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**Article Title:** Effects of Knee Position on the Reliability and Production of Maximal and Rapid Strength Characteristics During an Isometric Squat Test

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Effects of knee position on the reliability and production of maximal and rapid strength characteristics during an isometric squat test

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Conflict of Interest Disclosure: None

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Running Title: Reliability, Knee Position, and Squat Strength
Abstract

This study aimed to examine the effects of knee position on the reliability and production of peak force (PF) and rate of force (RFD) development characteristics during an isometric squat. Fourteen resistance-trained females performed isometric squats at 90, 120, and 150° knee angles (corresponding to parallel, half, and quarter squat positions, respectively) on two different occasions, from which PF, peak RFD, and early (RFD30, RFD50, RFD100) and late (RFD200) phase RFD variables were extracted. PF and RFD200 were highly consistent across trials for all three squat positions, with intraclass correlation coefficients (ICCs) ranging between 0.812-0.904 and coefficients of variation (CVs) between 6.6-19.4%. For peak and early RFD characteristics, higher ICCs and lower CV values were observed for the quarter squat (ICCs=0.818-0.852, CVs=17.3-19.4%) compared to the parallel (ICCs=0.591-0.649, CVs=30.1-55.9%) and half squats (ICCs=0.547-0.598, CVs=31.1-34.2%). In addition, isometric PF and RFD200 increased (P≤0.001-0.035) with squat position (parallel<half<quarter); however, there were no differences for peak RFD (P≥0.265), RFD30 (P≥0.999), RFD50 (P≥0.999), and RFD100 (P≥0.093). These findings suggest that performing isometric squats at higher (150°) rather than lower knee joint angles (90-120°) may provide for an improved capacity to produce greater PF and RFD200 as well as a more reliable testing position for measuring peak and early RFD characteristics.

Keywords: joint angles, peak force, rate of force development, consistency, resistance-trained

Word Count: 3541 words
Introduction

Strength-based performance characteristics, such as peak force (PF) and rate of force development (RFD), are commonly measured to assess functional ability,\(^1\) discriminate between athletes of different performance levels,\(^2\) and monitor neuromuscular performance changes in response to training or fatigue-related interventions.\(^3,4\) Single-joint isometric assessments at the hip,\(^5\) knee,\(^6\) and ankle\(^7\) are often used to examine PF and RFD variables; however, it has been suggested that these tests, given their low functional specificity, may not be sensitive enough to identify athletic performance abilities during dynamic activities, including vertical jumping, sprinting, and balance.\(^8\) In contrast, multi-joint assessments, such as the isometric squat, are kinematically similar to many jumping, sprinting, and balance-related movements,\(^2\) and thus, may have a stronger relationship with these types of performances. Indeed, previous authors have reported significant relationships between isometric squat PF and RFD and vertical jump power and postural stability in young, middle-aged, and older adults.\(^9,10\) Moreover, Tillin et al\(^2\) reported that rapid but not maximal force production as assessed during an isometric squat was greater in fast compared to slow sprinters, which suggests that isometric squat explosive strength may be an important variable for identifying sprint performance abilities in athletes.

Taken together, these findings demonstrate the utility of the isometric squat as an effective tool for assessing lower-body performance capacities in young and older adults. However, because the isometric squat and its utility as a performance test is influenced by the reliability and knee position from which it is performed,\(^8\) selecting the position that provides the most reliable strength values for this type of testing is critical. The isometric squat has been examined at knee joint angles ranging from 90 to 150° (180° fully extended).\(^2,3,9,11-15\) Recently, many studies have found that the isometric squat is a reliable assessment for examining maximal strength (i.e. isometric PF)
regardless of the knee position used for testing.\textsuperscript{2,3,11,12,15} However, for measurements of RFD, which represent explosive strength, previous reliability studies have reported conflicting results, with some research showing high test-retest reliability\textsuperscript{14} and others reporting lower reliability values for these variables.\textsuperscript{3,11} Because the reliability values reported in several of these studies were for early (≤100 ms) RFD characteristics derived from lower knee joint angles (90 and 120°),\textsuperscript{3,11} it remains unclear whether the consistency of these isometric squat measurements is greater at a knee position closer to full extension (150°). Greater muscle pain or discomfort, which would reduce RFD reliability,\textsuperscript{8} has been suggested to occur at flexed compared to more extended knee positions during multi-joint isometric assessments.\textsuperscript{16} Thus, it is possible that isometric squats at more extended knee joint angles of 150° may be a more reliable testing position than those at 90 and 120° knee angles for assessing RFD measurements within the early phase of contraction; however, further research is needed to test this hypothesis. Furthermore, increases in knee position for the isometric squat test have been shown to improve maximal force production, as indicated by increases in PF;\textsuperscript{17-19} however, we are aware of no studies that have evaluated the effects of knee position on isometric squat RFD measurements.

The majority of previous studies investigating maximal and explosive strength during an isometric squat test have measured these variables by having their subjects stand on a force plate against an immovable bar with the knees fixed at a specific angle.\textsuperscript{2,3,9,11,12,15} Although this testing configuration is commonly used in research settings, it has been criticized for being difficult to set-up and administer\textsuperscript{14} and potentially injurious.\textsuperscript{8} Recently, a new isokinetic squat device (eSQ, Exerbotics, LLC, Tulsa, OK, USA) was developed that may allow researchers to assess isometric force production in a safer and more efficient manner. Previous authors\textsuperscript{20,21} using this device have recently reported it to be a reliable assessment tool for measuring isokinetic squat strength;
however, they did not examine its reliability for measuring maximal and explosive strength isometrically. Moreover, because most previous reliability studies measuring isometric squat strength have only examined resistance-trained males,\textsuperscript{3,11,12,14} it may be of great value to examine resistance-trained females to help shed light on the reliability of PF and RFD variables in this population. Thus, the purpose of the present study was to examine the effects of 3 different knee joint angles (90°, 120°, and 150°) using a novel testing device on the reliability and production of PF and RFD characteristics as assessed during an isometric squat in healthy, young resistance-trained females. Based on the results reported by previous authors,\textsuperscript{3,11,14,17} we hypothesized that greater isometric squat reliability and force production values would be demonstrated for the higher (150°) compared to the lower (90 and 120°) knee joint angles.

**Methods**

Fourteen resistance-trained females (mean ± SD; age = 22 ± 3 years; height = 168 ± 10 cm; mass = 71 ± 14 kg) volunteered to participate in this study. Each participant completed a self-administered questionnaire prior to testing to assess their health history and volume of resistance training activity. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints. All participants reported being consistently engaged in a structured weight training program that involved lower body resistance training (which included the back squat exercise) 1-8 h per week for a minimum of at least 6 months prior to the study. This study was approved by the university’s institutional review board for human subject’s research, and each participant read and signed an informed consent document.

Each participant visited the laboratory three times, separated by 2 – 7 days at approximately the same time of day (± 2 h). The first visit was a familiarization trial (data were not collected) and the next two visits were experimental trials (trial 1 and trial 2) from which data were collected.
and used for subsequent analyses. During the familiarization trial, participants practiced the strength testing protocol, which consisted of performing several isometric back squats at each knee position. For each experimental trial, participants completed six isometric squat assessments involving two assessments at each condition which included knee angles of 90, 120, and 150°, corresponding to parallel, half, and quarter squat positions, respectively.\textsuperscript{22} Knee joint angles were defined as the relative angles between the leg and thigh and were measured using a goniometer. The order of the parallel, half, and quarter squat assessments was randomized during each trial. Participants were instructed to maintain the same lifestyle between trials and to refrain from any vigorous physical activity or exercise within 24 h of testing.

Isometric strength testing was performed using a calibrated isokinetic squat device (eSQ, Exerbotics, LLC, Tulsa, OK, USA), which consisted of a motor-driven rig and back and shoulder pads that were connected to a load cell designed to measure force production during squatting.\textsuperscript{20} The height of the pads could be adjusted and fixed at any position within the range of motion. When using a barbell during the back squat, Wretenberg et al\textsuperscript{23} reported that placing the bar at a high position on top of the shoulders provides a more equal distribution of load between the hip and knee, which may reduce the risk of hip overload when compared to placing the bar at a lower position across the spine of the scapula. Therefore, from a safety standpoint, we instructed our participants for all testing to assume a similar “high-bar” position,\textsuperscript{23} which consisted of them grabbing onto the handles (for stability purposes) and placing the top of their trapezius against the back pad of the squat device.\textsuperscript{21} Feet were positioned shoulder-width apart with the toes pointed slightly outward.\textsuperscript{20,21} Foot position was recorded using a custom grid overlaid on the platform of the squat device to ensure the same stance for each trial. For each assessment, participants were instructed to keep their cervical spine in a neutral position. All participants wore tennis shoes and
no weight belts or knee wraps were permitted during testing. Before the maximal isometric strength testing, participants performed 3 submaximal isometric back squat muscle actions (at the knee angle from which the first strength assessments were to be performed) at approximately 75% of their perceived maximal strength. After the submaximal contractions, each participant performed 2 isometric back squat maximal voluntary contractions (MVCs) at 90, 120, and 150° knee joint angles (Figure 1) with 1 minute of recovery between each contraction and 3 minutes of recovery between positions. At the start of each MVC, participants were instructed to apply a light steady baseline force to the back and shoulder pads, which was confirmed via visual feedback using the force-time curve tracing from our computer. This baseline force ensured a good contact between the participant and device and removed the initial compliance caused by soft tissue compression. Once the baseline force was completely steady, participants were verbally instructed to simultaneously extend at the hips and knees “as hard and fast as possible” for a total of 3-4 seconds and strong verbal encouragement was given throughout the duration of the MVC. Trials with an initial countermovement (identified by a visual drop in the force trace) were always discarded, and additional MVCs were performed until 2 trials presented acceptable data. No participant required more than 3 trials (2 trials plus 1 additional trial) to achieve this criterion. Consequently, all of our participants had 2 MVCs with acceptable data to assess at each squat position.

During each isometric strength assessment, the force signal (N) was sampled from the load cell at 1 kHz (MP150WSW; Biopac Systems, Inc, Santa Barbara, CA, USA), stored on a personal computer (Dell Inspiron 8200; Dell, Inc, Round Rock, TX, USA), and processed off-line using custom-written software (LabVIEW, Version 11.0; National Instruments, Austin, TX, USA). The scaled force signal was low-pass filtered, with a 20-Hz cutoff (zero-phase lag, fourth-order
All subsequent analyses were conducted on the scaled and filtered force signal.

Isometric MVC PF (N) was determined as the highest mean 500 ms epoch during the entire 3-4 s MVC plateau (Figure 2). RFD (N·s⁻¹) was calculated as the linear slope of the force-time curve (Δforce/Δtime) at time intervals of 0-30 (RFD30), 0-50 (RFD50), 0-100 (RFD100), and 0-200 (RFD200) ms (Figure 2). In addition, peak RFD was calculated as the highest slope value for any 50 ms epoch that occurred over the initial 200 ms of the force-time curve. For each MVC, the onset of contraction was determined manually by visual inspection where the force signal first deflected from baseline. Of the two MVCs performed for each squat condition, the MVC with the higher PF was selected for analysis, unless the MVC with the lower PF was 1) within 50 N of the MVC with the high PF and 2) the RFD values for this lower PF MVC were greater (> 100 N·s⁻¹) than the RFD values for the high PF MVC, in which case, the MVC with the lower PF was selected instead. These selection procedures helped to ensure that the MVC with the best overall PF and RFD values was chosen for analysis.

Paired samples t-tests were used to examine the systematic variability for all force variables at each squat position across trials 1 and 2. The intraclass correlation coefficient (ICC) representing relative consistency (test-retest reliability), the standard error of measurement (SEM) and coefficient of variation (CV) representing absolute consistency, and the minimal difference (MD) needed to be considered real were calculated across trials for each squat position.

Model “2,1” from Shrout and Fleiss was used to calculate the ICC. Model 2,1 utilizes random and systematic error in the denominator of the ICC equation, and consequently, the ICCs generated with this model can be generalized to other laboratories and testers. The ICC (2,1) was calculated with the following equation.
ICC_{2,1} = \frac{MS_S - MS_E}{MS_S + (k - 1)MS_E + (k(\text{MS}_T - MS_E)/n)}

where MS_S is the mean square for subjects, MS_E is the mean square error, MS_T is the mean square trials, k is the number of trials, and n is the sample size. The SEM for model 2,1 was calculated with the following equation:\textsuperscript{30}

\text{SEM} = \sqrt{MS_E}

The CV was calculated as a normalized measure of the SEM using the following equation:\textsuperscript{30,31}

\text{CV} = \frac{\text{SEM}}{\text{Grand mean}} \times 100

The MD for model 2,1 was calculated using the following equation:\textsuperscript{29}

\text{MD} = \text{SEM} \times 1.96 \times \sqrt{2}

Separate paired samples t-tests with Bonferroni corrections from data averaged across both trials were used to analyze differences in PF and RFD variables between squat positions. The calculations for ICC, SEM, CV, and MD were performed using a custom-written spreadsheet (Microsoft Excel; Microsoft Corporation, Redmond, WA, USA). All other data analyses were performed using SPSS Version 22.0 (SPSS, Inc., Chicago, IL, USA). An alpha level of \( P \leq 0.050 \) was considered statistically significant for all analyses.

**Results**

For test-retest reliability, there was no systematic differences (\( P = 0.057-0.917 \)) across trials for any of the variables at the parallel, half, and quarter squat positions. Reliability analysis revealed that PF and RFD200 were highly consistent across trials for all three squat positions, with ICCs ranging between 0.812 and 0.904 and CV values between 6.6 and 19.4\% (Table 1). For peak
RFD, RFD30, RFD50, and RFD100, relative and absolute consistency revealed higher ICCs and lower CV values for the quarter squat (ICCs = 0.818-0.852, CVs = 17.3-19.4%) compared to the parallel (ICCs = 0.591-0.649, CVs = 30.1-55.9%) and half (ICCs = 0.547-0.598, CVs = 31.1-34.2%) squat positions (Table 1).

For position-related differences, isometric PF and RFD200 increased ($P \leq 0.001-0.035$) with squat position (parallel < half < quarter) (Table 2). No differences were observed between squat positions for peak RFD ($P \geq 0.265$), RFD30 ($P \geq 0.999$), RFD50 ($P \geq 0.999$), and RFD100 ($P \geq 0.093$) (Table 2).

**Discussion**

The results of the present study indicated that there was no systematic variability across trials and the ICC and CV values ranged from 0.547 to 0.904 and 6.6 to 55.9%, respectively, for the PF and RFD variables at the parallel, half, and quarter squat positions (Table 1). In addition, PF and RFD200 increased with squat position (parallel < half < quarter); however, no differences were observed between squat positions for peak RFD, RFD30, RFD50, and RFD100 (Table 2).

The high ICCs ($\geq 0.812$) and relatively low CV values ($\leq 19.4\%$) observed in the present study for PF and RFD200 demonstrated that the Exerbotics squat device was a reliable assessment tool for measuring isometric maximal and late rapid strength characteristics at all positions in healthy resistance-trained, college-aged females. These findings were comparable to the reliability of previous isometric squat studies examining PF measurements using force plates in younger male populations, reporting ICCs of 0.730 – 0.990 and CV values of 2.3 – 8.0%. For late rapid force production ($\geq 200$ ms), isometric squat reliability coefficients of 0.760 – 0.940 and technical error of measurement values (equivalent to CV$^{32}$) of 8.1 – 9.4% have been reported for RFD200 and RFD250, which are also comparable to those observed in the present study. A key finding
of this study was the higher ICCs and lower CV values at the quarter squat compared to the parallel and half squat positions for peak RFD and early RFD characteristics at RFD30, RFD50, and RFD100. Previous isometric squat studies examining the reliability of peak and/or early RFD have reported conflicting results, with some studies showing ICCs of less than 0.700 and CV values of 19.6 – 48.7% and other research showing higher ICC (0.943) and lower CV (15.2%) values for these variables. Such discrepancies may be due to differences in testing procedures and equipment, the knee joint angles used to assess RFD, and/or the sex and resistance-training levels of the participants that were tested. Collectively, the majority of isometric squat studies that have reported poor reliability for peak and early rapid force characteristics examined RFD at knee joint angles of 90 and 120° whereas other research that has reported high reliability examined RFD at more extended knee joint positions (140°). The results of our study support these findings by demonstrating a position-related increase in the reliability of peak RFD and RFD30, RFD50, and RFD100 at the quarter squat compared to the parallel and half squats. Although the reason for these position-related disparities are uncertain, it is possible that the early slope of the force time curve which is also where peak RFD typically occurs, is more variable for the parallel and half squats (possibly due to greater muscle pain or discomfort experienced at these positions) which may contribute to the poorer absolute and relative consistency scores when compared to the quarter squat position. Given these findings, future research studies using isometric squats to assess rapid force characteristics within the early phase of contraction (≤100 ms), may want to consider performing them at higher (150°) rather than lower (90 or 120°) knee joint angles.

In this study, the quarter squat elicited 61 and 27% higher PF values than the parallel and half squats, and the half squat elicited 26% higher PF values than the parallel squat. These findings of greater PF values at higher squat positions are in agreement with those of previous isometric
squat studies\textsuperscript{17-19} and are likely a reflection of the greater mechanical advantage, due to improved musculoskeletal mechanics gained when the knees are in a position closer to full extension.\textsuperscript{34} It is important to note that although the quadriceps is an important muscle group for the isometric squat,\textsuperscript{17} the hip extensors have also been reported to be a major contributor to the forces produced during this exercise.\textsuperscript{3,18} Therefore, it is likely that the position-related differences in PF values observed in this study were affected not only by mechanical changes in the quadriceps but also the hip extensors. Future studies using more sophisticated methodology (i.e., three-dimensional kinematics combined with electromyography and force data) are needed to further elucidate the effects of knee and hip position on the precise contributions of each of these muscles during squat-related performances.

Despite several studies examining position-related changes in isometric squat PF, interestingly, for isometric squat RFD characteristics, we are aware of no studies that have examined the effects of squat position on these variables. Our findings revealed significant position-related increases in RFD\textsubscript{200}; however, no differences were observed between squat positions for peak RFD nor any of the early RFD characteristics. The smaller position-related differences in peak and early RFD compared to RFD\textsubscript{200} may be due to discrepancies in the relationships between maximal strength and early versus later rapid force production. It has been suggested that peak and early (\leq 100 \text{ ms}) RFD values, which are primarily influenced by neural factors (i.e., motor unit firing rates, doublet counts, etc.),\textsuperscript{5,35} have a smaller relationship with maximal strength than later RFD values (\geq 200 \text{ ms}).\textsuperscript{33} Thus, given the present findings of greater PF at higher squat positions, it is possible that peak and early RFD, due to their smaller relationship with maximal strength, may be less affected by these position-related PF changes, resulting in smaller differences than those observed at later time points. It is also possible because of the high
variability and low number of participants in this study that the lack of statistical significance for some of these position-related comparisons may be due to inadequate statistical power. Indeed, although the differences between positions for RFD50 and RFD100 (10-23%) were non-significant and relatively lower than those observed for RFD200 (34-49%), they still may be considered large and practically relevant. Nevertheless, the present findings of position-related differences for RFD200 but not for peak RFD nor early RFD characteristics, provide support that differences in knee joint angles during an isometric squat test may have a significant impact on rapid force production but only at the late phase of contraction. Previous authors have recommended that isometric strength assessments be performed at a position where force output is the highest and/or within a range of joint angles specific to sport-related tasks, as this may help reduce test variability and improve the relationships of muscular strength with dynamic performances. Therefore, given the fact that the quarter squat elicited higher maximal and late rapid strength characteristics than the parallel and half squats and because most lower-body, sport-specific tasks (i.e., sprinting, walking, regaining balance to avoid a fall) occur in a range of joint angles closer to full knee extension, it may be advantageous to perform isometric squat testing with the knees in a more extended position.

In summary, the Exerbotics device at all 3 squat positions showed high relative (ICC values) and low absolute (CV values) consistency values for PF and RFD200; however, for peak and early (≤100 ms) RFD variables, the quarter squat exhibited higher test-retest reliability than the parallel and half squats. In addition, we found higher PF and RFD200 values for the quarter squat compared to the parallel and half squats, but no differences were observed between squat positions for peak RFD nor any of the early RFD characteristics. Collectively, these findings suggest that the isometric quarter squat may provide for an improved capacity to produce higher
maximal and late rapid strength characteristics as well as a more reliable testing position for measuring peak and early RFD when compared to the parallel and half squat assessments. As a result of these findings and given the importance of isometric strength testing at joint angles specific to sport-related tasks, future researchers and practitioners using isometric squats to examine maximal and early and late rapid force characteristics, may want to consider performing them with the knees in a more extended position (150°), similar to the knee position for the quarter squats used in the present study.
References


Figure 1. Illustration of the isometric strength assessments at knee joint angles of (a) 90°, (b) 120°, (c) and 150°, corresponding to parallel, half, and quarter squat positions, respectively. For each assessment, participants were verbally instructed to push “as hard and fast as possible” against the back and shoulder pads of the squat device for a total of 3-4 seconds.
Figure 2. An example of an absolute force-time curve tracing taken from a participant during a back squat isometric maximal voluntary contraction (MVC). Peak force (PF; N) was determined from the highest 500 ms epoch. Rate of force development (RFD; N·s⁻¹) was determined from the linear slope of the force-time curve at time intervals of 0-30 (RFD30), 0-50 (RFD50), 0-100 (RFD100), and 0-200 (RFD200) ms from onset.
Table 1. Reliability statistics for peak force (PF) and rate of force development (RFD) variables at the parallel, half, and quarter squat positions.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parallel Squat</th>
<th>Half Squat</th>
<th>Quarter Squat</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P)-value</td>
<td>0.341</td>
<td>0.880</td>
<td>0.121</td>
</tr>
<tr>
<td>ICC(2,1)</td>
<td>0.840</td>
<td>0.839</td>
<td>0.904</td>
</tr>
<tr>
<td>SEM (N)</td>
<td>93.5</td>
<td>111.1</td>
<td>82.9</td>
</tr>
<tr>
<td>CV (SEM%)</td>
<td>12.0</td>
<td>11.2</td>
<td>6.6</td>
</tr>
<tr>
<td>MD (N)</td>
<td>259.1</td>
<td>307.9</td>
<td>229.7</td>
</tr>
<tr>
<td>Peak RFD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P)-value</td>
<td>0.283</td>
<td>0.066</td>
<td>0.917</td>
</tr>
<tr>
<td>ICC(2,1)</td>
<td>0.601</td>
<td>0.547</td>
<td>0.852</td>
</tr>
<tr>
<td>SEM (N·s(^{-1}))</td>
<td>3343.5</td>
<td>4158.3</td>
<td>2276.1</td>
</tr>
<tr>
<td>CV (SEM%)</td>
<td>30.2</td>
<td>33.5</td>
<td>19.2</td>
</tr>
<tr>
<td>MD (N·s(^{-1}))</td>
<td>9267.8</td>
<td>11526.2</td>
<td>6308.9</td>
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<tr>
<td>RFD30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P)-value</td>
<td>0.156</td>
<td>0.854</td>
<td>0.057</td>
</tr>
<tr>
<td>ICC(2,1)</td>
<td>0.591</td>
<td>0.598</td>
<td>0.835</td>
</tr>
<tr>
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<td>1788.5</td>
<td>874.8</td>
</tr>
<tr>
<td>CV (SEM%)</td>
<td>55.9</td>
<td>34.2</td>
<td>17.3</td>
</tr>
<tr>
<td>MD (N·s(^{-1}))</td>
<td>9118.6</td>
<td>4957.5</td>
<td>2424.7</td>
</tr>
<tr>
<td>RFD50</td>
<td></td>
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<tr>
<td>( P)-value</td>
<td>0.210</td>
<td>0.432</td>
<td>0.210</td>
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<tr>
<td>ICC(2,1)</td>
<td>0.644</td>
<td>0.572</td>
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<td>3723.2</td>
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<td>1367.4</td>
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<td>CV (SEM%)</td>
<td>46.3</td>
<td>34.2</td>
<td>19.4</td>
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<td>MD (N·s(^{-1}))</td>
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<td>RFD100</td>
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<td></td>
<td></td>
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<td>( P)-value</td>
<td>0.309</td>
<td>0.142</td>
<td>0.813</td>
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<td>0.818</td>
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<tr>
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<tr>
<td>CV (SEM%)</td>
<td>30.1</td>
<td>31.1</td>
<td>18.5</td>
</tr>
<tr>
<td>MD (N·s(^{-1}))</td>
<td>4296.4</td>
<td>5760.3</td>
<td>3390.5</td>
</tr>
<tr>
<td>RFD200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P)-value</td>
<td>0.271</td>
<td>0.710</td>
<td>0.880</td>
</tr>
<tr>
<td>ICC(2,1)</td>
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<td>0.814</td>
<td>0.812</td>
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<tr>
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<td>383.6</td>
<td>473.4</td>
<td>475.4</td>
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<tr>
<td>CV (SEM%)</td>
<td>19.4</td>
<td>15.9</td>
<td>12.3</td>
</tr>
<tr>
<td>MD (N·s(^{-1}))</td>
<td>1063.4</td>
<td>1312.1</td>
<td>1317.8</td>
</tr>
</tbody>
</table>

\( P\)-value = type I error rate for the paired samples t-test across trials 1 and 2. ICC\(2,1\) = intraclass correlation coefficient, model 2,1. SEM = standard error of measurement. CV = coefficient of variation. MD = minimal difference needed to be considered real.
Table 2. Mean (SD) values* for peak force (PF) and rate of force development (RFD) variables at the parallel, half, and quarter squat positions.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parallel Squat</th>
<th>Half Squat</th>
<th>Quarter Squat</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF (N)</td>
<td>781.91 (223.77)</td>
<td>988.84 (256.98)‡</td>
<td>1256.07 (275.66)†</td>
</tr>
<tr>
<td>Peak RFD (N·s⁻¹)</td>
<td>11077.44 (4770.11)</td>
<td>12403.66 (5836.19)</td>
<td>11877.65 (5499.13)</td>
</tr>
<tr>
<td>RFD30 (N·s⁻¹)</td>
<td>5886.41 (4740.13)</td>
<td>5230.57 (2454.95)</td>
<td>5045.10 (2275.26)</td>
</tr>
<tr>
<td>RFD50 (N·s⁻¹)</td>
<td>8036.87 (5769.01)</td>
<td>7245.36 (3326.64)</td>
<td>7045.79 (3275.89)</td>
</tr>
<tr>
<td>RFD100 (N·s⁻¹)</td>
<td>5157.60 (2382.02)</td>
<td>6685.56 (2848.33)</td>
<td>6614.53 (2648.65)</td>
</tr>
<tr>
<td>RFD200 (N·s⁻¹)</td>
<td>1979.68 (856.21)</td>
<td>2977.71 (1014.87)‡</td>
<td>3873.22 (1010.33)†</td>
</tr>
</tbody>
</table>

* Represents data averaged across trials 1 and 2.
† Significantly greater for the quarter squats than the parallel and half squats
‡ Significantly greater for the half squats than the parallel squats