Repetition Tempo, Time Under Tension, and Metabolic Stress

I. Introduction

What is metabolic stress?

Simply, repeated muscular contractions and increased energy turnover during intense exercise result in the accruing of several anaerobic metabolites, such as adenosine, ammonia, inorganic phosphates, hydrogen, and lactate (Gorastiaga et al., 2014). Although some of these metabolites contribute to feelings of discomfort (e.g., hydrogen) and others may participate in muscular fatigue (e.g., ammonia and inorganic phosphate), they may also play a role in adaptations to resistance training (RT) (Tanimoto & Ishii, 2006). Specifically, whether they upregulate the molecular pathway that stimulates muscle protein synthesis directly or simply help recruit higher threshold motor units (Dankel et al., 2017). Pertaining to peripheral adaptations that are typically characteristic of aerobic exercise, such as increased capillary and mitochondrial density, others have argued that lower-external load, higher-repetition RT can mimic aerobic exercise by stimulating the muscle cell with high metabolic stress (Parry et al., 2020). Regardless of the specific effect or mechanism, it is important for fitness professionals to understand what RT training variables influence metabolic stress during a training session.

What is time under tension?

Of all RT variables that influence metabolic stress during RT, time under tension (TUT) may be the most important. As evidence for this statement, the literature consistently demonstrates that metabolic stress, which is typically measured as blood lactate, increases directly with the TUT of a set of exercise (da Silva, 2017; Rogatzki et al., 2014; Tanimoto & Ishii, 2006). To use a simple definition, TUT is the duration of one set of exercise which generally reflects how much time the muscle group was under load or exerting force during that specific set of exercise. Mathematically, TUT can be quantified as the product of repetitions completed x duration of each individual repetitions (i.e., tempo), which means that repetition volume and speed both influence TUT. From a broader perspective, assuming that repetition tempo is constant between conditions (e.g., lower the weight for 2 sec, raise the weight for 1 sec), higher-TUT training is associated with lower-external loads while lower-TUT training is associated with higher-external loads. Although some exceptions exist, the bulk of research in this area consistently suggests that higher-TUT training is better for muscular endurance while lower-TUT training is better for muscular strength (Kubo et al., 2021; Schoenfeld et al., 2015). Both are effective for skeletal muscle hypertrophy (Schoenfeld et al., 2021).

What is repetition tempo?

As mentioned above, repetition tempo, which is generally defined as the duration of one repetition during a set of RT, also plays a role in TUT. This variable basically describes if the lifter is moving fast or slow during a repetition and is often broken down into eccentric and concentric phases (Schoenfeld et al., 2015). For example, a traditional "lower for 2 sec, raise for 1 sec" repetition would be denoted as a 2:1 sec tempo while a slower "lower for 4 sec, raise for 2 sec" repetition would be listed as a 4:2 sec tempo. If an isometric is used in the middle of a repetition, such as holding the bottom of a squat or push up for an extended period of time, this should be accounted for in the repetition tempo as well (Wilk et al., 2021). For instance, if a lifter lowers into a squat for 2 sec, pauses at the bottom for 2 sec, and stands up from the squat for 2 sec, this would be defined as a 2:2:2 sec tempo. To keep matters simple, we will only discuss repetition tempos with eccentric and concentric phases today. Below are several examples of how repetition volume and tempo can be manipulated to effect TUT:

Keep repetition tempo (2:1 sec) constant but decrease external load in order to perform more repetitions per set:

4 reps x 2:1 sec = 12 sec of TUT

8 reps x 2:1 sec = 24 sec of TUT

12 reps x 2:1 sec = 36 sec of TUT

Keep TUT constant (60 sec) while changing repetition volume and tempo, which may result in slight variations in external load (the research in this area is very limited):

20 reps x 2:1 sec = 60 sec of TUT

10 reps x 4:2 sec = 60 sec of TUT

6 reps x 6:4 sec = 60 sec of TUT

Keep repetition volume constant (6 reps) while changing repetition tempo and TUT, which will likely result in decreasing external loads to allow for slower reps and higher TUT.

6 reps x 2:1 sec = 18 sec of TUT

6 reps x 4:2 sec = 36 sec of TUT

6 reps x 6:4 sec = 60 sec of TUT

Are Slower-Repetition Tempos a Magic Bullet?

There is a consistent trend in the literature for slower-repetition tempos to result in greater metabolic stress, local tissue hypoxia, energy expenditure, and "anabolic hormone" concentrations (Barreto et al., 2010; Martins-Costa et al., 2016; Tanimoto et al., 2008; Wilk et al., 2021). Because of this, it is common for fitness professionals and personal trainers to over-emphasize this style of training for clients who are looking to build muscle, burn fat, and ultimately improve their body composition. Although this style of training is effective, its supposed superiority over faster repetition-training is misleading because of two major confounding issues in the aforementioned studies: TUT and effort were typically not matched. Consider the following example to understand why this is an issue:

Condition A (Slow): 3 sets, 10 reps, 4:2 sec, 25 pound dumbbell

Condition B (Fast): 3 sets, 10 reps, 2:1 sec, 25 pound dumbbell

The lifter is performing 2X the TUT during Condition A and is likely closer to muscular failure when compared to Condition B because external load is matched. Of course, all measures of physiological stress will be greater during Condition A, but it is unclear if the increased stress is caused by the repetition speed, effort of exertion, or total TUT.

In fact, when researchers have matched effort (e.g., lift to failure) and TUT (e.g., 60 sec for both conditions), opposite results have been reported, as metabolic stress and muscular activation are significantly greater during faster repetition training (Lacerda et al., 2016; Vargas-Molina et al., 2020). Hence, the purpose of the present study was to expand upon the research by Lacerda et al. (2016) and Vargas-Molina et al. (2020) by measuring the effect of repetition tempo on muscle oxygenation, metabolic stress, and cardiovascular stress with TUT and effort matched during sets of a lower-body exercise.

II. Methods

Subjects: We recruited 11 resistance-trained females (n = 5) and males (n = 6) who had performed lower-body RT 2 days/week for at least 12 months before enrolling in the study. More specifically, we used a pre-participation questionnaire to verify that they were currently using some type of squat pattern on their lower-body training days, were accustomed to performing 4-6 sets of that specific exercise, were familiar with training close to muscular failure, and were currently not using slow-tempo training.

Study Design: This was a repeated-measures study where subjects served as their own control and performed both experimental conditions in a randomized order. They visited our lab four times: paper work and baseline testing (visit 1), familiarization and confirmation of muscular strength (visit 2), and RT with slow- or traditional- repetition tempos (visits 3 and 4). The latter visits were most important to the experiment and will be detailed below.

Exercise Protocols: Before outlining the differences between protocols, I will explain what they had in common. Regardless of repetition tempo, both protocols involved 5 sets of belt squat, 60 seconds of TUT per set, 3 minutes of rest between each set, and ratings of perceived exertion (RPE) were capped at 8-10, which was the same thing as the subjects estimating that they were 0-2 repetitions shy of muscular failure. During the slow-tempo day (SLOW), the subjects performed 10 repetitions while using a 4:2 sec tempo. For the traditional-tempo day (TRAD), the subjects completed 20 repetitions while using a 2:1 sec tempo.

Outcome Measurements: Several dependent variables were measured during this study.

External load: How much weight was used during each set

Total volume load (TVL): The product of sets x reps x external load

Impulse (IMP): The product of sets x reps x external load x tempo

RPE: Perception of effort on a scale of 1-10

Blood lactate: Measured pre-, post-, and 10-min-post exercise

Muscle oxygenation: Minimum value achieved and delta values (max – min)

Heart rate (HR): average for the session + min and max for each individual set

III. Results + Discussion

External load: Our results showed that subjects used slightly heavier loads during the SLOW condition (53 vs. 49% 1-RM). This is probably explained by the force-velocity curve in which lifters can express more force when slower contractions are performed. Regardless, we need to be pragmatic when applying this result, because it is unlikely that such a slight difference in external load would result in divergent fitness outcomes over the course of time.

Training volume: When calculated as TVL (see above), training volume was much higher during TRAD because repetition volume was 2X as high (20 vs. 10 reps). When calculated as IMP (see above), training volume was slightly higher during SLOW because repetition tempo was 2X as long. It is not clear if RT programs with different IMP would lead to different fitness outcomes, but it is likely more accurate to include repetition tempo when comparing training volume between programs with different tempos.

RPE: Despite lifters performing sets close to muscular failure, they ranked their effort to be slightly higher during TRAD compared to SLOW (9.2 vs. 8.8). Considering the nature of the measurement, the significant difference between these numbers is likely a rounding error, and our research team is confident in saying that both protocols resulted in an RPE of ~9.

HR: Whether it was expressed as a session average, max-HR during a set, and min-HR immediately before a set, TRAD was significantly higher than SLOW. Although it was not measured, subjects were noticeably breathing harder during TRAD, and were much more out of breath after these sets. The differences in HR are likely explained by repetition volume (20 vs. 10 reps) and faster repetition tempos (3 vs. 6 sec).

Blood lactate: SLOW and TRAD elicited high peak values for lactate (~8 mmol/L) but average lactate accrued was significantly greater during TRAD, which supports findings from previous research. Because blood lactate is directly related to mechanical work performed during sessions of RT, the difference between TRAD and SLOW is likely explained by the difference in repetition volume (20 vs. 10 reps). In other words, mechanical work was 2X higher during the TRAD protocol (imagine walking up-and-down the stairs 20 times instead of 10), which led to greater metabolic stress.

Muscle oxygenation: Whether it was expressed as a minimal or delta value, muscle oxygenation was similar between protocols. This finding supports previous research that local muscle hypoxia tends to be greater as TUT increases. Because TUT was matched between protocols (60 sec), it makes sense that muscle oxygenation was similar between them.

IV. Practical Application

Here are the 4 primary take-home messages for the fitness professional:

1. When quantifying your client's training volume while using different repetition tempos, use IMP instead of TVL to provide a more accurate measurement of work performed during each session.

2. If TUT and effort are matched, and external loads are relatively similar, blood lactate will be higher during faster-tempo training, but local hypoxia will be similar regardless of repetition tempo.

3. Considering our results with previous research, it is clear that when TUT and effort are matched, heart rate, oxygen consumption, and energy expenditure are greater when faster tempos are used, which is important information for clients with a weight loss and/or cardiovascular fitness goal.

4. Taken together with previous research, when sets are performed to failure, and TUT is matched, lifters will rank their perception of effort higher during faster-tempo, higher-repetition training. Although we did not quantify it, nearly every subject in our study mentioned that the SLOW condition was less arduous and more enjoyable. An abundance of research now suggest that low-external load, high-repetition training is effective for hypertrophy and strength, but the literature also suggests that this style of lifting results in lower enjoyment and higher perception of pain. With that in mind, using slower tempos with fewer repetitions may serve as a strategy to make low-external load training more tolerable.

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Practical Applications for Tempo

I. Introduction

Two Critical Papers

- ***Schoenfeld, 2015:*** A meta-analysis of 8 randomized-controlled trials (n = 204) concluded that when sets are completed to failure, or close to failure, hypertrophy occurs between 0.5-8 sec. Although few studies were available, the data also indicated that very-slow tempos (> 10 sec) might be inferior for hypertrophy.
- ***Davies, 2017:*** A meta-analysis of 15 randomized-controlled trials (n = 509) concluded that when sets are completed to failure, or close to failure, muscular strength occurs with fast (< 2 sec), moderate (2-4 sec), and slow (> 4 sec) repetition tempos. However, when using moderate external loads (60-79% 1-RM), faster-repetition tempos may be more effective for strength.

Why these studies matter: Slow, moderate, and fast repetition tempos can be used to stimulate hypertrophy and strength for your clients, which means you have a wide array of tempos to choose from.

II. Fast for Strength, Slow for Growth?

Another critical paper by Lyons & Bagley, 2020: In their review, the authors made a strong case for including slower and faster tempos in your client's programming. Below are the two primary points that they made.

1. Moderate-slow repetitions may be most advantageous for hypertrophy-based training.
    - Considering the force-velocity curve, slower-repetition tempos may allow for greater force production, which may stem from increased binding of myosin to actin during muscular contractions.
    - In addition, it is easier for lifters to "feel" the movements when repetitions are slower, which may allow for a better mind-muscle connection. Although much of the evidence for the mind-muscle connection for increasing hypertrophy is anecdotal, recent empirical research has suggested that this may be the case (Schoenfeld, 2018).
2. Faster repetitions may be more advantageous for strength and power.
    - At the other end of the force-velocity curve, lifting lighter loads with high velocity may transfer more to speed and power performance, which could be governed by increased neural adaptations to RT such as increased motor unit recruitment and speed of action potential transmission through the motor units.
    - Also, there is a bevy of research to suggest that for those who have a performance goal, faster repetition tempos are more effective, especially when they are performed during the concentric phase of motion. In other words, controlling the eccentric phase and exploding through the concentric phase may improve athletic (e.g., running speed) and functional (e.g., sit-to-stand test) performance.

The conclusion of this paper was excellent, because the authors indicated that because the range of effective repetitions is so wide, you should allow your client's primary goal (e.g., hypertrophy, strength, or power) to drive your decision, and to vary repetition tempos as a unique form of overload within an RT program.

III. 10 Evidenced-based Repetition Tempos

1. ***Chaves, 2020:*** Subjects were instructed to use a self-selected tempo that resulted in ~1.7 seconds per rep. This led to significant hypertrophy and strength.
2. ***Sampson + Groeller, 2016:*** Subjects were instructed to lower the weight for 2 seconds and then to explode up. This led to significant hypertrophy and strength.
3. ***Schoenfeld, 2015:*** A classic body-builder tempo of 2 seconds down, 1 second up led to significantly hypertrophy as well as upper- and lower-body strength.
4. ***Ramirez-Campillo, 2014:*** Here, the subjects were instructed to lower for 3 seconds, and then to explode up. Strength, power, and functional task performance were all improved after this intervention.
5. ***Chaves, 2020:*** This was a controlled tempo during which subjects lowered for 2 seconds and lifted for 2 seconds. Hypertrophy and strength both significantly improved during this study.
6. ***Kojic, 2021:*** Lowering the weight for 4 seconds and lifting the weight for 1 second led to significantly hypertrophy and strength.
7. ***Keeler, 2001:*** A 6-second tempo that consisted of lowering for 4 seconds and lifting for 2 seconds resulted in massive improvements for muscular strength. Total-body muscle mass did not increase, but we cannot determine if site-specific hypertrophy occurred because advanced measurements, such as ultrasound or MRI, were not used.
8. ***Watanabe, 2013:*** A unique, slow + tonic muscular contraction style during which subjects lowered for 3 seconds, held an isometric for 1 second, and then raised for 3 seconds led to significant hypertrophy and strength. Interestingly, subjects were instructed to not pause between repetitions in order to keep constant muscle tension.
9. ***Neils, 2005:*** A very-slow tempo during which subjects lowered for 5 seconds and raised for 10 seconds had a significant effect on strength while body composition did not change. Same as before, more advanced measurement tools are required to determine if hypertrophy occurred or not.
10. ***Carlson, 2020:*** A very, very slow tempo during which subjects lowered for 10 seconds and raised for 10 seconds resulted in significant improvements for 10-RM and 1-RM for upper- and lower-body lifts. This type of tempo should be reserved for low external load and/or body weight training.

IV. Conclusion and Practical Application

Here are 3 big take-home messages from the literature:

1. Hypertrophy occurs when 0.5-8 second tempos are used.
2. Strength occurs when 1-20 second tempos are used, and faster tempos may be more beneficial when moderate loads are lifted (60-79% 1-RM).
3. Fast/rapid concentric muscular actions are most effective for improving power and athletic performance.

Practical Applications for Tempo

Here are several practical applications to use with your clients:

1. For hypertrophy, use a variety of tempos based on access to equipment, enjoyment, and overload requirements. Keep things simple with 1:1, 2:1, 3:3, and 4:2 second tempos.
2. When strength is your goal, faster tempos should be used with moderate/heavy loads and slower tempos should be used with lighter loads. The latter has a positive effect on strength likely because of improved motor control and stability.
3. Use 2:X and 3:X tempos for those with power and athletic goals. This means that you lower for 2-3 seconds before performing a maximal-effort concentric muscle action.
4. Change tempos daily, weekly, or monthly to provide variety and overload.
5. Use several tempos within the same session. For example, a lower-body day could include rapid-tempo squat jumps, moderate tempo hex-bar dead lift, and slow tempo bodyweight lunges.

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