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Article

# Impact of Rest Intervals on the Force-Velocity Relationship Obtained During the Keiser's 10-Repetition Leg Press Test

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**Abstract: Background:** The Keiser 10-rep leg press test employs very short rest intervals between each of the ten repetitions (2-38 seconds). This raises concerns about whether the rest periods are sufficient for the athlete to perform optimally in each individual repetition. **Objectives:** The study aims to investigate the effect of using short (2-38s) or long (3min) rest intervals on maximal force ( $F_0$ ), velocity ( $V_0$ ), power ( $P_{max}$ ), and the slope of the FV-profile ( $FV_{slope}$ ) in the Keiser's 10-repetition leg press test. **Methods:** A total of 30 athletes (age  $17.1 \pm .9$  years, height  $177.8 \pm 8.8$  cm, body mass  $71.9 \pm 11.3$  kg), performed 3 separate tests (total of ~ 900 repetitions) in a Keiser A420 leg press machine, separated by 4 to 8 days. Test day 1 included a 1RM test followed by a 10-repetition force-velocity test with short rest intervals between the repetitions. Test days 2 and 3 involved the same test, with pre-programmed either short rest intervals, or manually conducted long rest intervals, between repetitions. **Results:** Increasing inter-repetition rest significantly improved  $V_0$  and  $P_{max}$ , while also altering the FV slope. A small but significant reduction was observed in  $F_0$ . These benefits of longer rest were associated with light to moderate loads, where standard Keiser rest intervals are short (2–9 seconds). However, extending rest intervals beyond approximately 30 seconds, as used at higher loads, provided no additional advantages. **Conclusions:** Longer rest intervals improve  $V_0$ ,  $P_{max}$ , and FV slope, particularly at light to moderate loads where standard short rests are insufficient. Extending rest beyond 30 seconds at higher loads offers no additional benefits.

**Keywords:** physical testing; force-velocity test; power; mobilizing; rest intervals; recovery

## 1. Introduction

Force-velocity (FV) profiling, and specifically the Keiser 10-rep test, has seen a significant rise in popularity over the last decades [1,2]. Due to the fixed seating position and back support, machine exercises such as this are considered safe, less technically demanding, and require less familiarization compared to more traditional free-weight exercises [3]. In sports requiring significant strength, power, and speed, FV profiling has become an essential tool for assessing performance, monitoring training adaptations, and providing coaches with valuable insights to optimize training programs for athletes [3–8]. The concept of FV profiling is grounded in the fundamental properties of skeletal muscle, wherein an inverse relationship exists between force and velocity [9,10].

The FV relationship in multi-joint movements exhibits a linear pattern, contrasting with the hyperbolic relationship seen in isolated muscles or single-joint movements [9]. This linearity allows the calculation of a linear regression line and the extrapolation of its endpoints, identifying four key metrics: the theoretical maximum force ( $F_0$ ), representing the force at zero velocity, and the theoretical maximum velocity ( $V_0$ ), representing the velocity at zero force. Additionally, the theoretical maximum power is calculated using the formula  $(F_0 \cdot V_0)/4$ , and the slope of the FV profile ( $FV_{slope}$ ) is determined as  $F_0/V_0$  [6,11].

For assessing lower body musculature, force-velocity (FV) profiling has most commonly been determined using vertical jumps with incremental loads [12,13]. However, this method has limitations, including the technical difficulty of jumping with heavy loads near  $F_0$  and the inability to measure velocities close to  $V_0$  due to body weight being the lightest possible load [7]. The pneumatic resistance-based Keiser leg press, widely used in sports and research facilities globally, offers several advantages over traditional weight-based exercises [14]. One of the main advantages with pneumatic based resistance is that it allows for more precise assessment near the  $F_0$  and  $V_0$  intercepts since the effects of inertia and body weight are minimized. Obtaining measurements closer to  $F_0$  and  $V_0$  has been shown to produce more reliable results [6,15]. The Keiser A420 leg press is equipped with a pre-installed, standardized protocol for force-velocity profiling based on a series of 10 repetitions at different loads. The test requires an input of an estimated 1RM value, from which it calculates appropriate loads for each repetition necessary to obtain a full FV profile [16].

To achieve a valid test result that can be used to assess development in high-level athletes, it is crucial that the test accurately reflects the performance capacity [17]. In the context of FV-profiling, using appropriate inter-repetition rest intervals is crucial for achieving full recovery, which in turn facilitates consistent and optimal performance results [18–20]. In the Keiser A420 10-rep test, the inter-repetition rest intervals are pre-determined, ranging from 2 seconds between the two lightest loads (reps 1 and 2) to 38 seconds between the two heaviest loads (reps 9 and 10), which diverge from widely accepted recommendations for maximal effort strength, speed and power testing [18,21–23]. For one-repetition maximum (1RM) testing, rest intervals of 2 to 5 minutes are commonly recommended [21,24]. In assessments of explosive strength and sprint, rest intervals of 1 to 3 minutes have been suggested as optimal [23]. These rest intervals are reference ranges and may need to be adjusted based on gender, age, sport, and training status [25–28]. Previous studies have indicated that strong individuals with a significant amount of muscle mass may require longer rest periods than weaker individuals with less muscle mass [29].

To our knowledge, no previous investigations have explored the influence of longer inter-repetition rest interval duration on the FV-outcome using the Keiser A420 leg press. The aim of this study was to compare the results of the Keiser protocol using standard incremental inter-repetition rest intervals of 2-38 seconds, with a modified protocol using fixed 3 inter-repetition rest duration, focusing on the main test outcome variables:  $V_0$ ,  $F_0$ ,  $P_{max}$ , and  $FV_{slope}$ .

## 2. Methods

### 2.1. Participants

A total of 30 participants, all enrolled in a sports program at the same high school in Norway, were recruited for this study. Their age, height, and body mass (mean  $\pm$  SD) were  $17.1 \pm 0.9$  years,  $177.8 \pm 9.0$  cm, and  $71.9 \pm 12.1$  kg. The study included both male ( $n=14$ ;  $16.9 \pm 0.9$  years;  $185.3 \pm 6.6$  cm;  $77.7 \pm 12.1$  kg) and female ( $n=16$ ;  $17.1 \pm 0.8$  years;  $171.3 \pm 4.7$  cm;  $66.4 \pm 8.1$  kg) athletes. Fifteen of the participants were handball players, and the remaining 15 participants were endurance athletes competing in track (middle-distance and long-distance,  $n = 6$ ), orienteering ( $n = 1$ ), cycling ( $n = 2$ ), rowing ( $n = 5$ ), and swimming ( $n = 1$ ). All participants competed at a national junior level in their respective sport (Table 1).

**Table 1.** Baseline characteristics of the athletes in the study ( $n = 30$ ).

Variable	All athletes ( $n = 30$ )		Endurance athletes ( $n = 15$ )		Handball athletes ( $n = 15$ )	
	F (16)	M (14)	F (8)	M (7)	F (8)	M (7)
Sex (n)	F (16)	M (14)	F (8)	M (7)	F (8)	M (7)
Age (years)	$17.1 \pm .8$	$16.9 \pm .9$	$17.5 \pm .8$	$16.2 \pm .4$	$16.9 \pm 0.8$	$17.7 \pm .5$
Height (cm)	$171.3 \pm 4.7$	$185.3 \pm 6.6$	$171.3 \pm 5.5$	$180.6 \pm 4.9$	$173.0 \pm 11.3$	$189.9 \pm 7.6$
Weight (kg)	$66.4 \pm 8.1$	$71.9 \pm 12.1$	$64.5 \pm 10.3$	$71.9 \pm 10.1$	$74.8 \pm 12.7$	$86.8 \pm 5.9$

## 2.2. Experimental Approach to the Problem

All participants completed three days of testing (Table 2), separated by 4 to 8 days to allow for adequate physical recovery. All tests were performed on a Keiser A420 pneumatic leg press machine at the Norwegian Olympic Federation test center in Stavanger, Norway. On Test Day 1, participants underwent a 1RM (one-repetition maximum) test protocol, followed by a familiarization session using the Keiser 10-repetition force-velocity (FV) profiling test. Standard rest intervals of 2–38 seconds were implemented between repetitions during the familiarization session. The recovery time between the two tests was 5 minutes. During test day 2 and 3, the participants performed either the Keiser 10-repetition FV-profiling test with standard (Short) incremental rest intervals of 2-38 seconds, or a fixed manually timed 3-minute rest intervals (Long) between each repetition. Participants were randomized into two groups, ensuring a balanced distribution of gender and sport background in each group. Differentiating the test order aimed to minimize the potential influence of test familiarization on the results.

**Table 2.** The content of the test days.

Group	Test day 1	Test day 2	Test day 3
1	1RM + FV profiling (Short)	FV profiling (Short)	FV profiling (Long)
2	1RM + FV profiling (Short)	FV profiling (Long)	FV profiling (Short)

## 2.3. Procedures and Warm-Up

On test day 1, body weight and height were measured using a Seca 877 floor scale and a Seca 222 mechanical telescopic measuring rod. All subjects performed a standardized warm-up prior to each test session. This included a general warm-up consisting of 5 minutes of ergometer rowing (pace 2-2:30 min/500m), followed by a specific warm-up on the Keiser leg press, consisting of 1 x 3 repetitions at 20%, 40%, and 60% of estimated 1RM, with a 1-minute rest interval between each load level. In advance, all participants received written instructions to prepare themselves for each test sessions as they would for a competition, with regards to diet, fluid intake, and rest. They were also instructed to avoid any strenuous exercise 24 hours prior to testing. The equipment, test leader, and location were identical for all tests.

## 2.4. Strength Testing Protocols

For both the 1RM and Keiser's 10-rep tests, each participant's seat on the Keiser A420 leg press was adjusted to achieve a nearly vertical femur, with the position recorded and consistently used across all tests. Feet were positioned with the heels flush at the lower end of the foot pedal to standardize testing across participants.

Maximum strength was assessed using Earle's 1RM testing protocol [21,27]. Following a warm-up, participants rested for 2 minutes before doing 2-3 repetitions at a submaximal load equivalent to approximately 80% of their predicted 1RM. The load was then progressively increased, with 3-minute rest intervals between attempts, until 1RM was achieved. All participants successfully determined their 1RM within 3–5 attempts.

All participants underwent Keiser's 10-rep test protocol on 3 separate occasions (Table 2). The value from the 1RM test was entered and based on this the Keiser A420 software calculated and dictated individual test loads. Participants were instructed to execute each repetition with maximum effort during the concentric phase, starting from the predetermined pedal position ensuring concentric-only actions without countermovement. The eccentric phase was performed submaximally and was not recorded.

**Table 3.** Rep-by-rep values for loads relative to 1RM and inter-repetition rest durations under the two test conditions: short (standard) and long (fixed 3 minutes).

Repetition:	1	2	3	4	5	6	7	8	9	10
% of 1RM	15	27	35	45	54	63	72	82	91	100
Short rest intervals (sec)*	2	5	5	6	9	13	18	26	38	
Long rest intervals (min)**	3	3	3	3	3	3	3	3	3	

\* The total recovery time was 2:08 minutes using short rest intervals. \*\* The total recovery time was 27:00 minutes using long rest intervals.

#### 2.4. Statistical Analyses

A repeated measures multivariate analysis of variance (RM-MANOVA) was conducted to examine the overall effect of experimental conditions on the four dependent variables ( $V_0$ ,  $F_0$ ,  $P_{\max}$  and  $FV_{\text{slope}}$ ) while accounting for within-subject variability and the correlations among the dependent variables. The analysis included one within-subject factor, rest interval, with two levels: "Short" and "Long." The RM-MANOVA tested the main effect of rest intervals and the interaction between the two levels of conditions (Short and Long) and the dependent variables to determine whether the condition's effect varied across the different measures.

Before conducting the RM-MANOVA, data were restructured, and key assumptions were tested and confirmed within acceptable limits. These included normality (Shapiro-Wilk test), homogeneity of covariance matrices (Box's M test), and sphericity (Mauchly's test). Correlations among the dependent variables were also examined, confirming that multicollinearity was not a concern.

Follow-up univariate analyses were conducted for each dependent variable to identify specific effects. A significance level of  $\alpha=0.05$  was applied to all statistical analyses. Bonferroni correction was applied to control for Type I error across multiple comparisons, and effect sizes (partial eta squared,  $\eta^2$ ) are reported to indicate the magnitude of the observed differences. Consistent with established guidelines, effect sizes values were interpreted as small ( $\eta^2=0.01$ ), medium ( $\eta^2=0.06$ ), and large ( $\eta^2=0.14$ ). All statistical analyses were conducted using SPSS (version 28, IBM Corp., Armonk, NY, USA). GraphPad Prism (version 10.4.0, GraphPad Software, San Diego, CA, USA) was used for data visualization and graphical representation of the results.

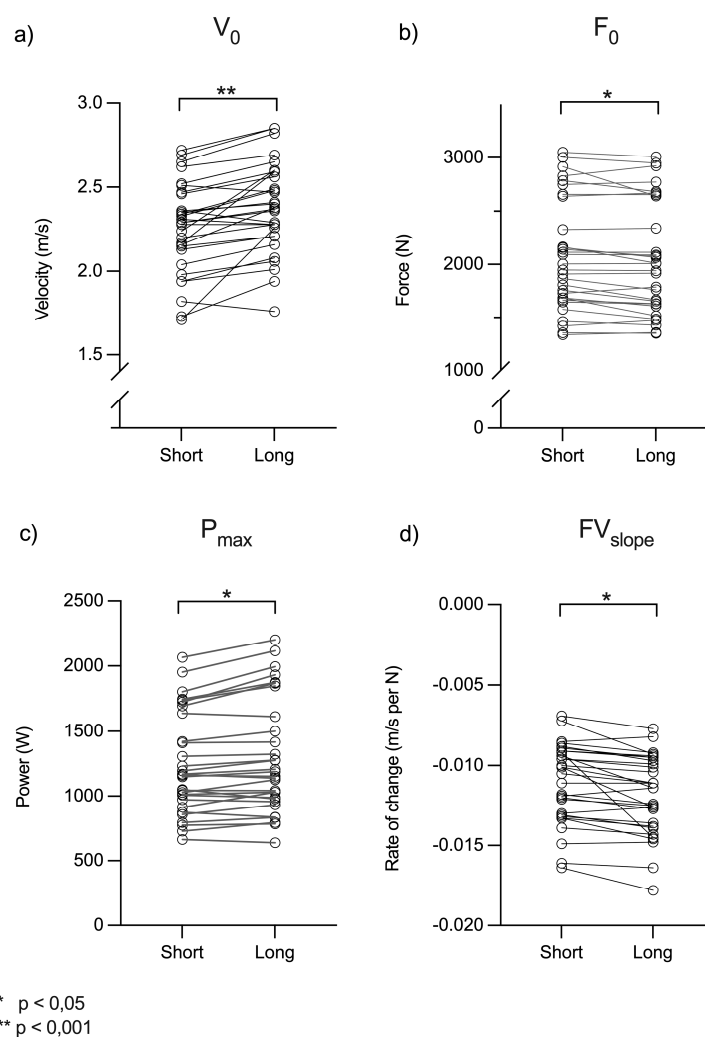
### 3. Results

The initial analysis (RM-MANOVA) showed no significant difference of inter-repetition rest interval length when considering all dependent variables together ( $F_{1,29} = 0.329$ ,  $p = 0.571$ , partial  $\eta^2 = 0.011$ ). However, a significant interaction effect was found between rest and dependent variables ( $F_{3,27} = 8.969$ ,  $p < 0.001$ , partial  $\eta^2 = 0.499$ ), suggesting that the effect of rest interval length varied across the dependent variables. Follow-up univariate analyses revealed significant differences between short and long rest intervals across all measured variables (Table 4). Participants exhibited a significantly higher theoretical maximum velocity ( $V_0$ ) following long rest intervals compared to short rest intervals (Mean  $\pm$  SD:  $2.38 \pm 0.27$  m/s<sup>2</sup> vs.  $2.26 \pm 0.27$  m/s<sup>2</sup>;  $p < 0.001$ ). This represented a 5.7% increase with a large effect size ( $\eta^2 = 0.344$ ), suggesting that extended recovery optimizes velocity-dominant performance. Conversely, maximum force ( $F_0$ ) was slightly but significantly greater with short rest intervals compared to long rest intervals (Mean  $\pm$  SD:  $2082.6 \pm 523.7$  N vs.  $2040.2 \pm 523.0$  N;  $p = 0.010$ ). Although the mean difference was modest (-2.1%), the effect size was moderate ( $\eta^2 = 0.208$ ), indicating a potential benefit of shorter rests for force output. Long rest intervals produced significantly higher peak power outputs (Mean  $\pm$  SD:  $1296.7 \pm 440.3$  W vs.  $1243.2 \pm 389.6$  W;  $p = 0.005$ ), with a mean increase of 3.69% and a moderate effect size ( $\eta^2 = 0.253$ ). This underscores the importance of recovery for optimizing power performance. The force-velocity slope ( $FV_{\text{slope}}$ ) was steeper following long rest intervals compared to short rest intervals (Mean  $\pm$  SD:  $-0.0119 \pm 0.002$  vs.  $-0.0111 \pm 0.002$ ;  $p = 0.035$ ). Although the percentage change was relatively large (+8.12%), the effect size was small ( $\eta^2 = 0.146$ ), suggesting a less pronounced but significant influence of rest duration on the relationship between force and velocity.

**Table 4.** Mean values and results from univariate analyses of all FV-metrics calculated using the Keiser 10-repetition test, with Bonferroni-corrected p-values, for standard short (2–38 seconds) and long (3-minute) inter-repetition rest intervals.

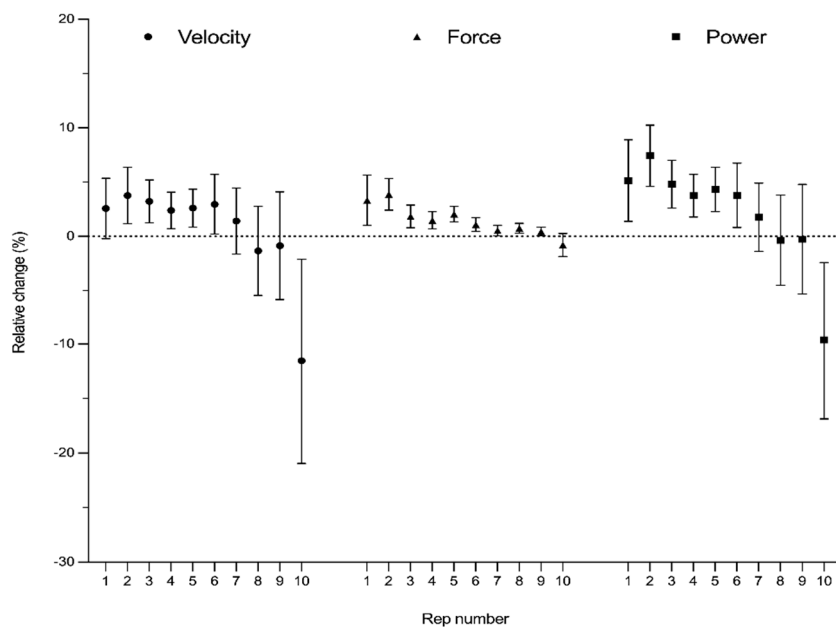
FV-variable	Mean value ( $\pm$ SD)		Mean difference (%)	Effect size ( $\eta^2$ )	P-value
	Short	Long			
$V_0$ (m/s <sup>2</sup> )	2,26 (0,27)	2,38 (0,27)	5,7	0,344	< 0,001
$F_0$ (N)	2082,6 (523,7)	2040,2 (523,0)	-2,1	0,208	0,010
$P_{\max}$ (W)	1243,2 (389,6)	1296,7 (440,3)	3,7	0,253	0,005
$FV_{\text{slope}}$ (N•m/s)	-0,0111 (0,002)	-0,0119 (0,002)	8,1	0,146	0,035

The individual test results for each metric, shown in Figure 1 (a–d), provide a detailed visualization of participant-level variability. Figure 1a demonstrates consistently higher  $V_0$  values observed with long rest intervals across most participants. In contrast, figure 1b demonstrates greater variability in  $F_0$  values, with some individuals performing similarly, or in some cases better, with short rest intervals. Figure 1c illustrates a clear trend toward higher  $P_{\max}$  with longer rest intervals, while Figure 1d shows individual responses for  $FV_{\text{slope}}$  with an overall trend pointing towards steeper slopes with longer recovery. These figures illustrate the range of individual adaptations to different rest interval protocols, complementing the statistical findings reported in Table 4.



**Figure 1.** Individual test results for the Keiser 10-rep test for  $V_0$  (a),  $F_0$  (b),  $P_{\max}$  (c) and  $FV_{\text{slope}}$  (d). “Short” refers to standard rest intervals as dictated by Keisers 10-rep test protocol (2–38 s), while “Long” represents consistent 3-minute rest intervals between each repetition.

Figure 2 illustrates the average relative changes in velocity, force, and power metrics across repetitions during the 10-repetition test. For velocity, average changes ranged from 2.57% to -11.53% across repetitions, with increasing variability reflected by a standard deviation of 7.79% to 23.54%. Similarly, force changes ranged from 3.33% to -0.79%, showing lower variability (SD: 6.46% to 2.62%). Power demonstrated the largest relative changes (5.14% to -9.63%) and the greatest variability (SD: 10.51% to 20.20%). These trends highlight the advantage of longer rest intervals at lower loads, with progressively diminishing performance benefits of long rest intervals as loads increase.



**Figure 2.** Mean values for each repetition from light (1) to maximal (10) loads for velocity, force and power. Error bar: 95% CI.

#### 4. Discussion

This study aimed to investigate if longer inter-repetition rest intervals influence force-velocity (FV) metrics—specifically  $V_0$ ,  $F_0$ ,  $P_{max}$ , and  $FV_{slope}$ —during the Keiser A420 leg press 10-rep test. A significant interaction revealed that the impact of inter-repetition rest duration varied across the FV metrics. Follow-up analyses demonstrated significant differences in all four metrics, with the largest average difference in the  $FV_{slope}$  (8.1%), followed by a 5.7% increase in  $V_0$  and 3.7% increase in  $P_{max}$ . In contrast, a small but significant reduction (2.1%) was observed in  $F_0$  when longer rest intervals were used. Individual repetition analysis revealed a load specific effect, indicating that the very short rest intervals (2-9 seconds) used in the Keiser 10-rep test at low and moderate loads impair optimal performance and should be increased to elicit optimal performance and test results.

Accurate assessments of metrics such as  $V_0$ ,  $F_0$ ,  $P_{max}$ , and  $FV_{slope}$  are critical for tailoring athlete training programs [5,7,14]. When assessing athletic performance, even subtle improvements can be meaningful if they represent a genuine enhancement in an athlete's capabilities rather than variability caused by testing protocols, instrumentation, or fluctuations in athlete preparedness on a given day. In sports testing, the smallest worthwhile change (SWC) is frequently calculated as  $0.2 \times$  the baseline standard deviation (SD), as suggested by Cohen [30,31]. Applying this threshold to our data, both  $V_0$  and  $FV_{slope}$  comfortably exceeds the SWC, while  $P_{max}$  approaches but remains just below this limit. However, for elite athletes, even smaller relative changes might be considered worthwhile, given the minimal margins often separating competitors at the highest level [32,33].

Another important consideration when interpreting test performance data is the reliability of the test itself. Reliability ensures that observed differences are not the result of random measurement error. In this context, the typical error (TE), a widely recognized measure of reliability, quantifies the random variation inherent in repeated measurements [34]. Although the TE was not explicitly

reported in this study, all differences in FV-variables, except for  $F_0$ , exceeded TE thresholds (data not shown). This indicates that the performance changes due to longer rest intervals are unlikely due to random variability, thereby underscoring the practical significance of our findings. Together, evaluation of SWC and TE strengthens the confidence that the reported improvements in this study reflect real and meaningful changes in performance rather than measurement noise [35].

In agreement with our findings, both velocity and power have previously been shown to be highly sensitive to recovery times [36]. Although the initial loads in the Keiser 10-rep test start as low as 15% of 1RM, each repetition requires maximal efforts and must elicit the highest possible rate of force development (RFD), requiring maximal bursts of action potentials in the nervous system [37,38]. It seems plausible that resting for only 2-9 seconds, which is the case for rep 1 through 6, does not give the nervous system enough time to fully recover and prepare for another maximal effort action potential discharge [20]. Other explanations for the benefits of longer rest intervals might lie within the muscle cells energy delivery system, as high intensity efforts rely on fast acting glycolytic energy systems. Depleting PCr stores and accumulating metabolic byproducts, such as  $H^+$  ions, have previously been shown to impair muscle function ([24,29]). Extending rest intervals beyond 2-9 seconds would thus increase muscle cells ability for sufficient PCr replenishment and pH stabilization, potentially enabling higher force and velocity outputs [29].

In contrast to the results observed at light and moderate loads, and somewhat unexpectedly, extending rest intervals at loads above 80% of 1RM (repetitions 8–10) did not improve performance. Instead, it resulted in a small yet statistically significant reduction in performance. One possible explanation for this finding might lie in the fact that resting as long as 3 minutes might be counterproductive. Extending inter-repetition rest intervals longer than needed might cause participants to lose focus and optimal level of arousal, thereby reducing the psychological basis to optimally perform maximal effort attempts [39]. In fact, this sensation was reported to the test leader by several of the athletes during and after testing. In accordance with this hypothesis, a study by Nibali and coworkers [20], found no significant benefits of additional rest beyond one minute, when performing FV-profiling using a loaded squat jump. As shorter rest intervals were not tested in their study, and considering our findings, it is plausible that a threshold exists somewhere around 30–60 seconds, beyond which no further improvement in performance can be achieved. Extending rest intervals beyond this time frame may negatively impact maximal effort test results during single repetitions, such as in force-velocity profiling.

The substantial inter-subject variation observed at high loads, particularly during repetition 10, likely results from a combination of factors. Firstly, the final repetition in the Keiser 10-rep test represents the participant's 1RM. Notably, six out of the 30 participants were unable to complete a full concentric repetition at their predetermined 1RM (established during test day one) on one or both subsequent test days. Despite instructions to prepare consistently, as they would for competition, individual differences in readiness and day-to-day variations are inevitable. Additionally, we believe that excessively long rest intervals may have contributed to the increased variance observed at higher loads, likely due to fatigue from prolonged duration and a loss of optimal arousal levels, as previously mentioned. While rest protocols were counterbalanced for half of the participants to reduce familiarization and learning effects, the load sequence remained consistent across all participants. Future research should explore reversing the load sequence, starting with the highest loads, to assess whether prolonged test durations and potential psychological fatigue are specifically related to the load or the overall testing time.

From a methodological standpoint, our findings emphasize the importance of aligning FV profiling protocols with physiological and psychological recovery principles. Furthermore, while 3-minute rest intervals were used in this study, reducing unnecessarily long rest intervals—and thereby shortening the total test duration—would be advantageous from a practical perspective. Given that tests are often conducted on larger groups or teams, logistical efficiency, cost-effectiveness, and time management are important considerations. Future research should therefore aim to identify the optimal recovery time required to balance these practical constraints with accurate performance assessment.

## 5. Conclusion

In conclusion, this study highlights the need to re-evaluate inter-repetition rest interval lengths in FV profiling using the Keiser A420 leg press. While longer rest intervals significantly enhance performance metrics at light to moderate loads, they offer no additional benefits at higher loads. Future research should aim to optimize load-specific rest intervals to maximize performance outcomes without compromising the efficiency of testing protocols.

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**Institutional Review Board Statement:** The study was conducted in accordance with the ethical standards of the responsible academic institution. Approval for data protection and management was obtained from the Norwegian Center for Research Data (reference number: 339372) and performed in agreement with the Declaration of Helsinki.

**Data Availability Statement:** The datasets generated and/or analyzed during the current study can be obtained from the corresponding author upon reasonable request.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

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