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Rate of Force Development Scaling Factor in Hamstring Muscles: Feasibility and Relationship to Deadlift Performance among Resistance Trained Individuals

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Abstract

The aim of this study was to examine the relationship among hamstring peak force (PF), rate of force development scaling factor (RFD-SF), countermovement jump (CMJ), and one-repetition maximum (1RM) strength in recreationally trained individuals, as well as to establish the feasibility of RFD-SD assessment for knee flexor muscles. Eighteen volunteers (12 males, 27.3±5.2 years, 6 females, 24.4±3.1 years) participated in the study. Participants performed a knee flexion maximal isometric voluntary contraction and followed a standard RFD-SF protocol. The 1RM for the deadlift was assessed to determine maximal dynamic strength, while CMJ was used to evaluate explosive movement capability. The study found no significant correlations between RFD-SF, CMJ, and 1RM. Additionally, it was observed that RFD-SF in the hamstring muscles can be effectively assessed (mean R2=0.92). In addition, RFD-SF was not different between men and women, which highlight its potential as sex-independent measure of knee flexor muscle function. Future research should involve a more diverse group of athletes to further investigate the relationships among RFD-SF, strength, and explosive movements like CMJ for more comprehensive insights.

Keywords: *deadlift, rapid force development, scaling factor, knee flexion, strength, countermovement jump*

Introduction

Resistance training is a fundamental component of sports and exercise regimes, aimed at enhancing muscle strength, power, and local muscle endurance (Stricker et al., 2020). Its primary objectives include increased physical demands, achieve better performance outcomes, and reduce injury risks (Refalo et al., 2023; Schoenfeld et al., 2019; Stricker et al., 2020). Muscle performance assessment is vital in both scientific research and applied sports science, as well as in clinical practice (Kozinc et al., 2022; Oliveira et al., 2016). Recently, scientific research has increasingly focused on evaluating the capacity for rapid force generation, termed rapid strength (Guizelini et al., 2018; Kozinc et al., 2022; Maffiuletti et al., 2016). This aspect of muscle function is typically measured using the rate of force development (RFD), which quantifies the rate of force increase within a specific timeframe (Aagaard et al., 2002; de Oliveira et al., 2013). RFD assessment involves analysing the force or torque curve in relation to the time of explosive muscle contractions (Aagaard et al., 2002; Methenitis et al., 2019). Notably, enhancing RFD is a key adaptation in resistance training, with larger improvements correlating to increased maximum force and speed during rapid movements (Aagaard et al., 2002; Andersen et al., 2010; Methenitis et al., 2019).

Oliveira et al. (2013) found that participants undergoing isometric resistance training for six weeks exhibited a significant 61% increase in maximum RFD, especially during the

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early phase of torque increase in the joint (de Oliveira et al., 2013). An enhancement in RFD following resistance training, as Aagaard et al. (2002) pointed out, is crucial in rapid and forceful muscle contractions where achieving maximum muscle force is limited by the short contraction time, yet rapid force generation is essential for athletic performance and daily activities (Aagaard et al., 2002). The speed of muscle contraction is influenced by factors such as the ratio of fast to slow muscle fibers, muscle cross-sectional area, viscoelastic properties, and neural factors (Andersen et al., 2010; Methenitis et al., 2019). Methenitis et al. (2019) further explored this by assessing the relationship between muscle fiber composition and RFD in well-trained individuals, identifying a strong correlation between RFD and the proportion of type II fibers, particularly type IIx, and noting that resistance training leads to significant adaptations in the utilization of hypertrophied type IIx muscle fibers (Methenitis et al., 2019). Complementary to these findings, Oliveira et al. (2016) observed improvements in early RFD in knee extensors after an eight-week maximal isokinetic training program (Oliveira et al., 2016), which was also confirmed by Blazevich et al. (2008) who reported similar RFD enhancements in knee extensors following resistance training.

The rate of force development scaling factor (RFD-SF) has recently emerged as a novel means of assessing rapid force development capacity (Bellumori et al. 2011; Smajla et al., 2021). Briefly, during rapid isometric contractions performed at varying intensities, a pronounced linear relationship is observed between the peak force (PF) achieved and the corresponding RFD. This linear relationship's slope, termed RFD-SF, is indicative of an individual's RFD capacity across a broader range of contraction intensities. The RFD's proportional scaling to PF is reflected in the linearity of the relationship, as denoted by the R2 coefficient. A comprehensive review by Kozinc et al. (2022) highlighted the necessity for more research to elucidate the link between RFD-SF and sports performance. Further, the review concluded that RFD-SF is dependent on an individual's neuromuscular capacity, particularly the maximum motor unit firing rate, and motor control, which includes adjusting motor unit firing rates and coordinating actions across muscle groups. RFD-SF differs from maximal strength or traditional RFD assessments in that it does not necessitate maximal effort contractions, which makes it particularly suitable for clinical settings. It has been demonstrated that RFD-SF is highly sensitive to neuromuscular speed declines, a typical feature of aging and certain neurological conditions (Klass et al., 2008; Corrêa et. al., 2020; Uygur et al., 2020; Uygur et al., 2022; Uygur et al., 2023). However, further research is required to ascertain if RFD-SF provides unique insights not captured by conventional measurements of peak force/torque or standard RFD, which would establish its distinct value in assessment. In particular, the literature lacks research on associations between RFD-SF and athletic performance.

Suarez et al. (2019) presented substantial evidence indicating a strong association between success in weightlifting and the strength and RFD. In other words, weightlifting performance is primarily dependent on the capacity to generate large forces, achieve high RFD, and attain maximum power during competitive lifts (Suarez et al., 2019). A key example is the deadlift, where the posterior thigh muscles – comprising the semimembranosus, semitendinosus, and biceps femoris muscles – are crucial. These muscles primarily facilitate hip extension and knee flexion (Woodley and Mercer, 2005; Koulouris and Connell, 2005). Martín-Fuentes et al. (2020) observed slightly higher activation of the semitendinosus muscle compared to the biceps femoris during deadlifts (Martín-Fuentes et al., 2020). Given the vital role of the posterior thigh muscles in performing the deadlift, and our aim to explore the association between RFD-SF and sports performance, the objective of this study was to investigate the association between higher RFD-SF in these muscles and deadlift and countermovement jump. Additionally, we aim to explore the feasibility of assessing RFD-SF in knee flexors. This study addresses the existing gap in the literature by evaluating the feasibility of RFD-SF assessment for knee flexor muscles and exploring its relationship with deadlift performance, which has not been investigated in previous research.

Methods

Participants

This study involved competitive and recreationally-active weightlifters. A total of 18 participants (12 males, 27.3±5.2 years, 6 females, 24.4±3.1 years). volunteered to participate in the study. Participants reported regular resistance exercise participation (training status: 4.1±2.8 years) and included deadlifts in their training routine at least once a week, which was a condition for inclusion in the study. Exclusion criteria included the presence of significant injuries or illness in the six months prior to the study or the presence of pain that could affect the measurements. After presenting potential risks, benefits, and the course of the study, the subjects completed informed consent to participate in the research, in accordance with the Helsinki Declaration. Participants were also informed of the option to withdraw from the study without consequences. The study was approved by the Republic of Slovenia National Medical Ethics Committee (No. 0120-690/2017/8) and adhered to research ethics requirements.

Study Design

In this cross-sectional study, participants executed a knee flexion maximal isometric voluntary contraction and a standard RFD-SF protocol (Kozinc et al., 2022). For all subjects, only one visit was required. They were instructed to arrive well-rested, having consumed a suitable energy meal and ensuring proper hydration. Initially, participants were briefed on the procedure, risks, and benefits of the research. Following this, they completed a personal information sheet and a brief questionnaire about their injury history and training characteristics. Subsequently, each participant filled out an informed consent form to partake in the study. A warm-up session was then conducted, comprising 5 minutes of stepping onto a raised platform, dynamic stretching exercises for the entire body with 10 repetitions each (including circles for the head, shoulders, arms, hips, knees, and ankles), and 5 strengthening exercises. These exercises included 10 squats with a 4 or 6-kilogram weight lifted on toes, 10 single-leg deadlifts with a 4 or 6-kilogram weight, 10 elbow flexions in both supine and prone forearm positions with a 4 or 6-kilogram weight in each hand, and 10 single-leg bridge lifts.

Procedures

During the testing protocol, participants were seated in an isometric knee dynamometer's chair (S2P, Science to Practice Ltd., Ljubljana, Slovenia), with measurements taken at 60° of knee flexion (full knee extension = 0°) and hips at 100°. All participants performed knee flexion with their right leg. The knee axis was aligned with the axis of the dynamometer's lever arm, and the minimally padded shank support was adjusted for each participant, approximately 2 cm above the lateral malleolus. Adequate hip and knee fixation was ensured with rigid straps over the pelvis and knee (as shown in Fig. 1.) As part of the acclimatization process, each participant executed two graded submaximal contractions at 50, 75, and 90% of their self-estimated maximal voluntary effort. After a 3-minute rest, they performed three maximal voluntary knee extensions, with a 30-second rest between each. Participants were instructed to gradually increase their torque and sustain maximal force for 3–5 seconds, which was used to determine the peak force of knee flexion. Finally, the participants undertook an RFD-SF familiarization protocol, consisting of 3 to 5 submaximal explosive contractions at 20, 40, 60 and 80 % of their maximal force recorded during maximal voluntary contraction.

After familiarization, each participant performed 15–20 explosive isometric contractions at four different submaximal levels which were selected randomly (20, 40, 60, and 80% of previously determined maximal voluntary force) (Bellumori et al, 2011; Kozinc et al., 2022). Participants were instructed to produce isometric knee flexion as quickly as possible and to relax the muscles immediately afterwards. The target level of force was presented on a computer screen in front of the participant as a horizontal line on a graph (Figure 1). Visual feedback on the amount of force the participant had generated during the pulse was also provided on the screen, while participants were instructed to apply a level of force matching (about) the red horizontal target force level during each pulse. There was a 60-s rest between two consecutive submaximal levels.

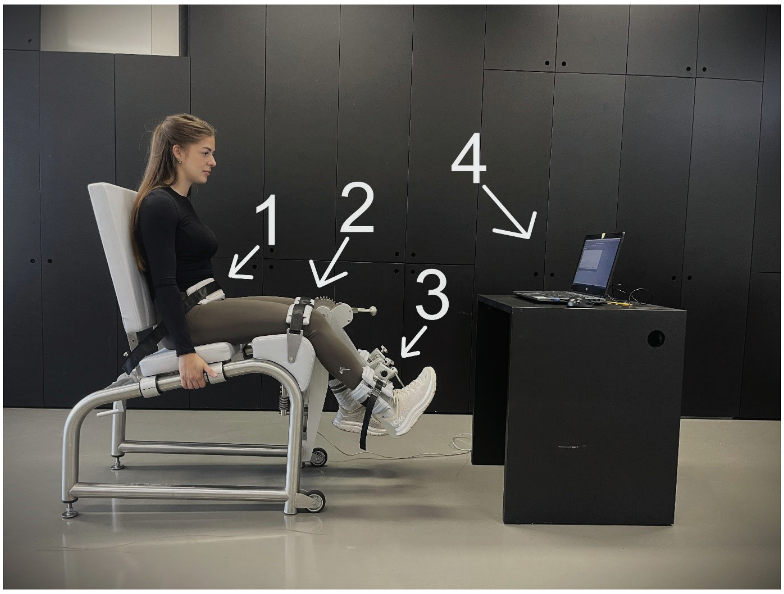

FIGURE 1. Position of the subject during the measurement of RFD-SF. 1 = a padded fixation of the pelvis; 2 = rigid straps for the knee fixation; 3 = force sensors; 4 = a monitor with visual feedback.

RFD-SF calculations were done as recommended in the literature (Kozinc et al., 2022; Mathern et al., 2019; Bellumori et al., 2011). Each pulse recorded included measurements of PF and peak RFD. To determine when the force pulses began and ended, the changes in force curves over time were calculated and filtered using a fourth-order zero-lag filter set at a frequency of 10 Hz. This specific frequency was chosen during initial testing as it closely matched the manually identified initiation and termination points. Identifying the start and end of force pulses was automated by marking the point where the force's rate of change reached 10% of its maximum value. The duration of each pulse was computed as the time gap between its termination and initiation. Pulses lasting longer than the mean plus two standard deviations of all pulse durations were excluded from the analysis.

The second set of measurements involved assessing maximum strength in the deadlift exercise. To measure the maximum strength in the deadlift, participants performed a 1RM for this exercise. They began the warm-up with an empty barbell, gradually increasing the load based on their own perception. After the initial warm-up sets, they performed only 1 repetition at subsequent loads to avoid the effects of fatigue. Participants could determine the pace of warm-up, weight increments, and rest periods on their own, with vocal encouragement provided during the execution. For the 1RM test, participants were allowed 3 attempts.

Statistical Analysis

The relationships between PF and corresponding peak RFD were analysed using regression parameters, treating them as indicators of rapid force production and relaxation, respectively. The slopes of these relationships quantified the magnitude of the ability to scale RFD with the magnitude of force produced. The R^2 values from these regressions showed how consistently force development and relaxation scaled concerning peak force (Bellumori et al. 2011). Similar to prior studies (Šarabon et al.; 2020 Djordjevic and Uygur 2017), the y-intercepts of the regression lines were reported in the results, but were excluded from discussion due to their negligible impact in RFD-SF literature.

The statistical analysis was conducted using the IBM SPSS Statistics 25 software (IBM, New York, USA). After checking for normality of the data distribution with Shapiro-Wilk tests, associations were assessed with Pearson's correlation coefficient, which was interpreted as negligible (< 0.1), weak (0.1–0.4), moderate (0.4–0.7), strong (0.7–0.9) and very strong

(>0.9) (Akoglu, 2018). Differences between men and women were assessed with independent sample t-tests. Effect sizes were expressed as Cohen's d, which was interpreted as trivial (<0.2), small (0.2-0.5), medium (0.5-0.8) and large (>0.8) (Lakens, 2013). Threshold for statistical significance was set at $\alpha<0.05$.

Results

Descriptive statistics and gender differences

The descriptive statistics for all variables are included in Table 1. The peak force and RFD seem to exhibit a good linear relationship (mean R2=0.92; range=0.85-0.99), demonstrating the feasibility of RFD-SF assessment in knee flexors.

Table 1. Descriptive statistics.

Outcome variable	Mean	SD	Minimum	Maximum
RFD-SF (Slope)	7.05	1.25	5.00	9.96
Intercept	23.98	21.05	-11.45	74.92
R^2	0.92	0.04	0.85	0.99
Peak Torque (Nm)	311.06	94.17	116.00	459.00
Peak Torque (Nm/kgBW)	4.00	0.88	1.79	5.56
CMJ height (m)	0.36	0.08	0.25	0.49
Deadlift 1RM (kg)	158.24	46.13	95.00	225.00
Deadlift 1RM (kg/kgBW)	2.03	0.39	1.55	2.72

SD – standard deviation; BW – bodyweight; CMJ – countermovement jump;1RM – 1-repetition maximum

Men had larger CMJ height, as well as larger peak knee flexor torque and deadlift 1RM (all p<0.001). Large differences persisted even in body-mass-normalized values. On the other hand, RFD-SD (p=0.462), y-intercept (p=0.216) and R2 (p=0.404) were similar in men and women (Table 2).

Table 2. Differences between men and women

Outcome variable	Women (n = 6)		Men (n = 12)		Difference	
	Mean	SD	Mean	SD	p	ES (g)
RFD-SF (Slope)	6.76	0.74	7.21	1.47	0.462	-0.33
Intercept (Nm)	15.83	9.30	28.42	24.58	0.216	-0.58
R^2	0.93	0.02	0.92	0.04	0.404	0.46
Peak Torque (Nm)	210.33	52.53	366.00	58.31	0.000	-2.62
Peak Torque (Nm/kgBW)	3.24	0.73	4.42	0.66	0.002	-1.63
CMJ height (m)	0.28	0.03	0.40	0.06	0.000	-2.30
Deadlift 1RM (kg)	106.67	10.80	186.36	29.67	0.000	-3.02
Deadlift 1RM (kg/kgBW)	1.65	0.08	2.25	0.32	0.000	-2.16

SD – standard deviation; BW – bodyweight; CMJ – countermovement jump;1RM – 1-repetition maximum

Correlations between RFD-SF and deadlift performance, maximal strength and CMJ

Table 3 shows the correlations between RFD-SF and deadlift performance, maximal strength and CMJ. RFD-SF and R2 were not in statistically significant with any other outcome variable. Y-intercept was in moderate correlation with absolute and normalized peak knee flexor torque (r=0.51-0.52; p=0.031–0.035). Similarly, there were no correlations when men and women were examined separately, other than very high positive correlations between y-intercept and peak knee flexor force in women (r=0.86–0.91; p=0.012–0.028).

Table 3. Correlations among RFD-SF, CMJ and deadlift 1RM

	Peak Torque (Nm)	Peak Torque (Nm/kg BW)	CMJ height (m)	Deadlift 1RM (kg)	Deadlift 1RM (kg/kg BW)
RFD_SF	0.01	-0.10	0.01	0.25	0.23
Intercept	0.52*	0.51*	0.15	0.32	0.25
R^2	-0.15	-0.18	-0.39	0.09	0.15

BW – bodyweight; CMJ – countermovement jump;1RM – 1-repetition maximum

Discussion

The primary objective of this study was to determine whether a higher rate of force development scaling factor (RFD-SF) in knee flexors muscles correlates with improved performance in the deadlift and countermovement jump (CMJ). Additionally, we aimed to assess the feasibility of measuring RFD-SF for these muscles. Our findings indicate no significant correlations between RFD-SF, CMJ, and increased one-repetition maximum (1RM) in the deadlift. Moreover, our results suggest the viability of RFD-SF assessments for knee flexors, as evidenced by a consistently high R2 value (mean R2 = 0.92). In addition, our results are indicating it could serve as a sex-independent measure of knee flexor muscle performance.

Our study revealed a consistent linear relationship between PF and RFD, supporting the feasibility of RFD-SF assessment for knee flexors. Notably, we observed no significant differences in RFD-SF measurements between male and female participants, suggesting that RFD-SF could be a novel method for assessing muscle function irrespective of sex. However, it is important to note that our study included only six female participants, which may limit the generalizability of these findings. This observation aligns with the review by Kozinc et al. (2022), who also reported no clear sex differences in RFD-SF. Similarly, Corrêa et al. (2020) found no sex differences in grip muscle RFD-SF in young individuals, although variations were noted across different muscle groups. For instance, Bozic et al. (2013) reported higher RFD-SF in knee extensors but lower RFD-SF in knee flexors for males compared to females. Conversely, Bellumori et al. (2011) observed no significant sex differences in RFD-SF for knee extensors, elbow extensors, and index finger abductors. In summary, while gender appears to have a negligible impact on RFD-SF in certain scenarios, the overall influence remains ambiguous and may vary depending on age and specific muscle groups. Additionally, the limited data on female participants in our study hinders a comprehensive analysis. Future research should prioritize including a larger number of female participants to enable more robust analysis and validation of our study outcomes.

The absence of a correlation between RFD-SF and 1RM in our study aligns with the mixed findings in existing literature regarding the relationship between RFD and 1RM strength, especially in exercises like the deadlift and countermovement jump (CMJ). For example, McGuigan et al. (2010) and McGuigan and Winchester (2008) reported no clear association between peak RFD and 1RM strength in bench press and squat during isometric mid-thigh pulls. In contrast, other studies, such as Wang et al. (2016), have identified a moderate-to-strong correlation (r = 0.60–0.75) between RFD and 1RM strength, particularly when RFD is measured within specific time frames (90–250 ms) during the mid-thigh pull. Additionally, research indicates that resistance training can lead to parallel improvements in strength and RFD, especially when assessed during the later phase (150–250 ms) of a movement (Aagaard et al., 2002; Häkkinen et al., 1981). In sum, while some studies did not observe a direct connection between peak RFD and maximal strength, others underscore a phase-specific relationship. These findings indicate that improvements in RFD in the context of dynamic strength could be closely linked to specific time intervals or phases during a movement. This variability in findings highlights the complexity of the relationship between RFD, RFD-SF, and maximal strength.

Our findings indicated un unchanged RFD-SF with training, which could be explained by the fact that both peak strength and RFD increased in parallel, while the scaling between the two remained the same. This means that RFD-SF, while feasible to assess in knee flexors, has limited utility in relation to weightlifting performance. In addition, recent findings, such as those by Del Vecchio et al. (2022), indicate that while maximal force can increase following short-term isometric strength training, RFD may remain relatively unchanged. This could be attributed to a combination of neural adaptations aimed at increasing RFD and musculotendinous adaptations that counteract these effects. Further studies are necessary to substantiate these findings. The lack of correlation between RFD-SF and CMJ performance in our study might be explained by the fact that none of our participants regularly perform CMJ as part of their daily routine, which hinders the reliability of the metrics related to this task. We hypothesize that including more athletes who regularly engage in jumping exercises in their training could potentially yield different results.

Strengths and Limitations

The strengths of this study include robust measurements of RFD-SF with state-of-the-art dynamometers and inclusion of highly-trained participants. However, this study also had several limitations. The small sample size may have limited the generalizability of our findings. Participants' dietary habits, which were not controlled, could have influenced the results. Moreover, not all participants were experienced with the CMJ protocol, potentially affecting the correlation analyses. Additionally, conducting all measurements on a single day might have caused participant fatigue, possibly impacted performance and underestimated the true effects on the outcomes. Future research should include a more comprehensive assessment across major lifts—squat, bench press, and deadlift—to better understand their relationship with RFD-SF and provide insights for training optimization and athletic performance enhancement. The cross-sectional design minimizes potential confounding variables, ensuring that all participants were assessed under consistent conditions to provide reliable and accurate correlations between different measures of muscle performance. However, a resistance-training-based intervention study would provide a clearer insights into RFD-SF's utility.

Conclusion

This study examined the relationship between the hamstring rate of force development scaling factor (RFD-SF), peak force, countermovement jump (CMJ), and one-repetition maximum (1RM) deadlift performance among recreationally trained individuals. While RFD-SF assessment for knee flexors was found to be feasible (mean R2=0.92), no significant correlations were observed between RFD-SF, CMJ, and 1RM deadlift performance. Additionally, RFD-SF was not significantly different between men and women, indicating its potential as a sex-independent measure of knee flexor muscle function.

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Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics approval: The study was approved by the National Medical Ethics Committee of Slovenia (approval number 0120-690/2017/8) and was conducted in accordance with the Declaration of Helsinki.

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References

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology, 93*(4), 1318-1326. https://doi.org/10.1152/japplphysiol.00283.2002

Akoglu, H. (2018). User's guide to correlation coefficients. *Turkish Journal of Emergency Medicine*, *18*(3), 91–93. https://doi.org/10.1016/j.tjem.2018.08.001

Andersen, L. L., Andersen, J. L., Zebis, M. K. & Aagaard, P. (2010). Early and late rate of force development: differential adaptive responses to resistance training? *Scandinavian Journal of Medicine and Science in Sports, 20*(1), e162-e169. https://doi.org/10.1111/j.1600-0838.2009.00933.x

Blazevich, A. J., Horne, S., Cannavan, D., Coleman, D. R., & Aagaard, P. (2008). Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. *Muscle and Nerve, 38*(3), 1133-1146. https://doi.org/10.1002/mus.21021

Bellumori, M., Jaric, S., & Knight, C. A. (2011). The rate of force development scaling factor (RFD-SF): protocol, reliability, and muscle comparisons. *Experimental Brain Research, 212,* 359–369. https://doi.org/10.1007/s00221-011-2735-7

Corrêa, T. G. C., Donato, S. V. S., Lima, K. C. A., Pereira, R. V., Uygur, M., & de Freitas, P. B. (2020). Age- and Sex-Related Differences in the Maximum Muscle Performance and Rate of Force Development Scaling Factor of Precision Grip Muscles. *Motor Control, 24*(2), 274–290. https://doi.org/10.1123/mc.2019-0021

Djordjevic, D., & Uygur, M. (2017) Methodological considerations in the calculation of the rate of force development scaling factor. *Physiological Measurement, 39,* 015001. https://doi.org/10.1088/1361-6578/aa9f51

Guizelini, P. C., de Aguiar, R. A., Denadai, B. S., Caputo, F., & Greco, C. C. (2018). Effect of resistance training on muscle strength and rate of force development in healthy older adults: a systematic review and meta-analysis. *Experimental Gerontology*, *102*, 51-5

Häkkinen, K., Komi, P., & Tesch, P. (1981) Effect of combined concentric and eccentric strength training and detraining on force-time, muscle fiber and metabolic characteristics of leg extensor muscles. *Scandinavian Journal of Medicine and Science in Sports, 3*, 50–58

Klass, M., Baudry, S., & Duchateau, J. (2008). Age-related decline in rate of torque development is accompanied by lower maximal motor unit discharge frequency during fast contractions. *Journal of Applied Physiology (Bethesda, Md.: 1985), 104*(3), 739–746. https://doi.org/10.1152/japplphysiol.00550.2007

Kozinc, Ž., Smajla, D., & Šarabon, N. (2022). The rate of force development scaling factor: a review of underlying factors, assessment methods and potential for practical applications. *European Journal of Applied Physiology, 122*(4), 861–873. https://doi.org/10.1007/s00421-022-04889-4

Koulouris, G., & Connell, D. (2005). Hamstring muscle complex: an imaging review. *RadioGraphics, 25*(3). https://doi.org/10.1148/rg.253045711

Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance, 4*(4), 461-473.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

de Oliveira, F. B., Rizatto, G. F., & Denadai, B. S. (2013). Are early and late rate of force development differently influenced by fast-velocity resistance training? *Clinical Physiology and Functional Imaging, 33*(4), 282-287. https://doi.org/10.1111/cpf.12025

Martín-Fuentes, I., Oliva-Lozano, J. M. & Muyor, J. M. (2020). Electromyographic activity in deadlift exercise and its variants. A systematic review. *PLoS One, 15*(2); e0229507. Pridobljeno s https://pubmed.ncbi.nlm.nih.gov/32107499/

Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, *116*, 1091-1116.

Mathern, R. M., Anhorn, M., & Uygur, M. (2019). A novel method to assess rate of force relaxation: reliability and comparisons with rate of force development across various muscles. *European Journal of Applied Physiology, 119*(1), 291–300. https://doi.org/10.1007/s00421-018-4024-7

McGuigan, M. R., & Winchester, J. B. (2008) The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science & Medicine, 7*(1), 101.

McGuigan, M. R., Newton, M. J., Winchester, J. B., Nelson, A. G. (2010) Relationship between isometric and dynamic strength in recreationally trained men. *The Journal of Strength & Conditioning Research, 24*, 2570–2573

Methenitis, S., Spengos, K., Zaras, N., Stasinaki, A. N., Papadimas, G., Karampatsos, G. A., … & Terzis, G. (2019). Fiber type composition and rate of force development in endurance- and resistance-trained individuals. *The Journal of Strength and Conditioning Research, 33*(9), 2388-2397.

Oliveira, A. S., Corvino, R. B., Caputo, F., Aagaard, P. & Denadai, B. S. (2016). Effects of fast-velocity eccentric resistance training on early and late rate of force development. *European Journal of Sport Science, 16*(2), 199-205. https://doi.org/10.1080/17461391.2015.1010593

Refalo, M. C., Helms, E. R., Trexler, E. T., Hamilton, D. L., & Fyfe, J. J. (2023). Influence of resistance training proximity-to-failure on skeletal muscle hypertrophy: a systematic review with meta-analysis. *Sports Medicine, 53*(3), 649–665.

Schoenfeld, B. J., Contreras, B., Krieger, J., Grgic, J., Delcastillo, K., Belliard, R., & Alto, A. (2019). Resistance training volume enhances muscle hypertrophy but not Strength in trained men. *Medicine and Science in Sports and Exercise, 51*(1), 94-103.

Stricker, P. R., Faigenbaum, A. D., & McCammbridge, T. M. (2020). Resistance training for children and adolescent. *Pediatrics, 145*(6). https://doi.org/10.1542/peds.2020-1011

Suarez, D. G., Mizuguchi, S., Hornsby, W. G., Cunanan, A. J., Marsh, D. J., & Stone, M. H. (2019). Phase-specific changes in rate of force development and muscle morphology throughout a block periodized training cycle in weightlifters. *Sports, 7*(6), 129. https://doi.org/10.3390/sports7060129

Uygur, M., de Freitas, P. B., & Barone, D. A. (2020). Rate of force development and relaxation scaling factors are highly sensitive to detect upper extremity motor impairments in multiple sclerosis. *Journal of the Neurological Sciences*, *408*, 116500. https://doi.org/10.1016/j.jns.2019.116500

Uygur, M., Barone, D. A., Dankel, S. J., & DeStefano, N. (2022). Isometric tests to evaluate upper and lower extremity functioning in people with multiple sclerosis: reliability and validity. *Multiple Sclerosis and Related Disorders*, *63*, 103817. https://doi.org/10.1016/j.msard.2022.103817

Uygur, M., & Barone, D. A. (2023). The rate of force relaxation scaling factor is highly sensitive to detect upper and lower extremity motor deficiencies in mildly affected people with multiple sclerosis. *Multiple Sclerosis and Related Disorders*, *77*, 104897. https://doi.org/10.1016/j.msard.2023.104897

Wang, R., Hoffman, J. R., Tanigawa, S., Miramonti, A. A., La Monica, M. B., Beyer, K. S., ... & Stout, J. R. (2016). Isometric mid-thigh pull correlates with strength, sprint and agility performance in collegiate rugby union players. *The Journal of Strength & Conditioning Research*, *30*(11), 3051-3056.

Woodley, S. J., & Mercer, S. R. (2005). Hamstring muscles: architecture and innervation. *Cells Tissues Organs, 179*(3), 125-141.https://doi.org/10.1159/000085004