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The relationship of the isometric and dynamic rate of force development with sprinting ability

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ABSTRACT

Purpose: The rate of force development (RFD) is a commonly used indicator of explosive strength. While its relationship with various strength test parameters has been widely studied, its association with sprint performance remains less explored. This study investigated different RFD metrics from countermovement jump (CMJ) and isometric deadlift tests and their correlation with sprint performance.

Methods: Fifteen physically active male university students participated (age: 24.3±2.0 years, height: 181.8±5.4 cm, mass: 77.3±6.0 kg). Assessments included three CMJs, two isometric deadlift tests on a force plate, and two 30m sprints. Peak, mean RFD, and early-phase RFD values were analyzed, and Spearman's rank-correlation was used to assess their relationship with sprint performance.

Results: CMJ produced significantly higher RFD values than the isometric deadlift test, with peak RFD averaging 15349 ± 9866 N/s. No interpretable significant correlation was found between any RFD metrics and sprint performance. In contrast, relative isometric maximum strength ($r=0.55$; $p=0.033$) and jump height ($r=0.82$; $p<0.001$) showed significant correlations with sprint performance.

Conclusion: These findings suggest that RFD metrics from CMJ and isometric deadlift tests may not be suitable indicators of sprinting ability and likely reflect different physical attributes. Maximal isometric strength and jump performance appear to be more reliable predictors of sprint capability.

Keywords: RFD, explosive strength, sprint performance, vertical jump, isometric strength

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1. Introduction

Power is a key performance indicator in many individual and team sports (Diker et al., 2021; Herrington, 2021). One of the most widely used indicators of explosive strength is the rate of force development (RFD). The RFD is the increase in force per unit time (unit of measure: N/s) (Maffiuletti et al., 2016). The higher the force development over a given time, or the shorter the time it takes for the athlete to develop force, the higher the RFD value, which indicates better explosive force.

RFD is usually obtained using either isometric or ballistic test protocols (Barker et al., 2018; Wilson et al., 1995). Isometric protocols are often applied in strength testing since they provide a simple and reliable way to assess the athletes' capacity of maximal and rapid force exertion (Suarez et al., 2019; Merrigan et al., 2021). Isometric mid-thigh pull has been one of the most used protocols (Suarez et al., 2019; Merrigan et al., 2021) in maximal isometric testing, with the RFD being measured during the phase of rapid force development (Suarez et al., 2019; Merrigan et al., 2021).

On the other hand, ballistic movements may provide an alternative option in explosive force measurement, which compared to the isometric protocols are closer to real sports due to the similarities in movement pattern (McGuigan et al., 2010). Among ballistic movements, vertical jumping is an easy and cost-effective protocol to assess the explosive force of the lower limbs. The most common type of vertical jumping is the countermovement jump, which includes both eccentric and concentric muscle contractions evaluating in this way the stretch-shortening cycle (Cheraghi et al., 2017).

While both isometric and ballistic protocols are used to obtain the rate of force development, the connection of the latter with sprinting ability is yet unclear. Previous studies (McGuigan & Winchester, 2008; McGuigan et al., 2010; West et al., 2011; Miller et al., 2023; Barker et al., 2018) have focused mostly on the relationship of RFD with performance in various force tests (e.g., vertical jump, one-repetition maximum) reporting, however, inconsistent findings. For example, Barker et al. (2018) did not find any correlation between

RFD and jump height, whereas West et al. (2011) found significant positive relationship between these two metrics.

Another important consideration in RFD assessments is the calculation method used to determine RFD. Calculations may include either peak or mean RFD from the entire duration of the force development (McGuigan & Winchester, 2008) or the RFD at different time epochs (e.g.: the early or late phase of force development). According to the study of Haff et al. (2015), the RFD calculated from different time bands produces greater reliability than the peak RFD during the isometric mid-thigh pull exercise. In addition, the average RFD appeared to be less reliable (Haff et al., 2015).

The relationship between the RFD, assessed during isometric and ballistic test protocols, and sprint performance remains unclear. Given its use as a metric of explosive strength, RFD is expected to have a close connection with sprint performance. Therefore, the purpose of this study was to investigate the relationship between RFD values, measured in dynamic and isometric force tests, and sprint performance.

2. Methods

- ***Study Design***

Using an observational design, in this study we analyzed the results of a dynamic and static force test in relation to sprint performance. The same participants performed all measurements. Measurements were conducted on the same day, in the afternoon, in the same order for all participants. The testing protocol started with a basic anthropometric assessment, where body height and body mass were measured. This was followed by a 10-minute standardized warm-up to prepare the athletes for maximal power and sprint measurements. After the warm-up, the vertical jump test (CMJ) was performed first, followed by the isometric deadlift test after 15 minutes of rest. Finally, after another 20 minutes of rest, the 30m sprint measurement on a 50m long track was performed. A schematic representation of the test protocol is shown in Figure 1.

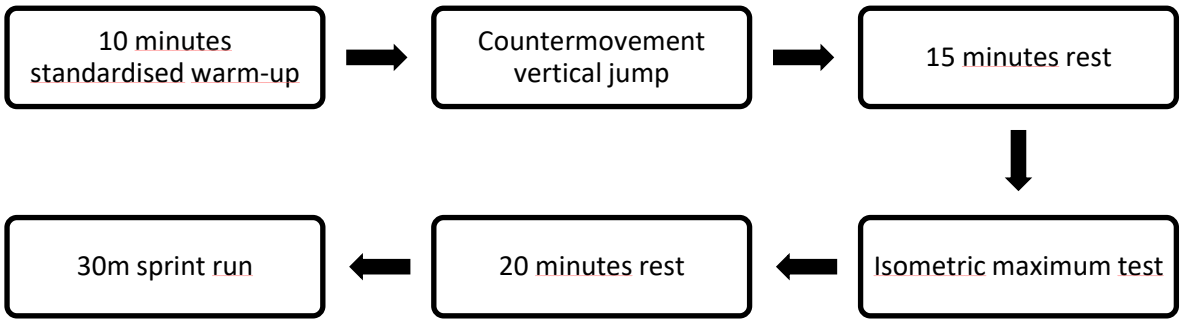

Figure 1. Schematic presentation of the research protocol

- ***Participants***

15 male, physically active university students participated. Their age was (mean±*SD*) 24.3±2.0 years, their body height 181.8±5.4 cm, and their body mass 77.3±6.0 kg. Participants had an average of four training sessions per week during the study period. They participated in different sports, including football, tennis, basketball, parkrun, and weightlifting. Most of the training sessions performed by the athletes were strength and endurance training sessions. Written and verbal explanations about the type of the measurements and their potential risks were provided to all participants before the measurements and then a written informed consent was obtained from all participants.

- ***Measurements***
- ***Vertical jump test***

In the vertical jump test, participants were required to perform a counter movement vertical jump (CMJ) on a forceplate (Bertec, FP4060-10-TM-2000, Bertec Corporation, Ohio, USA) with hands kept on hips. The sampling frequency was set at 1000 Hz. After a standardized 10 min warm-up (light jogging, dynamic stretching and mobility exercises, plyometric activation), the test consisted of three maximal jumps with a rest period of 2 min between jumps. Testing started from a still stance, followed by a quick knee bend ith a rapid jump-off aiming for maximum height. During the jumps, athletes were given continuous verbal motivation to jump as high as possible. Three jumps were performed, the jump with the highest jump height (calculated from impulse - momentum) and the corresponding mechanical variables (maximal and mean force and mechanical power) were used in the statistical analyses. The force-time curve extracted from the CMJ was used to calculate the RFD values from the moment the ground reaction force (GRF) exceeded body weight (after the unweighted phase) until peak force was reached (Figure 2, highlighted in grey). Peak RFD, mean eccentric RFD, and mean RFD during the first third of the

eccentric phase (0-33%) were obtained. Further, we calculated the time when maximal RFD was reached expressed in % of the total duration of the force development phase. Data were calculated using Templo (Contemplas GmbH, Kempten, Germany) software.

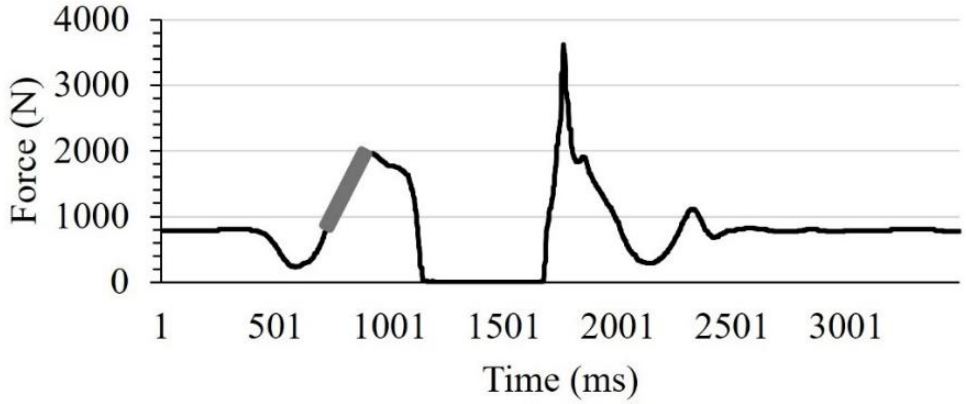

Figure 2. The force-time curve of the countermovement jump. Grey indicates the phase of the force development when peak and mean rate of force development were calculated.

- ***Isometric maximum test***

The isometric maximum measurement included a deadlift exercise using a fixed hex-bar on a force plate (Type 9286AA, Kistler Instruments, Corp., Winterthur, Switzerland) at a sampling frequency of 1000 Hz (figure 3). Knee flexion angle range was fixed at 115-120° throughout the entire pull, which was checked with a goniometer. The measurement was preceded by two warm-up deadlifts of respectively 50% and 70% of the perceived maximum followed by a trial with maximum force exertion. After maintaining a stationary position for 2–3 seconds, each trial started with a pre-tension followed by the maximal effort. The pre-tension was used to avoid a significant countermovement in the force development that could influence RFD calculations. The athletes were required to maintain maximum effort for 4-5 seconds and were verbally motivated to maximize effort. Participants were instructed to reach their maximum force as quickly as possible after the countdown, so that the actual maximum RFD values could be extracted during the force development phase. A rest period of four minutes was allowed between the two measurements.



Figure 3. Isometric deadlift test

For the RFD calculations, we considered the starting moment of force development when force raised above 3 standard deviations of baseline force (marked with grey dotted line in figure 4) and its termination when force started decreasing or flattening significantly (marked with grey solid line in figure 4). The total duration of the force development phase was then split into 1 ms time windows and the RFD for each window was calculated. From the RFD values of the 1 ms time windows, the time window with the highest RFD value was considered as the peak RFD (referred as Iso_RFDmax), the average value from the beginning of force development to peak force as the mean RFD (Iso_RFDaverage) and the RFD measured at the first 100 ms and 150 ms from the start of the force development (Iso_RFD100 and Iso_RFD150). Finally, the time (ms) when the maximal RFD was reached was recorded. The calculations were performed from the raw data of the vertical force (fz) over time (ms) in Excel (2016, Microsoft Office). For statistical analysis, the trial with the highest maximal RFD was processed, as the difference in maximum force between the two trials was generally negligible.

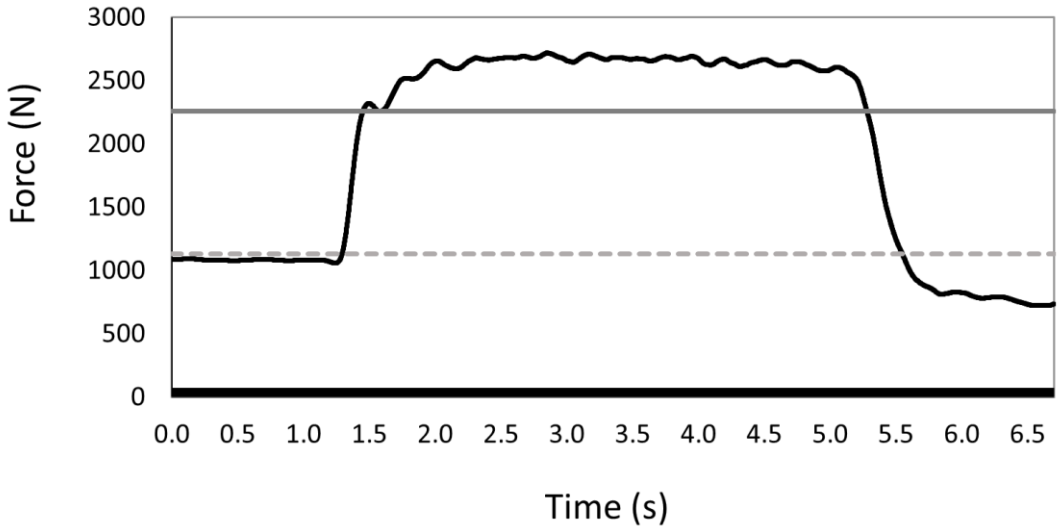

Figure 4. Force-time curve of the isometric maximum test. Grey dotted line: start of force development, grey solid line: end of the force development curve.

- ***Sprint Test***

Sprint performance was measured on a 50m indoor running track with built-in light gates (Microgate Srl, Bolzano, Italy). Participants performed two maximum 30m sprints with eight minutes rest between the two trials. Time results were recorded at 5-10-20-30m to the nearest hundredth of a second. The athletes started from a standing position without a starting gun, so they started the sprint at their own decision. The participants performed the sprint test in flat-soled running shoes. Throughout the run, athletes were motivated to run the best possible sprint time. The fastest of the two attempts at 30 m was used in the statistical analysis.

3. Statistical analysis

Statistical analysis was performed using using SPSS version 29.0 (SPSS Inc., Chicago, IL, USA). Results are presented as mean ± standard deviation. Normality was checked with the Shapiro-Wilk test. Since maximal RFD deviated from normality, comparisons between the RFD values obtained from the CMJ and the isometric force test were performed using the Friedman test. Comparisons between different RFD measures were then conducted with the Wilcoxon Test (with *r* effect size calculation) using the Bonferroni correction to control for the family-wise error (significance level was set at $p<0.002$). The relationship between RFD and sprint performance and vertical jump was evaluated using Spearman-rank correlation with the significance level set at $p<0.05$.

4. Results

Tables 1-3 show the descriptive results of the sprint test, the vertical jump, and the isometric maximum test. In the isometric and CMJ tests, on average, the athletes reached peak RFD in the second third of the force development phase. This was 43.4 ± 16.8% in the isometric test and 53.3 ± 17.0% in the CMJ test.

Table 1. Descriptive statistics of the sprint test.

	N	Mean	SD	Minimum	Maximum
5m (sec)	15	1,117	0,07	1,01	1,22
10m (sec)	15	1,878	0,09	1,71	2,05
30m (sec)	15	4,368	0,18	4,10	4,66
v_{peak} (m/s)	15	8,29	0,38	7,63	8,93
***v*5m (m/s)**	15	4,49	0,28	4,10	4,95

5m=first 5m of sprint test, 10m=first 10m of sprint test, 30m=first 30m of sprint test, v_{peak} = peak velocity measured during the sprint run, *v*5m=velocity measured during the first 5m

Table 2. Descriptive statistics of the vertical jump test.

	N	Mean	SD	Minimum	Maximum
Jump height (cm)	15	40,3	7,1	28,0	52,0
Maximum force (N)	15	1875	304	1019	2283
Relative maximum force (N/kg)	15	248,0	41,0	126,0	289,0
Average power (W)	15	2447	348	1843	2947
Relative average power (W/kg)	15	31,7	3,9	25,9	40,9
CMJ_TimeRFDpeak (%)	15	53,3	17,0	33,8	86,6

CMJ_TimeRFDpeak = time when peak RFD was reached during the CMJ expressed as percentage of the total duration of the jumping movement.

Table 3. Descriptive statistics of the isometric deadlift test.

	N	Mean	SD	Minimum	Maximum
Iso_Fpeak (N)	15	1576	323	975	2016
Iso_Fpeak_rel (N/kg)	15	20,4	3,71	13,7	27,01
Iso_TimeRFDpeak (%)	15	43,4	16,8	9,8	71,9

Iso_Fpeak = peak force measured in isometric test, Iso_Fpeak_rel = peak isometric force relative to body mass, Iso_TimeRFD peak = time when peak RFD was reached from the start of the force development phase.

Boxplots of the RFD values measured during the isometric deadlift and the CMJ are presented in Figure 4. Significant differences were found between the obtained RFD values (χ^2 = 59,7; p<0.01). Maximal RFD during the CMJ was significantly larger compared to all other conditions (p<0,01; r = 0.85 – 0.88). Collectively, all three RFD values calculated during the CMJ (maximal, mean, and mean of early phase) exhibited larger values than during the isometric deadlift. Among the RFD values obtained from the isometric deadlift test only the maximal RFD differed significantly (p<0.001; r>0.85), but there was no difference between the mean RFD and the RFD values at the first 100 and 150 ms.

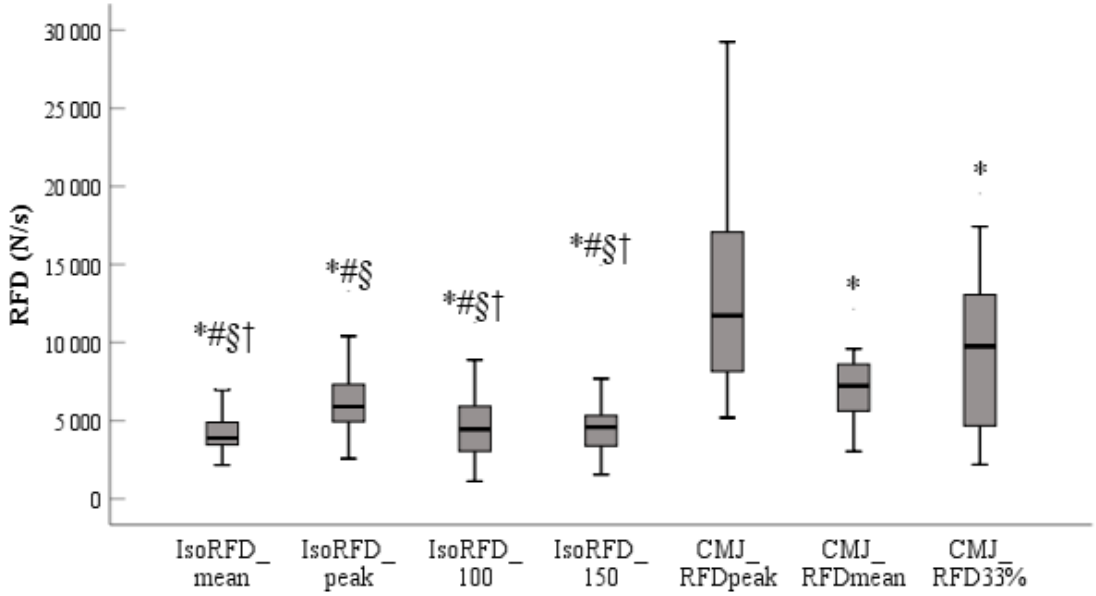

Figure 5. Boxplot of the RFD measures during the isometric deadlift and the countermovement jump tests.

*Iso_RFDmean = isometric mean rate of force development, Iso_RFDpeak = isometric peak rate of force development, Iso_RFD100 = rate of force development during the first 100ms of the isometric deadlift, Iso_RFD150 = rate of force development during the first 150ms of the isometric deadlift, CMJ_RFDmax = maximal rate of force development during the countermovement jump, CMJ_RFDmean = mean rate of force development during the countermovement jump, CMJ_RFD0-33% = mean rate of force development during the first third of the braking phase of the countermovement jump. * = significant difference compared to CMJ_RFDpeak. # = significant difference compared to CMJ_RFDmean, § = significant difference compared to CMJ_RFD33%, † = significant difference compared to ISO_RFDpeak*

Table 4 presents the Spearman-rank correlation coefficients between sprinting performance and various isometric and dynamic RFD metrics. Significant negative correlations were observed between the 5m sprint velocity and both the peak RFD and the RFD0-33% measured during the CMJ ($p < 0.05$). However, these findings appear in the opposite direction, as higher RFD values were associated with lower sprint velocities. Aside from these, no other significant correlations were found between any RFD metrics and sprint performance over 5m or 30m.

While RFD values did not correlate with sprint performance, other metrics demonstrated significant relationships. Jump height measured during the CMJ test showed a strong and significant correlation with sprint performance over 30 meters (Spearman's rho = 0.818, $p < 0.001$). Relative maximal isometric force during the isometric deadlift test also presented a moderate and significant correlation with 30-meter sprint performance (Spearman's rho = 0.552, $p = 0.033$).

Table 4. Spearman-rank correlation coefficients

	Iso RFD_{mean}	**Iso RFD_{peak}**	**Iso RFD_{100ms}**	**Iso RFD_{150ms}**	**CMJ RFD_{peak}**	**CMJ RFD_{mean}**	**CMJ $RFD_{33\%}$**
v5m	-0,147	-0,071	0,046	0,052	-0,524*	-0,411	-0,604*
v30m	0,163	0,148	0,295	0,277	-0,173	-0,191	-0,193
v_{max}	0,308	0,304	0,446	0,399	-0,014	-0,150	-0,050

*v*5m = mean velocity of the first 5m sprinting, *v*30m = mean velocity of the 30m sprinting, v_{max} = maximum velocity reached of the 30m sprinting Iso_RFDmean = isometric mean rate of force development, Iso_RFDpeak = isometric peak rate of force development, Iso_RFD100ms = rate of force development during the first 100ms of the isometric deadlift, Iso_RFD150ms = rate of force development during the first 150ms of the isometric deadlift, CMJ_RFDmax = maximal rate of force development during the countermovement jump, CMJ_RFDmean = mean rate of force development during the countermovement jump, CMJ_RFD0-33% = mean rate of force development during the first third of the braking phase of the countermovement jump. * = significant correlation at $p<0.05$

5. Discussion

The aim of the study was to investigate the relationship between isometric and dynamic RFD with sprint performance. Sprint performance requires quick and powerful force exertion, leading to the hypothesis that RFD, as a key

indicator of explosive strength, would be related to sprint outcomes. Our results did not support this hypothesis, as no interpretable significant correlation was found between RFD values and sprint performance.

The variability of the RFD as a performance indicator warrants consideration, as highlighted in previous research. For instance, Merrigan et al. (2021) found low reliability in repeated RFD measurements, suggesting that RFD can vary significantly within individuals. Although we did not include repeated measures in this study, the wide dispersion of values across participants was apparent, indicating that RFD measures and their related temporal variables can differ substantially.

Conflicting results have been reported in previous studies examining the relationship of RFD with performance metrics in explosive movements (McGuigan & Winchester, 2008; McGuigan et al., 2010; Barker et al., 2018; Miller et al., 2023, West et al., 2011; Tillin et al., 2013). This discrepancy suggests that the role of RFD in explosive movements, such as jumping and sprinting, remains uncertain in terms of performance outcomes. While explosive strength is undoubtedly critical for both high vertical jumps and high sprint performance (Herrington, 2021), our research did not validate RFD as a robust predictor of sprint performance, contrary to some previous studies like those by Wilson et al. (1995) and Tillin et al. (2013).

A key difference in our study compared to that of Wilson et al. (1995), lies in how RFD was measured. Wilson's calculated RFD during the concentric phase of a squat jump and found significant correlations between RFD and sprint performance. In contrast, in our study RFD was measured during the braking (eccentric) phase of the countermovement jump and under isometric muscle contraction during the isometric deadlift test. The differences in muscle contraction modes might explain the absence of significant correlations in our study, suggesting that the connection between RFD and sprint performance may be muscle contraction specific. RFD assessed during concentric muscle contraction may yield stronger correlations with sprinting.

We also observed strong relationships between relative maximum isometric strength and both vertical jump height and sprint performance. This finding indicates that while RFD may not differentiate between higher and lower sprint performances, measures of maximum strength and vertical jump height could be useful predictors of sprinting ability. Additionally, the significant correlation between vertical jump height and sprint performance suggests that

these variables may be more relevant for coaches when assessing explosive capacity and the effectiveness of training programs.

This may be attributed to the shared biomechanical and physiological demands of these activities. Both require the ability to generate high maximal force quickly, known as rate of force development (RFD). However, this alone does not fully account for the complexity of these movements. Vertical jumping and short sprints, involve dynamic, balanced, and highly coordinated muscle functions. These actions necessitate not only high force production but also the integration of elastic energy, core strength, and refined movement patterns. For example, the ability to explode upward in a vertical jump or accelerate from a standstill in a sprint requires the simultaneous activation and synchronization of multiple muscle groups. Additionally, both movements demand exceptional neuromuscular control to manage the transition between concentric and eccentric phases efficiently. This coordination allows athletes to optimize force transfer, maintain balance, and execute the movement efficiently under high-speed conditions.

In essence, the correlation may stem from the shared requirement for complex motor skills, muscular power, and structural adaptations, making these variables highly relevant for assessing explosive capacity and training program effectiveness.

Limitations

A factor to consider is the small and heterogenous sample considering that this study involved athletes from different sports with varying movement and force production patterns. This may have limited statistical power and eventually contributed to the lack of significant correlations. A more homogeneous sample, such as athletes from the same sport with similar training backgrounds and movement patterns, might provide clearer results regarding the relationship between RFD and sprint performance. Additionally, the isometric deadlift is a complex test that measures more than just lower limb strength. The contribution of core and trunk muscles to force production is much larger in this test compared to sprinting, where the lower limbs are the primary force generators. This difference in muscle activation may have contributed to the lack of significant correlations between the isometric RFD values and sprint performance.

In conclusion, RFD measured during isometric maximum force exertion and during the eccentric phase of a countermovement jump did not correlate with sprinting performance likely indicating different muscle contraction attributes

between the applied testing protocols and sprint tests. These findings suggest that RFD may not be suitable to evaluate sprinting ability. In contrary, maximal isometric force and vertical jump performance appear to be more reliable predictors of sprint capability.

- ***Acknowledgement***

- ***Conflict of interest***

On behalf of all authors, the corresponding author states that there is no conflict of interest.

- ***Data Availability***

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

- ***Funding***

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

- ***Ethical approval***

The study was approved by the Research Ethics Committee of the Hungarian University of Sports Science (approval number: TE-KEB/NO34/2019).

- ***Consent to participate***

Informed consent was obtained from all individual participants included in the study.

- ***Consent to publish***

Participants gave informed consent for publication of anonymized data in this article.

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