DOI Link: https://doi.org/10.82044/MN9B7
Vol.78, Issue.12, Part.1, Dec 2025, PP.30-41

FATIGUE-DRIVEN SELECTION OF CONTRACTION MODES: A COMPARATIVE ANALYSIS OF DYNAMIC AND ISOMETRIC CONTRACTIONS ON ACUTE FORCE PRODUCTION

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Received Feb 2025 Accepted Nov 2025 Published Dec 2025

ABSTRACT
Isotonic and isometric contractions, inherent to Resistance Training, have different magnitudes and patterns. The acute effects produced by performing each one are distinct and also impacts on performance. This study aimed to analyze the impact and variability of kinetic parameters between isotonic and isometric contractions performed until fatigue during leg extension exercise at different angular velocities. Seventeen participants performed 3 trials of evaluation in which the force production patterns were assessed: i) force production patterns were assessed without fatigue; ii) induced fatigue via isotonic contractions (F-CE) and iii) induced fatigue via isometric contractions (F-ISO). Significant torque differences were noted at 180º/s ($p = 0.034$) between baseline (98.2 ± 21.4N-m) and F-CE (86.2 ± 18.9N-m) and at 60º/s ($p < .001$) between baseline (130.0 ± 31.1N-m) and F-CE (121.0 ± 23.9N-m). Power declined significantly ($p < .001$) from baseline (242.0 ± 83.2W) to F-ISO (200.0 ± 67.0W). Work differences at 180º/s showed baseline (110.0 ± 23.1J) reductions for F-CE (94.6 ± 18.5J, $p = 0.035$) and F-ISO (100.0 ± 19.2J, $p < .001$). At 60º/s, baseline (140.0 ± 30.9 J) values dropped for F-CE (134.0 ± 22.8J, $p < .001$) and F-ISO (136.0 ± 26.3J, $p = 0.016$). Significant F-CE/F-ISO differences were identified at 60º/s ($F = 48.1$, $p < .001$, $\eta 2P = 0.750$). It suggests that isotonic contractions have a higher effect in torque, while isometric contractions have an impact power capacity more during exercise.

Keywords: Resistance training, dynamic, torque, power, work.

INTRODUCTION

As the sports context evolve, resistance training (RT) continues to be a well-established as an effective interventional strategy to enhance muscular adaptations (29) and force production, highly required to achieve higher performances. RT includes isotonic (concentric and eccentric) and isometric contractions, which are well described in the literature as their importance at different magnitudes, patterns of force production (20) and muscle activity (8). Furthermore, regarding torque, studies have shown that eccentric contractions can produce higher peak torque compared to concentric contractions, and isometric contractions can produce higher peak torque than concentric contractions but lower than eccentric contractions (11, 33) as well as peak torque during knee extensions progressively decreases with increasing angular velocity (13). Notably, torque is significantly higher during isometric contractions and at 10% of maximal angular velocity, highlighting the influence of movement speed on force maintenance under different contraction conditions (13).

Among different types of contraction, another variable related to RT is fatigue (32), which is defined as an exercise-induced reduction in force-generating capacity associated with an increase in the perceived effort to maintain a required power output (26). Central fatigue reduces muscle contractile force or power caused by processes before the neuromuscular junction (7), and peripheral fatigue occurs beyond the junction, within muscle fibers, leading to decreased force or power output (5), that when caused by voluntary exercise not only affects the fatigued muscles but also impairs endurance performance in non-fatigued muscles (16).

Programming strategies can be used to emphasize desired fitness characteristics and effectively manage neuromuscular fatigue (6). In a traditional RT set, the repetitions are performed without rest between them, however in some set variations, a small rest (10-45s) could be introduced between repetitions or blocks of repetitions to retardate the appearance of fatigue (22), which should be adjusted accordingly to the purpose of the training session. Vieira et al. (32) demonstrated that RT performed to failure results in a higher biomechanical decline, metabolic response, perceived exertion, movement velocity decline (more pronounced in upper-limb exercises), and muscle damage compared to RT not performed to failure.

Aiming to quantify the acute effects that either a separated and standardized leg or trunk muscle fatigue test had on strength, balance, agility, and straight sprint ability, Roth et al. (27) founded that lower-body strength is crucial for athletic power, as leg fatigue significantly impacts agility, sprint, and balance, while trunk fatigue mainly affects agility and balance, highlighting the importance of trunk strength as a supplementary focus in training. Also, the assessment using the leg extension movement is widely applied to evaluate and develop the strength and power of the knee extensor muscles, being particularly relevant in athletic performance contexts, functional performance and rehabilitation purposes (9, 18, 19).

Hong et al. (13) investigated the variation in the isokinetic parameters (torque and power) of knee extensors according to the individualized angular velocity during isokinetic contraction identified 30-60º/s ideal for peak torques and 180-240º/s for power. Which corresponded to 10% of the maximal angular velocity (40.89 ± 3.45º/s) and 40% of the maximal angular velocity (~163.56 ± 13.79º/s) and offered values of 208.00 ± 48.55Nm and 176.32 ± 49.64W, respectively.

Despite the substantial literature on the acute effects of RT, it is mainly focused on the effects of fatigue in muscle properties and force production or in the acute effects produced by isotonic contractions (12, 30), evaluating rest periods (15, 21, 25, 22), understanding RT to failure and recovery (21, 25, 32), and focusing on time under tension while monitoring fatigue (34). Therefore, there is no evidence as to which type of contraction (isotonic or isometric), performed to fatigue, has the highest impact on force production, or if there are differences between contractions, and if so, what differs considering that it is multifactorial. This lack of comparative data on muscular contraction types creates challenges for researchers and practitioners, restricting both physiological insight and evidence-based programming in resistance training. Clarifying these distinctions could enhance performance by optimizing the planning considering the exercise selection and order of it. Accordingly, the aim of the present study was to analyze the impact and variability of kinetic parameters (Torque, Power and Work) between isotonic and isometric contractions performed until fatigue during leg extension exercise at different angular velocities (60 and 180º/s). We hypothesize that the highest impact on kinetic parameters will be observed in torque in the isotonic test condition, and in power in the isometric condition.

METHODS

Experimental Approach to the Problem

Before the beginning of each test, all the subjects filled an anamnesis questionnaire and the 1RM was assessed for the leg extension exercise in the Technogym (Cesena, Italy). After, the subjects were familiarized to the exercises and equipment's where they will perform three submaximal and two maximal trial repetitions (31), at the isokinetic device. Previously to the test, each subject performed a 5 min of warming-up at 100 watts and 60 revolutions per minute on a cycle ergometer (23). In the first trial of evaluation, the subjects performed the isokinetic leg extension assessment, without fatigue (Baseline), at the second trial the subjects performed the isotonic contractions fatigue test (F-CE) and at the third trial the isometric contractions fatigue test (F-ISO), with an optimal 1-week interval between sessions being this duration considered to be long enough to minimize the impact of muscle fatigue, and to ensure that there is no significant change in strength (17). In both cases the subjects had a 5-minute rest period before engaging in torque, power and work assessment.

Subjects

17 healthy subjects (12 males and 5 females, 21.3 ± 1.8 years, 174.8 ± 8.5 cm, 70.2 ± 9.0 kg, 20.8 ± 7.0 % body fat, 23.0 ± 2.3 kg/m^2, 7.0 ± 3.2 hours of weekly training), all university students in sports sciences, took part in the study. Subjects were excluded if they had (i) injuries to their lower/upper extremity that limited their physical activity in the past 6 months; (ii) surgery on lower/upper extremity in the past 12 months; (iii) a medical condition that would affect their ability to perform the test correctly; (iv) taken medication that could impact their strength (10). Subjects were asked to sign an informed consent, and subjects were informed that they could withdraw from the study at any time without any consequences. This study was approved by the Ethics Committee (N.42-2024 ESDRM) and all procedures were in accordance with the Helsinki Declaration regarding human research.

Procedures

F-CE test included 3 sets, each set followed by a 2-minute rest period, involving a Concentric/Eccentric action. Each set was performed until failure, with verbal encouragement given to the subject to perform as many repetitions as possible, this set was concluded when the concentric action was not possibly realized. F-ISO consisted of 3 sets realized with a 2-minute rest at 180º of extension on leg extension, until failure, and the subject was verbally encouraged to hold the position for the maximum time possible, this set finished when the knee angle reached the 90º of flexion. During the test the subjects were constantly verbally supported to give their best, and the computer screen was positioned so that subjects could see real-time feedback of their effort. The first set was done after a 5-minute rest post F-CE/F-ISO, and the second set after a 3-minute rest post first set. Both sets were composed of 12 repetitions where only the concentric phase was realized, being it on the knee extension or knee flexion.

All tests were performed on a Humac NORM (Computer Sports Medicine, Inc. 101 Tosca Drive, Stoughton, MA 02072, USA), calibrated accordingly with the operating manual (4). Subjects sat upright with the backrest angled at 85°, and the knee’s rotational axis was aligned with the dynamometer’s axis, and the lever arm pad was positioned just above the medial malleolus to avoid restricting ankle movement (4). Tests range of motion were conducted from 90° to 0° and the weight of the testing leg was evaluated, and the gravity was adjusted using the same software. To prevent trunk movement during testing, subjects were secured with stabilizing straps as per the manufacturer’s instructions (4).

Torque is expressed in Newton-meter (N-m), Power in Watts (W) and Work in Joules (J) (23). Peak torque is defined as “the single highest torque output recorded throughout the range of motion of each repetition” (24). Power is defined as the rate of work production and refers to the amount of mechanical work performed in a given time. Work is defined as “the output of mechanical energy” (14). The force production patterns assessment for the knee extensors/flexors consisted of 2 sets, at 60 and 180°/s (10), performed at maximum intensity.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS, Version 25, IBM SPSS, Armonk, NY, USA) software. Descriptive statistics (Mean ±SD) and percentages of difference between baseline and conditions were assessed. The data distribution was assessed using the Shapiro-Wilk normality test. For all conditions the level of significance was $p > .05$. An ANOVA of repeated measures was performed to compare the effect between the three conditions (F-CE, F-ISO and baseline). Before the analysis, the assumption of sphericity was verified through the Mauchly test. The test did not reveal a violation of sphericity ($W = 0.865$, $p = 0.336$) so the degrees of freedom not corrected in the analysis were used. The ANOVA of repeated measures revealed a significant effect of the condition, $F(2,32) = 12.8$, $p < 0.001$. Tukey´s multiple comparisons test correction was performed to identify specific differences between the conditions. The magnitude of the difference was assessed between conditions F-CE and F-ISO considering the effect size index (partial eta square — η^2P) and was interpreted as: (i) small effect if $\eta^2P \approx 0.02$; (ii) medium effect if $\eta^2P \approx 0.13$; and (iii) large effect if $\eta^2P \approx 0.26$ (3). In addition to the inferential statistical analysis, indicators of variability and percentage impact were calculated. Fatigue-induced performance loss was determined based on the percentage variation between the baseline value and the post-fatigue value. At the same time, the consistency of data was evaluated through the coefficient of variation (CV%). The statistical analysis was carried out for $p = 0.05$.

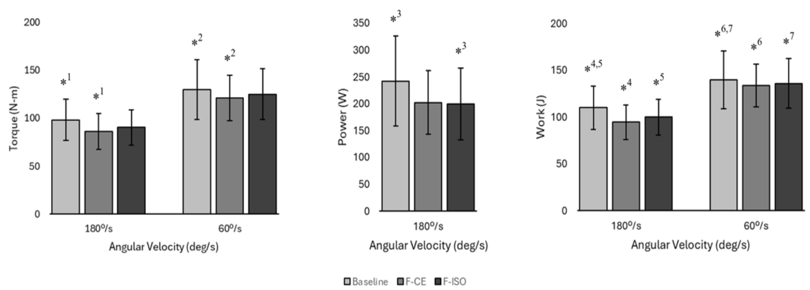
RESULTS

Table 1. Descriptive statistics (Mean±SD) and percentage of coefficient variation (CV %) of torque, power and work in the conditions of Baseline, in fatigue achieved with isotonic contractions (F-CE) and in fatigue achieved with isometric contractions (F-ISO) for 180 and 60º/s of angular velocity.

Condition		Baseline		F-CE				F-ISO				F-CE vs. F-ISO		
		Mean ± SD	CV (%)	Mean ± SD	*p*	CV (%)	Loss (%)	Mean ± SD	*p*	CV (%)	Loss (%)	F	*p*	Effect Size (η^2P)
Torque (N.m)	180º/s	98.2 ± 21.4	0.21	86.2 ± 18.9	0.034*	0.21	12.20%	90.4 ± 18.4	1.000	0.20	7.90%	12.8	0.126	0.44
	60º/s	130.0 ± 31.1	0.23	121.0 ± 23.9	<.001*	0.19	6.90%	125.0 ± 26.4	0.977	0.21	3.80%	2.63	0.430	0.14
Power (W)	180º/s	242.0 ± 83.2	0.34	202.0 ± 59.2	0.406	0.29	16.50%	200.0 ± 67.0	<.001*	0.33	17.30%	6.74	0.972	0.30
Work (J)	180º/s	110.0 ± 23.1	0.21	94.6 ± 18.5	0.035*	0.19	14.00%	100.0 ± 19.2	<.001*	0.19	9.00%	13.20	0.132	0.45
	60º/s	140.0 ± 30.9	0.22	134.0 ± 22.8	<.001*	0.17	4.20%	136.0 ± 26.3	0.016*	0.19	2.80%	48.10	<.001*	0.75

Table 1 showed that significant differences were found in torque for the 180º/s condition (p = 0.034) between the baseline (98.2 ± 21.4N.m) and F-CE condition (86.2 ± 18.9N.m) with a loss of 12.20%. Also, for the 60º/s condition, significant differences were found (p < .001) between baseline (130.0 ± 31.1N.m) and F-CE (121.0 ± 23.9N.m) with a loss of 6.90%. Regarding power (180º/s condition), significant differences were found (p < .001) between baseline (242.0 ± 83.2W) and F-ISO values (200.0 ± 67.0 W) with a loss of 17.30%. Regarding work, significant differences were found for the 180º/s condition (p = 0.035) between baseline (110.0 ± 23.1J) and F-CE values (94.6 ± 18.5J) with a loss of 14% between them. At 60º/s condition, significant differences were found (p < .001) between baseline (140.0 ± 30.9J) and F-CE (134.0 ± 22.8J) with a loss of 4.20%. Also, significant differences were found for the 180º/s condition (p < .001) between baseline (110.0 ± 23.1J) and F-ISO (100.0 ± 19.2 J) with a loss of 9 %, and for the 60º/s condition (p = 0.016) between baseline values (140.0 ± 30.9 J) and F-ISO values (136.0 ± 26.3 J) with a loss of 2.80%. Were found significant differences between conditions (F-CE/F-ISO) for the 60º/s condition (F = 48.1, p < .001. η2 = 0.75). In Figure 1 is observed the higher torque values in the 60º/s compared to 180º/s across all conditions. Also, the highest work also occurs in the 60º/s condition at the three conditions.

Figure 1. Mean ± SD and significant differences of torque, power and work between conditions (baseline, F-CE and F-ISO) at 180 and 60º/s of angular velocity.



DISCUSSION

The results of the present study revealed significant differences in force production patterns after fatiguing tasks with isotonic (F-CE) and isometric (F-ISO) contractions during knee extension. Torque loss was more pronounced after F-CE, especially at the 180º/s speed, with an average reduction of 12.2%, compared to the baseline condition. This pattern confirms previous studies (1,28) but our study expands understanding by revealing that, in addition to torque, variables such as power and work also respond differentially according to the type of contraction and execution speed. In the 180º/s condition, a 17.3% reduction in power was observed after the isometric condition (F-ISO), suggesting that, although torque was more preserved in F-ISO, the ability to generate power at high speeds was more compromised. This may have relevant implications in sports training, especially in modalities that require fast and explosive actions. The larger loss of power in the isometric condition may be related to the limitation of dynamic recruitment of specific motor units, which indicates that the predominant use of isometric exercises may not be ideal in training phases aimed at developing power.

On the other hand, the larger loss of torque after F-CE may be interpreted as a reflection of the greater mechanical and metabolic demand imposed by this type of contraction. The larger continuous eccentric-concentric involvement, characteristic of isotonic contraction, may have induced greater peripheral fatigue, directly affecting force production, as suggested by studies that associate this pattern with changes in contractile function and accumulation of metabolites (2). Thus, in contexts where the preservation of maximum force is a priority, using isometric strategies may be more indicated.

Another relevant finding was the difference between angular velocities. Torque and work output were consistently higher at 60º/s in all conditions, which is expected due to the strength-speed relationship of skeletal muscle. However, the magnitude of performance loss was generally greater at 180º/s, possibly due to the greater demand for neuromuscular control and the reduced time for force generation. This finding reinforces the importance of considering execution speed as a critical variable in exercise prescription, especially in athletes who need to maintain performance under fatigue at different speeds.

Comparing the differences between performing RT to failure and RT without failure, Vieira et al. (32) suggested the time under tension to explain the higher impact of RT performed to failure given the higher number of repetitions performed, particularly the higher number of concentric movements. However, in this study the time under tension undergone by the isometric contractions was largely higher than the time under tension in the isotonic contractions.

The analysis between conditions (F-CE vs F-ISO) in torque at 60º/s ($\eta^2 = 0.75$) demonstrates a very strong effect of contraction condition on performance, showing that the type of fatiguing task significantly influences subsequent force production. This result offers an opportunity for coaches to adjust the type of stimulus according to the objectives of the session: for example, using isometric contractions to minimize impact on subsequent maximum force, or isotonic contractions to simulate more fatiguing game or competition contexts.

Although the study has limitations, such as the absence of neuromuscular measures (e.g., EMG, twitch interpolation) that could elucidate central vs peripheral mechanisms of fatigue, the results provide applicable insights for planning sessions focused on performance or recovery.

In summary, both isotonic and isometric contractions performed to volitional fatigue led to significant acute reductions in torque, power, and mechanical work. However, the pattern and magnitude of these decrements differ according to contraction type and angular velocity. Isotonic fatigue induced greater losses in torque and work—particularly at higher velocities (180º/s)—as reflected in a fatigue index of up to 12.2% for torque and 14% for work. In contrast, isometric loading resulted in more pronounced impairments in power output (−17.3% at 180º/s), suggesting a distinct fatigue profile likely driven by sustained neuromuscular activation without movement and the associated metabolic constraints.

These differentiated fatigue responses highlight the importance of considering contraction mode and movement velocity when programming resistance training or fatigue-based testing. Practitioners planning to minimize torque losses might opt for isometric loading, while those seeking to challenge power output or assess velocity-specific fatigue may favor isotonic protocols. Ultimately, aligning contraction strategy with the targeted neuromuscular quality (e.g., torque vs. power endurance) may enhance the specificity and efficacy of training interventions.

PRACTICAL APPLICATIONS

The findings of this study offer relevant practical applications for strength and conditioning professionals seeking to optimize load handling and control neuromuscular fatigue in training programs.

1. Strategic selection of contractions according to the objective of the session:

- Isotonic contractions (eccentric-concentric), by inducing greater loss of torque and work, should be used with caution in training phases where preservation of maximum strength is critical (e.g., maximum strength days or performance tests).
- On the other hand, their application may be valuable in training blocks focused on muscular endurance or to simulate game/fatigue conditions, promoting greater metabolic stress.

2. Use of isometric contractions to preserve strength under fatigue:

- Despite significantly reducing power at high speeds (especially at 180º/s), isometric exercises showed less impact on torque maintenance and can be incorporated into training days with reduced volume, or in athletes in rehabilitation or recovery, when the objective is to preserve strength function with lower neuromuscular cost.

3. Execution speed as a load variable:

- The angular speed had a considerable effect on the performance parameters. The greater preservation of torque and work at 60º/s indicates that training at slower speeds may be useful in recovery or transition periods.
- On the other hand, training at high speeds (180º/s) can be used to challenge the neuromuscular system under fatigue but requires a longer recovery time.

4. Monitoring fatigue induced by different stimuli:

- Professionals should consider that different contraction modes produce fatigue of different natures. Thus, alternating stimuli (e.g., including isometric days between intense isotonic sessions) may be an effective strategy to maintain weekly performance and avoid unnecessary overloads.

5. Individualization of prescription:

- Although this study did not discriminate by sex or training level, the data point to considerable variations between participants. The individual response to fatigue by type of contraction reinforces the need for periodic assessments and individualized adjustments in training programs.

ACKNOWLEDGMENTS

Research concept and study design (AC), literature review (AC; HL), data collection (AC; RCM; JF; HL), data analysis and interpretation (AC; RCM; HL), statistical analyses (AC; RCM; FR; HL), writing of the manuscript (AC; RCM; DM; HL), or reviewing/editing a draft of the manuscript (AC; RCM; FR; DM; JF; HL).

Funding: This work is supported by National Funds by FCT - Portuguese Foundation for Science and Technology under the following project UI/04045.

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