, intensive conditioning work could reduce the explosiveness and agility of athletes. If your main goal is to maximize physical capacities related to power output, speed, or explosiveness, it wouldn't be a bad idea to limit endurance training to whatever extent is feasible.

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Study Reviewed: Wrist-Worn Devices for the Measurement of Heart Rate and Energy Expenditure: A Validation Study for the Apple Watch 6, Polar Vantage V and Fitbit Sense. Hajj-Boutros et al. (2021)

Is Everything That's Measured Worth Managing?

BY ERIC TREXLER

You may have heard the old adage, "What gets measured gets managed." This might be used as a justification for the increasingly common desire to utilize wearable technology in order to attain fitness goals. However, you might be surprised to learn that the adage listed above is actually incomplete. The full quote, delivered in the context of business management guidance (although there's disagreement regarding who actually said it first), reads: "What gets measured gets managed – even when it's pointless to measure and manage it, and even if it harms the purpose of the organization to do so." There would of course be considerable advantages conferred from valid, reliable, real-time measurement of energy expenditure data. However, whether or not such tracking is "pointless" or "harms our purpose" comes down to the validity, reliability, and utility of those measurements. If they're terrible, the act of tracking energy expenditure with wearable devices is pointless at best. If we're making significant adjustments guided by erroneous data, it might even harm our purpose.

The presently reviewed study (1) sought to evaluate the accuracy of three wrist-worn devices: the Apple Watch 6, the Polar Vantage V, and the Fitbit Sense. 60 young and healthy individuals (30 males and 30 females; age: 24.9 ± 3.0 years, BMI: 23.1 ± 2.7 kg/m^2) completed five different activities (sitting, walking, running, resistance exercise, and cycling) for ten minutes each while wearing each of the devices. Heart rate and energy expenditure were continuously measured using the Polar H10 chest strap and MetaMax 3B; these were the criterion (reference) measurements to which the wearable devices were compared.

The researchers performed a number of analyses to facilitate device comparison, including Pearson correlations between each device and the criterion measure, standardized typical error of the estimate for each device (a standardized version of "the typical amount by which the estimate is wrong for any given subject"), the coefficient of variation for each device (standard deviation / mean × 100), and Bland-Altman plots for each device (which assess the agreement between devices by plotting the difference between two devices against the

Table 1 Analysis of the accuracy of energy expenditure measurements during various activities

		APPLE WATCH 6	POLAR VANTAGE V	FITBIT SENSE
Sitting	Pearson's r	Impractical	Impractical	Very poor
	Standardized typical error of the estimate	Impractical	Impractical	Very large
	Coefficient of variation	Poor accuracy	Poor accuracy	Poor accuracy
Walking	Pearson's r	Poor	Very poor	Poor
	Standardized typical error of the estimate	Large	Very large	Large
	Coefficient of variation	Poor accuracy	Poor accuracy	Poor accuracy
Running	Pearson's r	Good	Poor	Good
	Standardized typical error of the estimate	Moderate	Large	Moderate
	Coefficient of variation	Poor accuracy	Poor accuracy	Poor accuracy
Resistance exercise	Pearson's r	Poor	Poor	Very poor
	Standardized typical error of the estimate	Large	Large	Very large
	Coefficient of variation	Poor accuracy	Poor accuracy	Poor accuracy
Cycling	Pearson's r	Poor	Very poor	Very poor
	Standardized typical error of the estimate	Large	Very large	Very large
	Coefficient of variation	Poor accuracy	Poor accuracy	Poor accuracy

average value of both). Pearson correlations were interpreted as ≥ 0.995: excellent; 0.95-0.994: very good; 0.85-0.94: good; 0.70- 0.84: poor; 0.45-0.69: very poor; < 0.45: impractical. Standardized typical error of the estimate values were interpreted as >2.0: impractical; 1.0-2.0: very large; 0.6-1.0: large; 0.3-0.6: moderate; 0.1-0.3: small; <0.1: trivial. Coefficients of variation were interpreted as > 10%: poor accuracy; 5-10%: acceptable accuracy; < 5%: high accuracy. So, just to be clear: a high value would be good for a Pearson correlation, but a high value would be bad for a standardized typical error of the estimate or coefficient of variation.

Unfortunately, the researchers found that these wearable devices were pretty disappointing when it comes to estimating energy expenditure. Given all of the different ways they quantified device agreement and different types of errors, we could drown in a sea of numbers here. However, the quantitative interpretation of these numbers isn't particularly intuitive, and I don't want us to miss the forest for the trees. So, I have adapted a table to concisely summarize the energy expenditure results using the authors' own categorized criteria for interpreting the values (Table 1).

As can be seen in Table 1, all three devices did quite poorly when aiming to estimate energy expenditure during various types of activity. The researchers also constructed a number of Bland-Altman plots; it would be a bit excessive to include them all here, so I will summarize them. It was fairly common to see mean bias values relatively far from zero (indicating that there is general disagreement between methods, on average), very wide limits of agreement (reflecting high variability in the magnitude of disagreement), some very big outliers (suggesting that estimates were very, very bad for some specific individuals), and some instances of proportional bias (indicating that disagreement systematically differed among people with lower-than-average energy expenditure and people with higher-than-average energy expenditure). In short, the estimates were pretty bad, but not in a way that would be easily predictable. If a device consistently overestimates everyone's energy expenditure by 100kcal/day, it's technically wrong, but still quite useful. However, when you're looking at large errors with a great deal of variability and some fairly substantial outliers, it's hard for an individual user to confidently act upon the estimate they receive.

I assume that many people view their energy expenditure estimates from wearable technologies as somewhat imperfect estimates that should be interpreted with some degree of caution, but these data reflect much more than a functionally negligible rounding error or a consistent magnitude and direction of error that can be easily adjusted for. As such, the researchers stated: "Collectively, based on these findings, we would suggest that evaluating energy expenditure using these 3 wrist-worn devices does not provide an acceptable surrogate method for the estimation of energy expenditure in research studies." Based on the data, it's hard to argue with them, and they're certainly not the first group to reach this type of conclusion – previous systematic reviews by Fuller et al (2) and Evenson et al (3) concluded that commercially available wearable devices estimated energy expenditure with insufficient validity.

Having said that, all is not lost. I know Dr. Helms gets upset when we mention any type of exercise that is not lifting, but there are plenty of folks who do various types of endurance exercise and find heart rate data to be quite helpful. The presently reviewed study found that the Apple Watch 6 did a pretty good job of tracking heart rate, whereas the heart rate accuracy of the other two devices varied depending on the type of activity being performed. So, if you were interested in using a wearable device to track your heart rate during endurance exercise (or incorporate heart rate-based exercise prescriptions), the Apple Watch 6 would probably get the job done. In line with this finding, previous systematic reviews by Fuller et al (2) and Evenson et al (3) have reported that certain wearable devices (but not all) are pretty effective for heart rate tracking.

In addition, we have previously discussed the many benefits of striving for higher daily step counts, and these systematic reviews also reported that certain wearable devices do a pretty nice job tracking step counts (2, 3). So, getting back to the old adage at the beginning of this research brief: the point is not that wearable devices are "pointless," but they may "harm our purpose" if we place too much confidence in their energy expenditure estimates. If you're altering your calorie intake in direct response to estimates from a wearable device with questionable validity, you might be chasing an inaccurate number that could be leading you astray. The available research suggests that many wearable devices tend to do a pretty poor job of estimating energy expenditure and sleep metrics (3), but some may be pretty valid when it comes to measuring heart rate and step counts. I say "may" because the relative validity and reliability of each specific device must be assessed independently, with some models performing substantially better than others (2).

Rather than using a wearable device to obtain an estimate of your daily energy expenditure, you might be better off with an approach that focuses on patiently and consistently observing your daily energy intake and fluctuations in body weight. Body mass changes reflect changes in the total metabolizable energy content of the body, which draws a direct mathematical link between body composition and energy balance. As I previously wrote elsewhere, "All you need to do is accurately track your body weight every morning and your daily energy intake, and you can identify the calorie target required to meet your goal. If you're trying to maintain body weight, then you're trying to find the calorie target that keeps your weight stable." Of course, if you're trying to achieve a particular rate of weight gain or weight loss, the same principle applies.

The primary downside to this approach is that changes in sodium intake, carbohydrate intake, hydration status, and the bulk of food in our gastrointestinal tract can cause some day-to-day fluctuations in body weight that can make it hard to determine which weight fluctuations are "signal" and which are "noise." You could keep yourself very busy developing spreadsheets or algorithms that use different smoothing, weighting, and adjustment techniques to sort out this variability and tighten up your estimates (see here), but the level of precision you wish to pursue is all up to you.

When writing about scientific topics, my general aim is to share robust conclusions that are likely to stand the test of time, with no bias related to "wanting" any specific outcome. However, this particular topic is an exception – I hope (and expect) that wearable devices will eventually get better at energy expenditure estimation, so studies describing their current estimation errors are sure to be outdated in the near future. It remains to be seen if these devices will become valid and reliable enough to independently inform dietary intake (in the absence of additional adjustments or algorithmic inputs). For now, the commercially available wearables that have been tested in the peer reviewed literature come up short. Wearables can be great for measuring and tracking other physiological metrics (such as heart rate and step counts), but patient and consistent tracking of changes in energy intake and body composition is currently our best option for making inferences about energy expenditure and energy balance.

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Study Reviewed: Myofibril and Mitochondrial Area Changes in Type I and II Fibers Following 10 Weeks of Resistance Training in Previously Untrained Men. Ruple et al. (2021)

An Update on Sarcoplasmic Hypertrophy

BY GREG NUCKOLS

Sarcoplasmic hypertrophy is an interesting topic where the perspective of the "evidence-based" fitness community largely seems to stand in opposition to the actual evidence on the topic. I still commonly see people argue that sarcoplasmic hypertrophy is just a broscience myth, when the actual evidence supporting the existence of sarcoplasmic hypertrophy is fairly strong and consistent, dating back at least 50 years (as I documented in my last MASS article on the topic, and in an older Stronger By Science article).

Just to rewind a bit, it's worth first operationally defining sarcoplasmic hypertrophy. When muscle fibers increase in size, that's referred to as hypertrophy. Muscle fibers are filled with structures called myofibrils (which contain contractile proteins), and the myofibrils are surrounded by "other stuff." That "other stuff" (intracellular fluid, organelles, etc.) is referred to as sarcoplasm. When fibers undergo hypertrophy, the absolute volume of the myofibrils increases (due to increases in size, number, or both), as does the absolute volume of sarcoplasm. When the myofibril-to-sarcoplasm ratio remains constant or increases, that's referred to as myofibrillar hypertrophy; when the myofibril-to-sarcoplasm ratio decreases (i.e., sarcoplasmic volume increases to a relatively greater degree than myofibrillar volume), that's referred to as sarcoplasmic hypertrophy.

In this research brief, I'm not interested in relitigating the existence of sarcoplasmic hypertrophy; rather, my primary aim is to illustrate the range of myofibrillar and sarcoplasmic hypertrophy responses to training.

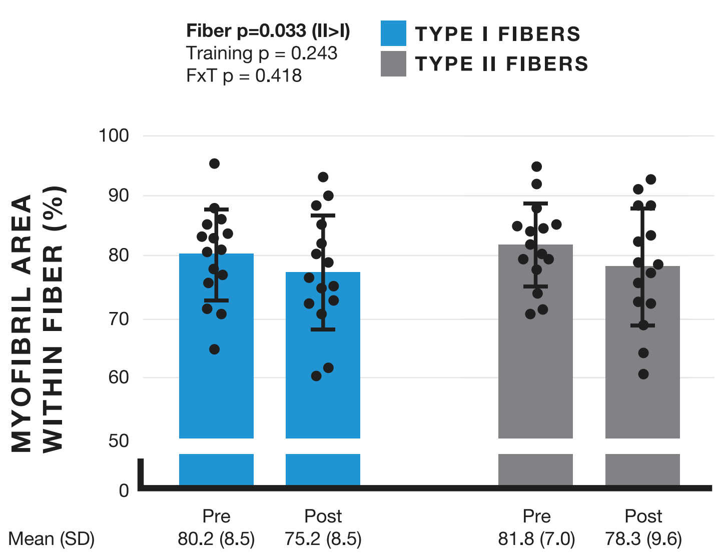
In a recent study by Ruple and colleagues (1), 15 untrained men completed ten weeks of moderate-rep (sets of 6-10 reps) full-body resistance training. Before and after the training intervention, researchers took biopsies of the subjects' vastus laterales to assess a variety of outcomes. For our purposes, the three most important outcomes were 1) changes in fiber cross-sectional area, 2) changes in the area of each cross-section composed of myofibrils, and 3) changes in the area of each cross-section composed of mitochondria.

The top-line findings were pretty straightforward: significant fiber hypertrophy occurred (26.5 ± 32.0% increase; p = 0.013), significant increases in mitochondrial area occurred (from 6% to 8% of intracellular space in type I fibers, and from 5% to 6% of intracellular space in type II fibers), and *significant* reductions in myofibrillar density *did not* occur (there was an average reduction of about 5%, but it wasn't statistically significant), suggesting that sarcoplasmic hypertrophy didn't occur *on average*.

However, those primary findings weren't the interesting part of this study to me. I was most interested in a series of scatterplots showing the relationship between changes in fiber cross-sectional area and myofibrillar density, and the relationship between changes in fiber cross-sectional area and changes in mitochondrial area. These scatter plots don't just show the relationships between these outcomes – they also illustrate the range of individual responses. If you know me, you know I'm a sucker for illustrations of interindividual variability.

Starting with myofibrillar density, individual subject responses spanned the range from ~20% decreases to ~20% increases, and these changes weren't associated with overall increases in fiber cross-sectional areas. In other words, some subjects experienced considerable sarcoplasmic hypertrophy, and some subjects experienced substantial myofibrillar packing (increases in myofibrillar density), even when exposed to the same training stimulus. Individual changes in mitochondrial area also varied considerably, ranging from decreases of ~4% to increases of ~9%. More interestingly, changes in mitochondrial area were moderately *negatively* associated with changes in fiber cross-sectional areas (the difference wasn't statistically significant for type I or type II fibers, but it was significant for all fibers). In other words, subjects that experienced larger increases in mitochondrial area also experienced less fiber hypertrophy, on average.

Figure 1 Type I and Type II fiber myofibril areas with training



This figure shows how training affected myofibril areas. Bar graph data are presented as means ± standard deviation values, and individual participant data are overlaid. n=15 participants; FxT = fiber x training interaction.

Figure 2 Relationships between changes in fiber cross-sectional area (fCSA) versus changes in myofibril area

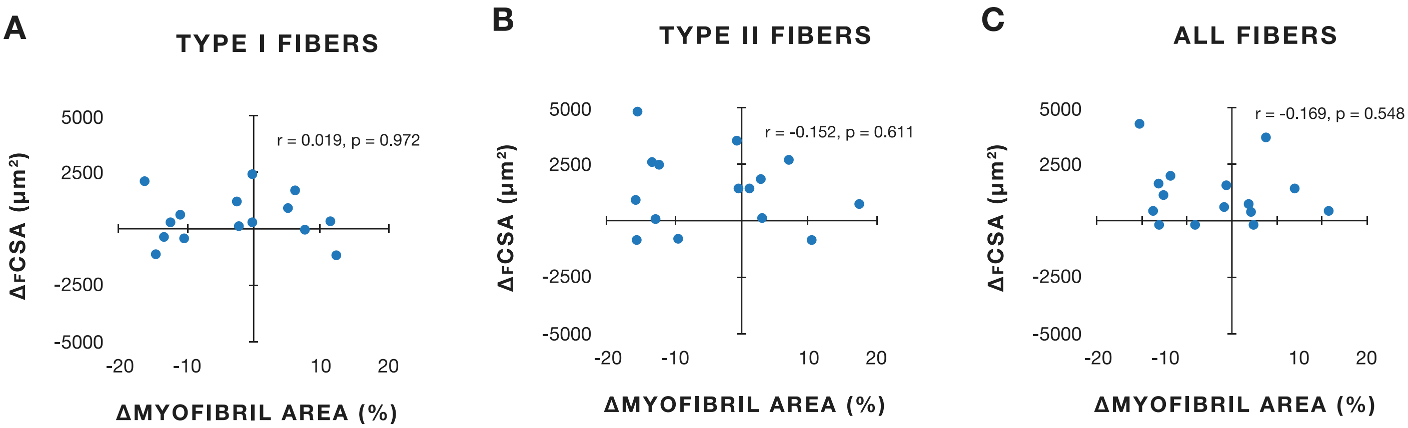
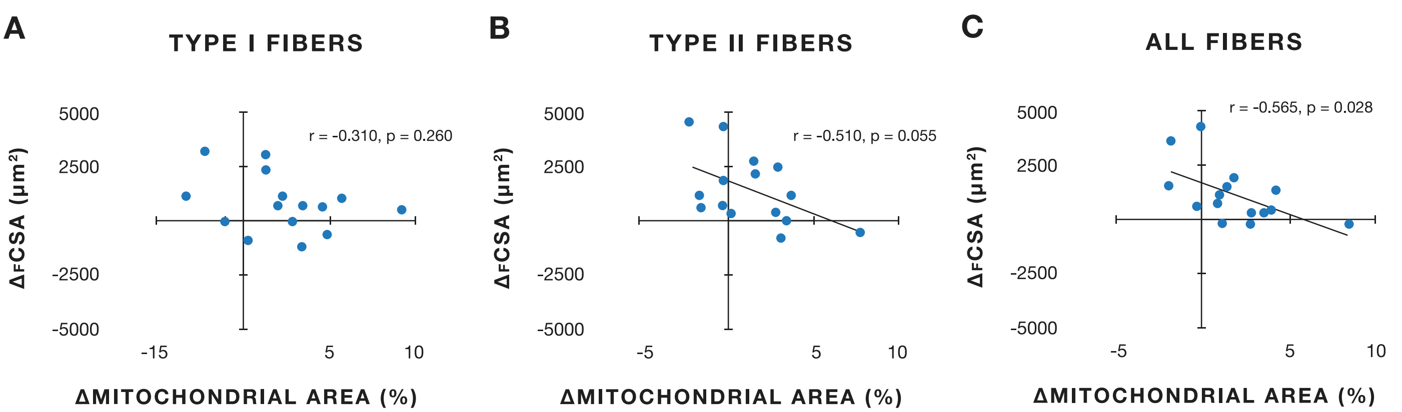


Figure 3 Relationships between changes in fiber cross-sectional area (fCSA) versus changes in mitochondrial area



I found the interindividual variability in myofibrillar density changes quite interesting. I'm not sure what can actually be done with that information, but it's a good thing to be aware of: when exposed to the same stimulus, some people may experience considerable myofibrillar packing, while other people experience considerable sarcoplasmic hypertrophy in a manner that's independent of the total amount of hypertrophy that occurs (though, it should be noted that *some* degree of the variability is probably just the result of noise in the measurements). That suggests we have a *lot* more to learn about what factors influence these responses, and whether these responses can be manipulated with specific training or nutrition interventions on an individual level.

I was also very intrigued by the inverse association between fiber hypertrophy and changes in mitochondrial area. One of my pet theories is that local muscular metabolic capacity influences hypertrophy (since this is a research brief, I can't go into all of the reasons here, but

I discuss it a bit in this podcast episode), and the mitochondrial findings in the present study *may* support that theory. Since the subjects who experienced the most hypertrophy also experienced the smallest increases (or even small decreases) in mitochondrial area, that might suggest that their muscles were "ready to grow," whereas the larger increases in mitochondrial area in subjects who experienced less hypertrophy may suggest that their muscle fibers needed to prepare themselves for the increased metabolic burden of both muscle growth and maintaining larger fiber sizes.

Ultimately, there aren't any obvious practical takeaways from this study for athletes or coaches. However, I think that simply learning more about muscle physiology and inter-individual variability can be its own benefit.

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Study Reviewed: Altered Brown Fat Thermoregulation and Enhanced Cold-Induced Thermogenesis in Young, Healthy, Winter-Swimming Men. Søberg et al. (2021)

Cold Exposure For Fat Loss: Physiology Can Be "Cool" Without Being Useful

BY ERIC TREXLER

You're currently reading MASS Research Review, so I assume we can generally agree that science is pretty cool. A positive aspect of this perspective is that we can embrace rigorous scientific principles and use them to optimize our habits and practices related to training, nutrition, and other health behaviors. There is, however, a potential drawback of this perspective. If we get a little too enthusiastic about how cool science is, we can sometimes get too enamored with fascinating aspects of human physiology. If we aren't careful, we can get sucked into overhyped concepts that encourage us to put the cart before the horse (i.e., apply an intriguing intervention before we have evidence to suggest that it's actually applicable). Not everything that is fascinating is actionable, and not everything that is actionable is fascinating.

That brings us to the concept of cold exposure. I'm not talking about cold water immersion to reduce inflammation following exercise or acute tissue injury, but simply exposing your body to cold conditions (usually in the form of water immersion, since water facilitates heat transfer so efficiently) to obtain a long list of other extremely speculative benefits. One of the purported outcomes most frequently discussed is increased energy expenditure and fat oxidation, which has caused some fairly notable figures to suggest that frequent cold exposure is an effective way to facilitate fat loss.

The idea is that cold exposure will acutely increase sympathetic nervous system activity, shivering, and brown adipose tissue activation. Sympathetic nervous system activation induces a neuroendocrine response that increases energy expenditure and fat oxidation, and shivering increases energy expenditure via increased muscle activity. You may be less familiar with brown adipose tissue because, until fairly recently, the prevailing belief was that adult humans typically had a negligible amount of this tissue. However, research over the last 10-20 years has indicated that adult humans do have clusters of brown adipose tissue, and that this tissue is stimulated by cold exposure (2). Upon stimulation, brown adipose cells (which are rich in mitochondria) ramp up their metabolic rate for the purpose of generating heat. So, energy expen-

Table 1 Subject characterization

SUBJECT CHARACTERIZATION	WINTER SWIMMERS (N=7)	CONTROL GROUP (N=8)	P
Age (years)	25 (2.5)	23.6 (2.0)	0.25
Weight (kg)	76.7	78.9	0.55
Physical training/week (h)	7	6	0.32
Bodyfat (%)	12.0 (4.6)	18.2 (4.3)	0.01
BMI (kg/m^2)	23.7 (4.8)	23.3 (1.8)	0.87
Resting energy expenditure thermal comfort state (kcal/24h)	2038 (96.0)	2005 (209.6)	0.69
Resting energy expenditure during 30min cooling (kcal/24h)	3044 (337.2)	2560 (348.1)	0.01

Data are presented as mean (standard deviation)

diture and fat oxidation are acutely increased due to these impacts on the sympathetic nervous system, shivering, and brown adipose tissue activation, but chronic effects are also likely. For example, there is some evidence that individuals who spend a lot of time in cold environments have upregulated brown adipose tissue activity, and that some of their white adipose tissue (i.e., "normal" subcutaneous fat) starts looking and behaving more like brown adipose tissue. This semi-converted fat is often referred to as "beige" adipose tissue, and the potential to intentionally induce this conversion has spurred interest in studying chronic cold exposure.

That's where the presently reviewed study (1) comes into play. Briefly, the researchers were interested in comparing a huge list of physiological characteristics and responses in "winter-swimming men" and a control group matched based on age, gender, BMI, and physical activity level. Two to three times per week, participants engaged in a form of winter swimming that involved a combination of brief immersion in very cold water and hot sauna bathing, which appears to be popular in some Scandinavian countries. The researchers measured a ton of different outcomes, but the most relevant (for our purposes) relate to energy expenditure and brown fat activity. In short, the researchers measured resting energy expenditure in a thermal comfort state (comfortable ambient temperature) and during a 30-minute cooling condition (which aimed to keep participants just slightly above the shivering threshold).

In the interest of staying true to the "brief" aspect of the research briefs section, I'll skip right to the point. As shown in Table 1, the group of winter swimmers was significantly leaner than controls (12.0 versus 18.2% body-fat), had similar resting energy expenditure in thermal comfort (2,038 versus 2,005 kcal/day), but had significantly higher resting energy expenditure during cold exposure (3,044 versus 2,560 kcal/day).

It seems that a recent resurgence of interest in cold-water immersion for fat loss purposes has been fueled, to a large extent, by a prominent podcast that sometimes covers fitness-related topics. In the linked episode, the presenter suggests that cold water immersion is a viable fat loss tool, but that you should be mindful not to adapt to it because of anecdotes involving cold-water swimmers with high body-fat levels. This anecdotal evidence was perceived to indicate that adapting to cold-water immersion would diminish the effects related to energy expenditure and fat loss. The presently reviewed study directly contradicts these recommendations; winter swimmers tended to be leaner than well-matched controls, and had more robust thermogenic responses to cold exposure.

More importantly, I'd like to focus on the most practical aspect of this topic: whether or not cold exposure is a viable fat loss target. The presently reviewed study reported cold-induced increases in energy expenditure of nearly 50% (relative to thermoneutral energy expenditure), but this is far from the norm. Other studies often report values around the 15% range (2, 3), with a high degree of variability from person to person. In addition, it's critical to recognize that this is the elevation observed during cold exposure; if you increase your resting metabolic rate by 250 kcal/day, but you only engage in one hour of cold exposure, you're talking about an absolute increase of less than 11kcal (in other words, an entirely negligible amount). You could argue that this magnitude underestimates the true value of cold water immersion, because these studies use temperatures just above the shivering threshold, which is intended to exclusively quantify the impact of brown adipose tissue activity in the absence of shivering-induced energy expenditure. However, this implies that in order for the intervention to have any hope of producing a meaningful effect, it must be applied in a manner that is impractical and tremendously uncomfortable.

My skepticism is comprehensively echoed in a recent review paper by Marlatt and colleagues (4). The highlights of their paper include the observations that "studies in humans do not support the hypothesis that induction and activation of [brown adipose tissue] may be an effective strategy for body weight control," cold-induced increases in energy expenditure likely lead to compensatory increases in appetite, and there is no evidence of seasonal body composition changes that would link colder conditions to reductions in body weight or fat mass. In short, there is little reason to believe that any practical and tolerable implementation of cold exposure will lead to meaningful body composition changes. In addition, unaccustomed cold water exposure can lead to severe adverse cardiovascular complications, so these types of interventions should be approached with extreme caution. We must always be skeptical of "sciency" interventions that are driven by mechanisms, anecdote, or intuition. Learning about science is always encouraged, but remember: not everything that is fascinating is actionable, and not everything that is actionable is fascinating. We've got plenty of boring strategies to effectively support body composition goals; physiological responses to acute and chronic cold exposure are really cool, but their relevance to fat loss is dubious at best.

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