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Data-Driven Recommendations for Assessing the Early-Phase Rate of Torque Development: An Intersession Reliability Study in Physically Active Men and Women

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ABSTRACT

The purpose of this study was to provide data-driven recommendations for assessing early-phase rate of torque development (RTD) in isometric knee extension and flexion, focusing on the optimal number of repetitions performed and trial selection criteria to ensure robust intersession reliability. Twenty subjects (10 males, 10 females) completed two test sessions with nine repetitions of unilateral "fast and strong" isometric contractions for the knee extensors and flexors. RTD was calculated from torque onset to 50 ms (RTD50) and 100 ms (RTD100), and peak RTD was assessed in a moving 50 ms interval within the first 100 ms (Peak50). Intersession reliability was assessed using intraclass correlation coefficient (ICC) for three to nine repetitions and four different criteria for trial selection. A mixed-effect linear regression model was performed with measured RTD as dependent variable with number of repetitions, selection criteria, and test session as independent variables. The results revealed high intersession reliability for RTD100 in knee extension (ICC 0.849–0.961) and flexion (ICC 0.835–0.944) across repetitions and selection criteria. Three repetitions were sufficient to optimize intersession reliability and measured values of knee extensor RTD. Assessment of knee flexor RTD required five repetitions to optimize reliability for RTD50 (ICC $\geq$ 0.700) and six repetitions to optimize absolute measured values of RTD100. Selection criteria based on peak RTD100 ensured optimal reliability and absolute RTD measurements for both peak50, RTD50 and RTD100. The assessment of knee flexion requires more repetitions than knee extension to ensure reproducible early-phase RTD outcomes.

1 | Introduction

Explosive muscle strength or rapid force capacity is important for a broad range of movement demands and activities of daily living in both elderly populations and young athletes, as it enables rapid and forceful movements [1, 2]. The rate of force or torque development (RFD/RTD) is a way to express explosive muscle strength and reflects the ability of the neuromuscular system to produce a rapid rise of muscle force within the initial 200–300 ms of maximal muscle contraction [3–6]. The rate

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of rise in muscle force/torque within the initial time interval of 0–100 ms of an explosive contraction is defined as early-phase RTD and plays a key role in athletic performance, musculoskeletal injury risk, and rehabilitation of athletes [5, 7–9].

Specifically, early-phase RTD is crucial to performance in high-speed athletic movements with short contraction times (50–200 ms), typically involving a rapid sequence of coupled eccentric–concentric muscle actions [10–12].

Additionally, explosive agonist and antagonist co-contraction is important to stabilize and thereby protect the joints during rapid dynamic loading conditions. Especially, rapid hamstring activation contributes to protecting the knee against noncontact rupture of the anterior cruciate ligament (ACL) [13, 14], which is a common musculoskeletal injury that typically occurs < 50 ms after foot strike [15, 16].

Consequently, exercise training to improve rapid force/torque production (i.e., RFD/RTD) may also be prioritized in the field of clinical rehabilitation, e.g., following ACL injury, with pain setting the limit for maximal force exertion. However, a meta-analysis conducted in 2020 [12] revealed a persistent decrease in RFD in both the quadriceps and hamstring muscles several years following ACL reconstructive surgery. This sustained reduction in lower limb rapid force characteristics could have detrimental effects on athletic performance [14] and may increase the risk of reinjury upon return to sport [17], given that the muscles controlling the knee often operate under time constraints. Consequently, RFD/RTD has been proposed as a standard measure in the evaluation of postoperative recovery following ACL reconstruction and return-to-sport assessments [12, 17–19].

In addition to its functional relevance, early-phase RTD (≤ 100 ms) provides valuable insights into muscle contractile properties that are distinct from maximal voluntary isometric contraction strength (MVIC), which has a stronger influence on late-phase RTD (≥ 150 ms) than on early-phase RTD [10]. Notably, early-phase RTD is sensitive to fluctuations in the neural drive to the muscle while it is also affected by methodological factors such as sensitive algorithms to enable force onset detection, resulting in a reduced signal–to–noise ratio in the very early rise of torque [2, 4, 9, 20, 21]. To this end, early-phase RTD measures typically demonstrate lower intersession reliability than measures of late-phase RTD (> 100 ms) or MVIC torque [4, 20, 22].

Numerous methodological recommendations have been proposed in an attempt to optimize the intersession reliability of early-phase RTD assessment [4, 5, 9]. Several studies recommend measuring RTD during contractions specifically performed with a focus on both rapid increases in force and high levels of force generation, with no instructions to maintain contraction to reach MVIC [2, 4, 23]. This protocol is suggested to prevent fatigue compared with test contractions performed to simultaneously measure RTD and MVIC, which typically require a much longer time (4–5 s) under sustained tension. In the literature, it is common practice to perform 3–6 test repetitions (REPS) and select trials for analysis based on either the highest RTD values in a given time interval or absolute torque values (selection criteria) [8, 9]. To the best of our knowledge, no previous study has investigated how many test repetitions and which selection criteria are recommended to optimize the intersession reliability of early-phase RTD.

The purpose of this study was to establish data-driven recommendations for measuring and analyzing early-phase RTD during maximal effort isometric knee flexion and extension. The primary objective was to identify the optimal number of REPS that should be performed to ensure robust intersession reliability for early-phase (≤ 100 ms) RTD assessment.

The secondary objective was to explore whether the optimal number of REPS could be reduced by applying alternative methods for trial selection yet resulting in reproducible early-phase RTD measurements.

2 | Methods

This study investigated the intersession reliability of early-phase isometric RTD for the knee extensors (quadriceps) and knee flexors (hamstrings) using a single-group intersession test–retest design. Two identical 1.5-h sessions were performed 7 (±3) days apart. The test sessions were completed from April to May 2022 and were conducted by the same experienced assessor with a clinical and scientific background. Knee extensor and knee flexor torque was measured during nine repetitions of "fast and strong" unilateral isometric test contractions in each session. Early-phase RTD (≤ 100 ms) measures were calculated to investigate the influence of the number of performed REPS on intersession reliability and validity of early-phase RTD.

2.1 | Subjects

Twenty subjects (males $n = 10$, females $n = 10$) aged 27.9 ± 4.8 years were recruited from a convenience sample comprising physically active men and women.

The inclusion criteria were ages 18–40 years, an active lifestyle, and the absence of lower-limb musculoskeletal injuries 12 months prior to testing. Subjects were excluded if they had any previous severe traumatic injuries to the lower limb. Prior experience with strength training or isometric testing was not part of the inclusion criteria, but most included subjects had substantial experience with maximal muscle contractions in the form of strength training (Table 1).

The participants were instructed to maintain their habitual level of physical activity throughout the study period and to avoid vigorous physical activity, including strength training, 24 h prior to each test session.

All participants received written and oral information about the content, risks, and purpose of the study. Informed written consent was subsequently obtained from each participant prior to engaging in the study. According to the Act on Research Ethics Review of Health Research Projects, the Committees on Biomedical Research Ethics for the Capital Region of Denmark did not consider the study a health research study, and thus, the study did not need to be notified for full ethical evaluation by the committee

TABLE 1 | Demographics, strength training status, and leg dominance of study participants.

Demographics	Women ($n = 10$)	Men ($n = 10$)
Age (year)	27 ± 4	28 ± 5
Height (m)	1.70 ± 0.09	1.85 ± 0.05
Body mass (kg)	65.3 ± 9.4	82.4 ± 8.7
Body mass index	23 ± 20	24 ± 21
Training exposure		
Physical activity (h/week)	12.4 ± 4.6	7.7 ± 2.8
Strength training (h/week)	4.8 ± 4.3	3.8 ± 2.3
Specific lower leg training (h/week)	3.4 ± 4.2	1.4 ± 0.9
Test setup		
Test-leg (dominant/nondominant)	dom = 6/nondom = 4	dom = 6/nondom = 4
Experience with isometric test (yes/no)	Yes = 4/No = 6	Yes = 6/No = 4

Note: Data are presented as mean ± SD.

(journal-nr. H-21030677). The study adhered to the proposed Guidelines for Reporting Reliability and Agreement Studies [24].

2.2 | Experimental Procedure

Prior to testing, all participants completed a 5 min standardized general warm-up with emphasis on the lower limbs, consisting of a specific combination of running and single-leg jumping drills for 5 min.

The maximal voluntary isometric contraction torque (MVIC) and rate of torque development (RTD) were determined for the knee flexors and knee extensors using static dynamometry (Good Strength, Metitur Ltd., Finland) [25]. The participants were seated with the hip joint flexed at 90° and the knees in 60° knee flexion (full knee extension = 0°). The participants were fastened by straps across the waist and the thigh for stabilization. The force transducer was positioned 7 cm above the lateral malleoli. The moment arm length was measured as the distance from the lateral femoral condyle to the center of the force transducer. Identical subject-specific settings concerning fixation, lever arm length, and dynamometer adjustments were used in both test sessions.

Subjects were familiarized with the task and the Good Strength device with three practice trials of submaximal contractions of approximately 50%–80% of maximum effort.

Rate of torque development was measured in nine successive REPS (Figure 1) of unilateral isometric knee extensor contractions separated by 30 s of rest [9]. Following a short break (5 min), this procedure was repeated, with participants performing nine trials for the knee flexors. The test leg was randomly selected for each participant, and each participant was familiarized with the task by performing three practice trials of increasing submaximal contraction intensities ranging from 50% to 80% of maximum effort.

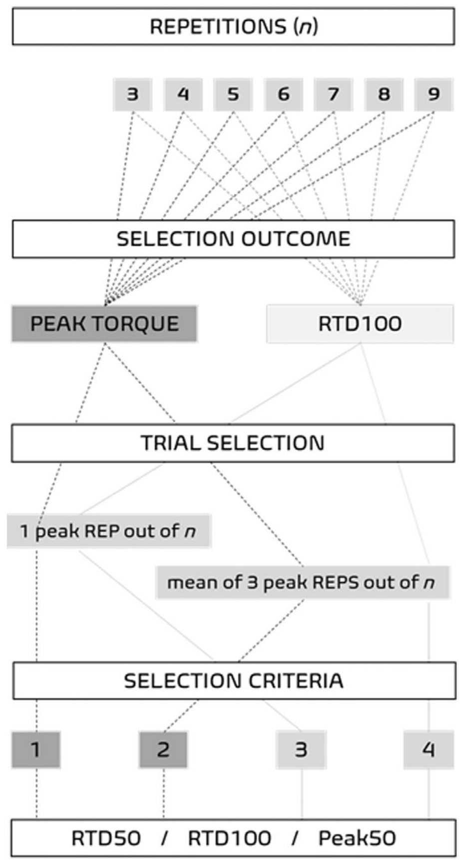

FIGURE 1 | Method of data analysis and trial selection. From the nine REPS performed, RTD values were calculated by including from three up to nine REPS in the data analysis. From the included REPS (n), RTD was derived according to four different selection criteria. [1] RTD outcomes derived from the one REP with the highest measured peak torque. [2] RTD averaged from the three REPS with the highest measured peak torque. [3] RTD outcomes derived from the one REP with the highest measured RTD100. [4] RTD averaged from the three REPS with the highest measured RTD100.

The participants were instructed to activate their knee extensors/flexors as fast and forcefully as possible for 2s. With emphasis on fast and strong force production, test contractions were completed without any preceding countermovement or pretension [4, 5]. As the early-phase rate of torque development was the primary outcome measure, participants were instructed to relax their muscles approximately 1.5s after the onset of force production, which allowed sufficient time to capture early-phase RTD while avoiding unnecessary sustained contraction.

The participants were given verbal instructions and strong encouragement during all REPS, and visual online feedback on force development was provided on a PC screen to all participants [4, 5].

Following the nine RTD repetitions in both directions, three maximal isometric muscle contractions were performed for the knee flexors and knee extensors to control for the level of force reached in the RTD repetitions in the data analysis. These were performed using the same test setup, but the instructions were to uphold the contraction for 4–5s [4, 5].

2.3 | Data Analysis

Strain-gauge force signals were sampled at 1000Hz using the Metitur Good Strength device (Good Strength, Metitur Ltd., Finland). Using MATLAB (MathWorks MATLAB version R2022a; MathWorks Inc., Natick, Massachusetts, USA), the force data were low-pass filtered using a 4th-order zero-lag Butterworth filter at a 15Hz cutoff frequency [3] and converted into torque by multiplying the force signals with the individual lever arm lengths.

Torque onset threshold was set at absolute values of 6Nm (knee extensors) and 3Nm (knee flexors) corresponding to 2.5% of the population MVIC peak torque [3, 4, 9, 10].

As instructions to perform contractions fast and strong, REPS with peak absolute torque below 50% MVIC were excluded from the analysis [26]. Among all the participants, a total of five REPS for the knee extensors (two participants) and three REPS for the knee flexors (three participants) failed to exceed 50% MVIC. These trials were excluded from the analysis.

RTD was calculated as the rate of change in torque (i.e., ΔTorque/ΔTime) during the initial time intervals from torque onset (0ms) to 50 and 100ms (RTD50, RTD100) of rising muscle force, respectively. The peak average RTD (slope) over the full torque-time slope (Peak50) was determined using a moving average with a window size of 50 data points moving along the torque-time curve in successive increments of 1ms. RTD_{50}, RTD_{100}, and $Peak_{50}$ were expressed in Nm/s.

From the nine REPS performed, RTD values were calculated by including three to nine REPS in the data analysis (Figure 1). From the included REPS (n), RTD was derived according to four different selection criteria:

1. RTD outcomes derived from the one REP with the highest measured peak torque.
2. RTD averaged from the three REPS with the highest measured peak torque.
3. RTD outcomes derived from the one REP with the highest measured RTD100.
4. RTD averaged from the three REPS with the highest measured RTD100.

2.4 | Statistical Analysis

Analysis outcomes were RTD50, RTD100, and Peak50. The selection factors were the number of REPS and, secondarily, four different trial selection criteria.

The intersession reliability of the selected RTD outcomes as a result of the number of REPS was assessed by the calculation of the intraclass correlation coefficient (ICC) using a two-way random effects model by absolute agreement with corresponding 95% confidence intervals (95% CI). The analysis was repeated for data quantified based on each of the four selection criteria. The reliability results were interpreted as poor ($ICC < 0.50$), fair ($0.50 \leq ICC \leq 0.75$), good ($0.75 \leq ICC \leq 0.90$) or excellent ($ICC \geq 0.90$) [27, 28]. An ICC of 0.700 was deemed acceptable, adopting standards reported in the clinical literature [29]. The same interpretation was applied to the 95% CI lower limit of the calculated ICC to evaluate the accuracy of our estimate [27, 28]. Tables with a full overview of the calculated ICCs with corresponding 95% CI lower limits, and mean RTD outcomes for all measures from the test and retest sessions are submitted in Appendices A and B. The standard error of measurement was calculated as: SEM $ICC = \sigma^* \text{ sqrt}(1 - r)$, where σ = the standard deviation of the measurements and r = ICC, and added to Appendices A and B.

Stability of absolute measured values of the selected RTD outcomes and systematic bias from either number of REPS, test sessions, or selection criteria was analyzed using a mixed effect linear regression model in SPSS (IBM SPSS Statistics for Mac, version 28, Armonk, NY: IBM Corp). RTD outcome was set as the dependent variable, with number of REPS, selection criteria, and test session as independent variables. The main effect of the independent variables was analyzed as well as the interactions between number of trials with selection criteria and session, respectively. The level of significance was set at 0.05 (two-tailed), and post hoc comparisons of separate number of REPS and selection criteria were Bonferroni corrected. All RTD outcomes are expressed as group mean values ± SD, and 95% confidence intervals are provided for all the statistical outcomes. Detailed results for the estimates from the mixed linear models are included in Appendix C and D. Q–Q plots of the model residuals were visually inspected to evaluate the normality assumption for the mixed models. For the knee extensors, the statistical analysis revealed that an outlier in the residuals appeared to be caused by the results from one specific participant. A sensitivity analysis was performed by removing the participant from the model, which improved the probability distributions and affected the significance of the model for RTD50, with no large impact on the estimates of the model. Because of this, it is assumed that no bias was introduced by removing the participant, and the distribution assumption was more valid. Therefore, the results from the sensitivity analysis are presented for this model.

Recommendations for the optimal number of REPS and trial selection criteria were based on a qualitative analysis of the ICC and corresponding 95% CI lower limit while taking systematic bias on absolute measured RTD values into account.

As Peak50 results revealed similar patterns to those observed for RTD100, these results are presented in Appendices C and D.

3 | Results

A reliability analysis was performed to investigate interclass correlations and the systematic effect of the number of performed repetitions and, secondly, trial selection criteria on early phase reliability. The main results from this analysis are presented in Figures 2 and 3 and in full detail in Appendices A and B.

In addition, a mixed-effect linear regression model was performed to analyze the stability of absolute measured values of the selected RTD outcomes and systematic bias from either the number of REPS, test sessions, or selection criteria. The main results from this analysis are presented in Table 2 and in full detail in Appendices C and D.

Following the visual presentations of the main results, distinct trends and patterns from the results for RTD50 and RTD100 will be presented separately. As Peak50 results revealed similar patterns to those observed for RTD100, these results are presented in Appendices A–D.

3.1 | Influence of Number of Repetitions

3.1.1 | RTD50

For the knee extensors, the intersession reliability analysis indicated no systematic effect of the number of REPS on the reliability of RTD50, with ICCs ranging from 0.826 to 0.909 and a

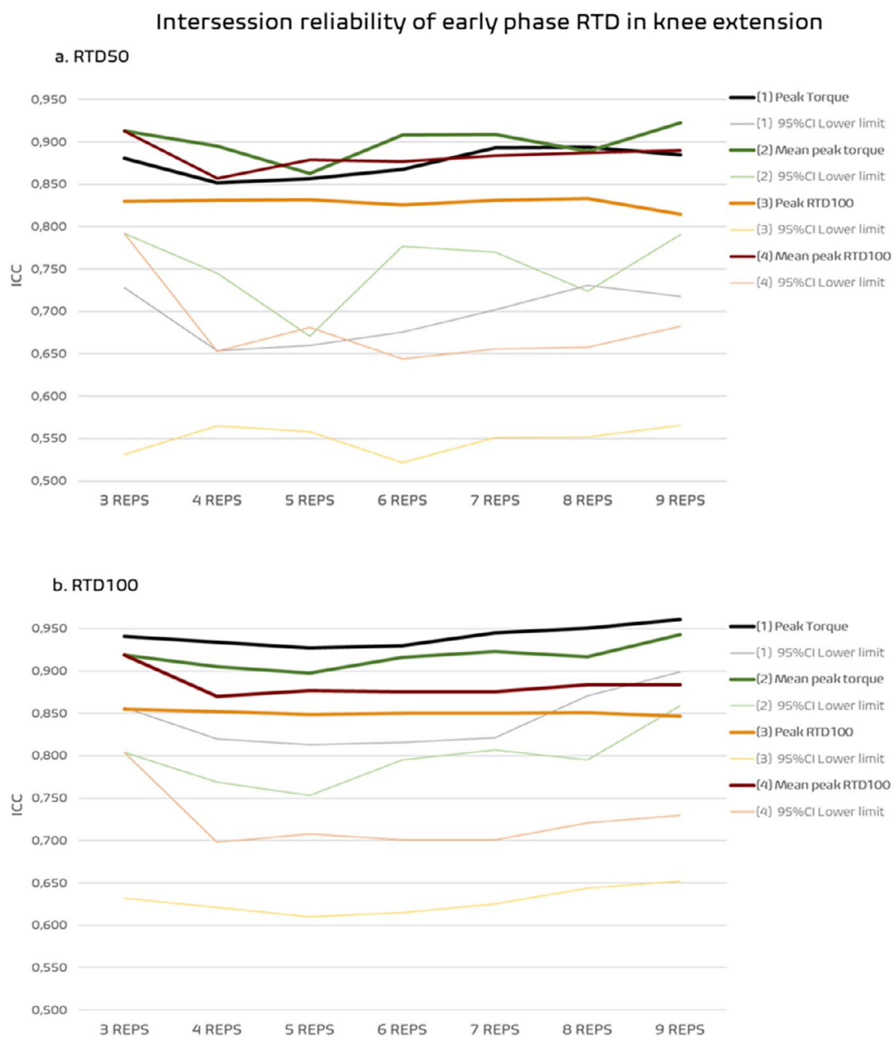

FIGURE 2 | Graph showing the intraclass correlation coefficients (ICCs) for RTD50 (a) and RTD100 (b) in knee extension as a function of the number of REPS for the four selection criteria. Each selection criterion is illustrated with the ICC (*BOLD line*) and corresponding 95% CI lower limit (*PALE line*). Selection criterion [1]: RTD outcomes derived from the one REP with the highest measured peak torque is illustrated in black selection criterion [2]: RTD averaged from the three REPS with the highest measured peak torque is illustrated in green. Selection criterion [3]: RTD outcomes derived from the one REP with the highest measured RTD100 is illustrated in red. Selection criterion [4]: RTD averaged from the three REPS with the highest measured RTD100 values is illustrated in orange.

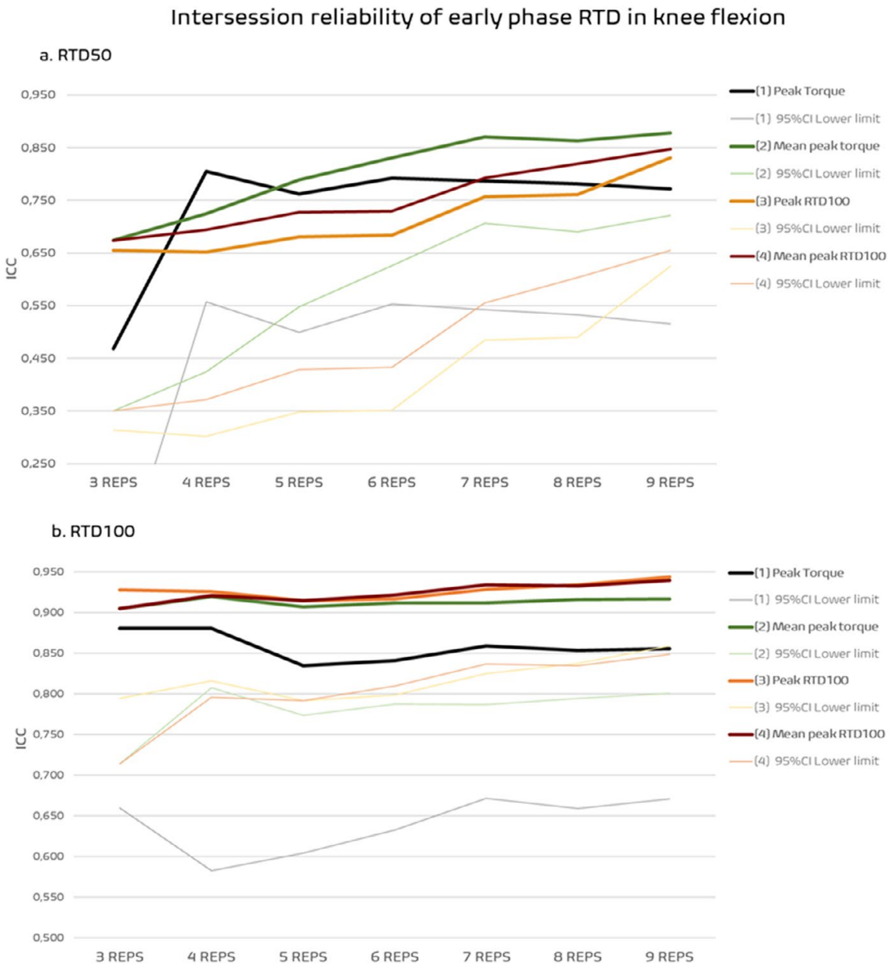

FIGURE 3 | Graph showing the intraclass correlation coefficients (ICCs) for RTD50 (a) and RTD100 (b) in knee flexion as a function of the number of REPS for the four selection criteria. Each selection criterion is illustrated with the ICC (*BOLD line*) and corresponding 95% CI lower limit (*PALE line*). Selection criterion [1]: RTD outcomes derived from the one REP with the highest measured peak torque is illustrated in black Selection criterion [2]: RTD averaged from the three REPS with the highest measured peak torque is illustrated in green. Selection criterion [3]: RTD outcomes derived from the one REP with the highest measured RTD100 is illustrated in red. Selection criterion [4]: RTD averaged from the three REPS with the highest measured RTD100 is illustrated in orange.

TABLE 2 | Main results from the mixed effect linear regression models for RTD50, RTD100, and Peak50 investigating systematic bias from session, number of trials, and selection criteria on measured RTD50, RTD100, and peak50 values.

	Knee extension			Knee flexion		
	RTD50	**RTD100**	**Peak50**	**RTD50**	**RTD100**	**Peak50**
Main effects						
Test session	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$
Number of REPS	$p = 0.923$	$p = 0.629$	$p = 0.998$	$p = 0.428$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$
Selection criteria	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$	$\boldsymbol{p \leq 0.001}$
Intersects						
Number of REPS + test session	$p = 0.945$	$p = 0.826$	$p = 0.968$	$p = 0.241$	$p = 0.933$	$p = 0.906$
Number of REPS + selection criteria	$p = 0.519$	$p = 0.505$	$p = 0.286$	$p = 0.256$	$p = 0.999$	$p = 1.00$

Note: Statistically significant results are marked in BOLD.

95% confidence interval lower limit ranging from 0.531 to 0.791 (Figure 2a).

The absolute measured RTD50 values for knee extension did not change with the increasing number of REPS (Appendix A, Table 2).

For the knee flexors, the intersession reliability analysis indicated a slight systematic effect from the number of REPS on intersession reliability. When the trial selection criteria were based on peak absolute torque (criteria 1 and 2), a minimum of five performed REPS was required to generate consistently "good" ICCs ($0.750 \leq ICC \leq 0.900$), and seven REPS were needed to obtain an acceptable 95% CI lower limit ($0.700 \leq ICC$). When selection criteria were based on RTD100 (criteria 3 and 4), five performed REPS were required to achieve "acceptable" reliability ($0.700 \leq ICC$) in knee flexion, and seven REPS were needed to achieve "good" reliability (Figure 3a, Appendix B).

The absolute measured RTD50 values for knee flexion did not change with an increasing number of REPS (Table 2, Appendix B).

3.1.2 | RTD100

For the knee extensors, the intersession reliability analysis indicated no systematic effect of the number of REPS on the reliability of RTD100, with ICCs ranging from 0.849 to 0.961 across all four selection criteria and a 95% confidence interval lower limit ranging from 0.610 to 0.899 (Figure 2b, Appendix A).

The absolute measured RTD100 values for knee extension did not change with an increasing number of REPS (Figure 4a, Table 2).

For the knee flexors, the intersession reliability analysis indicated no apparent systematic effect of the number of REPS on reliability on RTD100, with ICCs ranging from 0.835 to 0.944 across selection criteria and the 95% confidence interval lower limit ranging from 0.583 to 0.859 (Figure 3b, Appendix B).

The absolute measured RTD100 values for knee flexion increased consistently when more REPS were performed (Table 2). The effect of performing more REPS on the measured RTD100 was no longer significant, with six REPS ($p = 0.089$) compared with the RTD100 values measured based on nine REPS (Figure 4, Appendix D).

3.2 | Influence of Selection Criteria

3.2.1 | RTD50

For the knee extensors, the reliability analysis showed a slight indication that criteria based on absolute torque (criteria 1 and 2) yielded the highest ICCs, consistently being above 0.900 and the 95% CI lower limit consistently above 0.750 (Figure 2a, Appendix A). Selecting the one trial with the highest RTD100 (criterion 3) to quantify RTD50 was the lowest, but still consistently above 0.800. The 95% CI lower limit is, however, lower than the three other criteria, indicating more variable results.

The measured RTD50 values in knee extension differed between selection criteria according to the linear mixed model (Table 2, Appendix C). Selecting the one trial with the highest RTD100 (criterion 3) yielded the highest RTD50 values; however, only statistically higher than the criteria based on absolute torque (criteria 1 and 2).

For the knee flexors, the reliability analysis showed a slight indication that criteria based on absolute torque (criteria 1 and 2) yielded the highest ICCs, reaching an acceptable level from four to five REPS (Figure 3a, Appendix B). However, averaging three trials with the highest RTD 100 was equally or more reliable

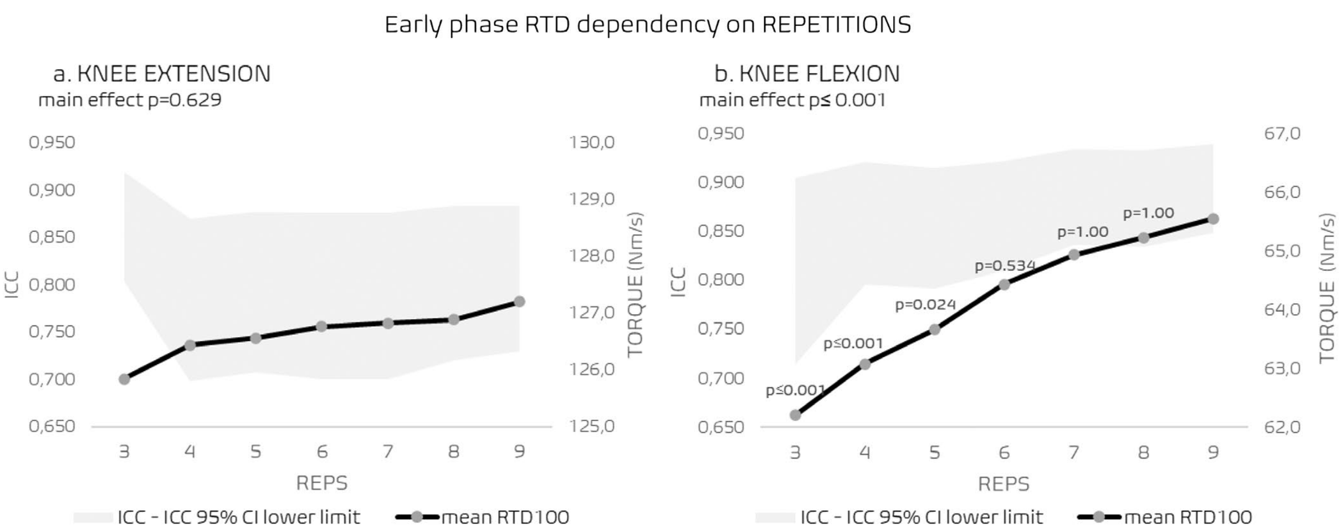

FIGURE 4 | Illustration of the main effect from repetitions on the measured RTD100 in knee extension (a) and knee flexion (b) with selection criterion 4. The range between ICC and the corresponding 95% CI lower limit is illustrated in grayscale, with units shown on the primary y-axis. The measured RTD100 is illustrated with black bars and units on the secondary y-axis. The level of significance for the main effect of the number of repetitions on the measured RTD100 mixed linear effects model is indicated below each title, and the significance of the separate estimates is indicated with p values above the corresponding bars.

with seven or more REPS performed in knee flexion. All four criteria had 95% CI lower limits below 0.700 (Figure 3a).

The measured RTD50 values in knee flexion differed between selection criteria according to the linear mixed model (Table 2, Appendix D). Selecting the one trial with the highest RTD100 (criterion 3) yielded the statistically highest RTD50 values (Appendix D).

There was no interaction between the number of performed REPS and selection criteria on RTD50 in either knee flexion or knee extension, according to the linear mixed model (Table 2).

3.2.2 | RTD100

For the knee extensors, the reliability analysis showed a slight indication that criteria based on absolute torque (criteria 1 and 2) yielded the highest ICCs, consistently being above 0.900 and the 95% CI lower limit consistently above 0.750 (Figure 2b, Appendix A). When selection criteria were based on RTD100 (criteria 3 and 4), reliability was *"good"* for RTD100, with ICCs above 0.800. The 95% CI lower limit was consistently above 0.700 with criterion 4 but only "fair" with criterion 3 (Figure 2b, Appendix A). The measured RTD100 values in knee extension differed between selection criteria according to the linear mixed model (Table 2, Appendix C). Selecting the one trial with the highest RTD100 (criterion 3) yielded the highest RTD100 values (Figure 5a), although only statistically significantly higher than criteria 1 and 2 after correcting for multiple testing.

For the knee flexors, the reliability analysis showed that selecting the one trial with the highest absolute torque (criterion 1) yielded ICC's consistently lower than the three other criteria and with the 95% CI falling below 0.700 (Figure 3b, Appendix B). ICC's for criteria 2–4 were consistently "excellent," with values exceeding 0.900 and a 95% CI lower limit above 0.750 (Figure 3b). The measured RTD100 values in knee flexion differed between selection criteria (Figure 5b, Appendix D). Selecting the one trial with the highest RTD100 (criterion 3) yielded the statistically highest RTD100 values (Appendix D) although only statistically significantly higher than criteria 2 and 4 after correcting for multiple testing.

There was no interaction between the number of performed REPS and selection criteria on RTD50 in either knee flexion or knee extension, according to the linear mixed model (Table 2).

3.3 | Test–Retest Bias on Measured Early Phase RTD

A systematic difference in measured RTD50, RTD100, and peak50 from sessions 1 and 2 was found according to our mixed effect linear model. However, it was in the opposite direction for knee flexion and knee extension (Appendices C and D).

In extension, the estimates for the measured RTD values were higher at session 1 than at session 2 (RTD50: 4.74 Nm/s [95% CI: 2.15–7.32]; RTD100: 3.31 Nm/s [95% CI: 0.34–6.29]). In flexion, the estimates for the measured RTD values were lower at session 1 than at session 2 (RTD50: −1.81 Nm/s [95% CI −2.48 to −1.14]; RTD100: −4.58 Nm/s [95% CI −5.27 to −3.89]).

No interaction was found between session and the number of REPS in either knee extension or knee flexion (Table 2).

4 | Discussion

The overall intersession reliability of early-phase RTD across various numbers of REPS and varying selection criteria shown in this study aligns with previous findings in the literature [9, 21]. While the ICC values in this study generally ranged from good to excellent, it is important to consider the 95% CI lower

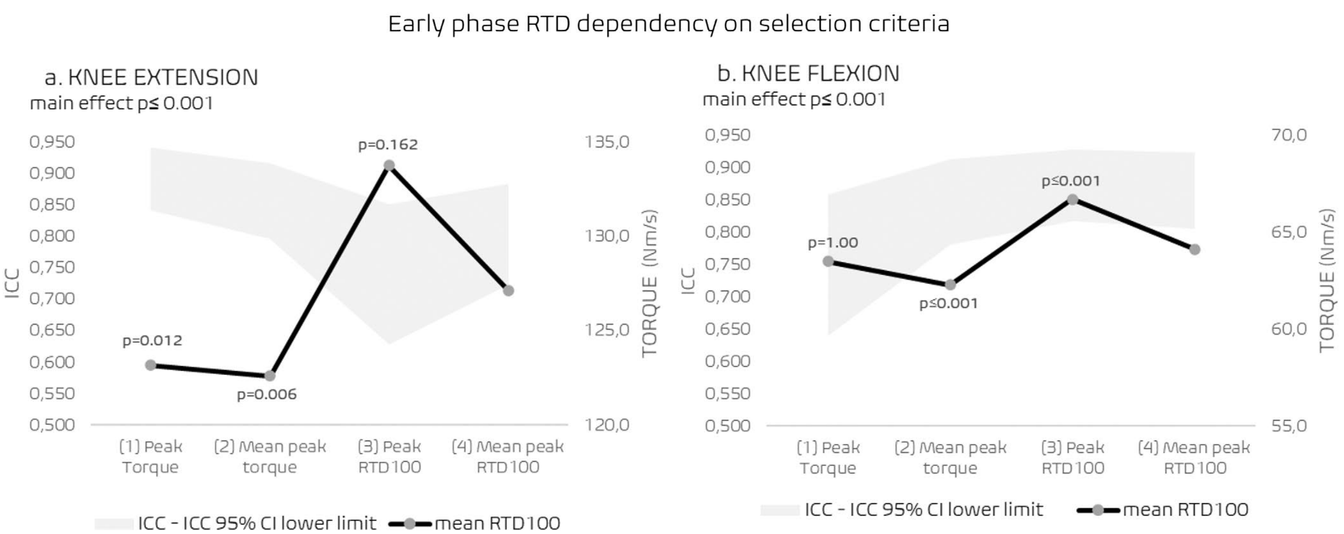

FIGURE 5 | Illustration of the main effect from selection criteria on the measured RTD100 in knee extension (a) and knee flexion (b). The range from the ICC to the corresponding 95% CI lower limit is illustrated in grayscale, with units shown on the primary Y-axis. The measured RTD100 is illustrated with black bars and units on the secondary y-axis. The level of significance for the main effect of the number of repetitions on the measured RTD100 mixed linear effects model is indicated below each title, and the significance of the separate estimates is indicated with *p* values above the corresponding bars.

limit and systematic biases from the number of REPS and selection criteria for a more complete assessment of reliability [27].

4.1 | Influence of Number of Repetitions

The presented data indicate that for the knee extensors, the intersession reliability, or measured values of RTD100, did not improve significantly beyond those of the three performed REPS. Thus, three knee extensions appear sufficient to obtain reproducible RTD measurements, with neither RTD100 nor RTD50 affected by the number of REPS.

With respect to knee flexion, the intersession reliability of RTD100 did not significantly improve beyond that of the three REPS. However, improved reliability was noted for RTD50 when five or more REPS were performed, depending on the specific selection criterion employed. Notably, the measured RTD100 values in knee flexion increased numerically with the number of REPS. The increases ceased to reach statistical significance with six REPS. In summation, the results from knee flexion suggest that performing five to seven REPS is needed to achieve optimal intersession reliability of early-phase RTD.

These findings indicate differences between knee extension and knee flexion in the required protocol to optimize reliability and absolute early-phase RTD measurements. The authors refrain from speculating on the physiological reasons behind this observation owing to the lack of supporting data. However, given that the study participants performed regular strength training, they may have been more familiar with knee extension exercises (e.g., squats, knee extension, leg press, and hack squats) than with knee flexion machines. Methodically, it has been recognized that the cutoff for the onset of force should differ between knee flexion and knee extension due to the differences in muscle properties [4, 5]. These results suggest that differences in the recommended number of performed REPS should be applied and that performing too few REPS could impact clinical and scientific interpretations. Conducting only 3–4 REPS, as commonly reported in the literature, may underestimate RTD100 and yield less reliable RTD50 in knee flexion. Given that a low ratio of knee flexion RTD to knee extension RTD appears to be sensitive for predicting ACL rupture [14, 30], performing only 3–4 REPS could potentially categorize athletes as more "injury prone" than if 6–7 REPS were performed [14].

4.2 | Influence of Selection Criteria

For the knee extensors, all four selection criteria consistently yielded high ICC values for RTD100 across different numbers of repetitions. No statistical interaction was found between the number of performed REPS and selection criteria, indicating that alternative trial selection methods did not reduce the number of repetitions needed for acceptable ICC values.

Trial selection criteria impacted intersession reliability in knee extension independently, with the highest reliability observed when early-phase RTD measures were based on trials selected from peak torque (criteria 1 and 2). Conversely, selection criteria based on RTD100 (criteria 3 and 4) resulted in higher absolute RTD measurements but with a less convincing 95% CI lower limit. A similar trend was observed for RTD50. Thus, for the assessment of knee extension RTD, a trade-off was observed between consistency and achieving the highest values that researchers need to be conscious of when choosing selection criteria for the calculation of early-phase RTD measures.

In summation, averaging the three trials with the highest RTD100 values appeared to be a robust selection criterion for obtaining a high RTD100 value with good reliability and an acceptable 95% CI lower limit on the ICC. Selecting REPS based on an RTD outcome and not peak torque appears logical and is supported by Dirnberger and collagues [9]. They showed the best intersession reliability and highest RTD values in combined RTD-MVIC test REPS when early-phase RTD values were derived from the trial with the highest peak RTD.

Like knee extension, alternative methods for trial selection did not reduce the number of REPS needed to achieve acceptable ICCs in knee flexion RTD100. There was a small trend indicating that selection criteria based on RTD100 (criteria 3 and 4) required more repetitions for acceptable reliability in knee flexion RTD50.

Selection criteria also independently impacted intersession reliability in knee flexion. The early-phase RTD from one single trial with the highest peak torque was opposite knee extension, the least reliable criterion, outperformed by criteria 1, 2, and 4, which had similar ICCs and 95% CIs. Additionally, criteria 3 or 4 yielded high measured RTD100 values, suggesting that for knee flexion, averaging the three trials with the highest RTD100 values could be recommended to optimize early-phase RTD assessment.

Our results indicate that when designing a test protocol to assess early-phase RTD, considerations should be given to which outcomes are most accurate and relevant for performance or injury prevention. This involves balancing reliable and consistent measurements that reflect true maximal RTD performance while potentially being less reproducible. Methodologically, it is crucial to weigh the gains in obtained RTD value against the required sample size to achieve statistically significant results when designing future scientific or clinical trials.

4.3 | Study Limitations

This study was performed on a convenience sample of 10 men and 10 women. While a larger sample size is generally recommended, the sample size used in this study is consistent with those commonly reported in published test–retest studies [9, 20]. With our population and two test sessions, we should be able to show with a 95% certainty an internal width of the confidence level of 0.159 if the expected ICC is 0.750. To address possible limitations stemming from sample size, we have illustrated the 95% lower limit of the ICC in figures and appendices to ensure full transparency.

Both flexion and extension showed a significant effect of test session on measured RTD values. Given the inherently variable nature of RTD measurements, separate familiarization sessions are often recommended [4, 5]. However, the systematic differences in RTD measurements between sessions were in opposite directions for knee extension and knee flexion, indicating that task familiarity does not always improve outcome measures in healthy active subjects. Additionally, as there was no interaction between session and number of REPS, task familiarization did not influence the recommendation of the number of REPS in this study.

Finally, the participants were asked to perform an extensive protocol of knee extensions and knee flexions. To this end, general fatigue following knee extension could have influenced the knee flexion RTD. However, as we observe a statistically significant increase in RTD over the nine repetitions in knee flexion, this does not appear to be the case.

5 | Conclusions

This study provides data-driven recommendations for measuring and analyzing early-phase RTD. For optimal reliability and validity, we recommend performing five to six repetitions for knee flexion and three repetitions for knee extension, averaging the three trials that display the highest RTD100.

6 | Perspectives

Notably, the chosen number of repetitions may vary in each study protocol assessing early-phase RTD for scientific or pragmatic reasons. These results indicate that the intersession reliability of early-phase RTD in knee flexion appears to be impacted the most by this methodological choice.

The authors have attempted to present results with full transparency, enabling readers to make informed data-driven decisions in the future assessment of early phase RTD, rather than relying solely on summarized conclusions.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Appendix A

Intraclass Correlation Coefficients and RTD Measures in Knee Extension

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
Knee extension - RTD50							
1 × Peak torque							
RTD Session A	82.34 ± 32.08	82.87 ± 31.37	81.93 ± 32.49	81.53 ± 33.11	81.22 ± 33.37	80.13 ± 32.93	79.63 ± 33.02
RTD Session B	78.84 ± 32.45	75.61 ± 33.17	74.43 ± 33.26	73.84 ± 33.54	73.17 ± 33.57	73.19 ± 33.50	72.86 ± 31.97
ICC	0.881	0.852	0.857	0.868	0.893	0.894	0.885
95% CI Lower limit	0.728	0.654	0.660	0.676	0.702	0.731	0.718
SEM ICC	11.13	12.42	12.43	12.11	10.95	10.81	11.02
3 × Peak torque							
RTD Session A	82.31 ± 29.60	82.14 ± 29.67	81.62 ± 29.28	80.68 ± 28.18	80.25 ± 28.26	79.82 ± 28.23	78.72 ± 28.27
RTD Session B	77.59 ± 30.99	76.44 ± 31.15	74.71 ± 31.46	75.56 ± 31.79	74.60 ± 31.83	73.64 ± 30.78	73.32 ± 29.30
ICC	0.913	0.895	0.863	0.908	0.909	0.889	0.923
95% CI Lower limit	0.792	0.745	0.671	0.777	0.770	0.724	0.791

(Continues)

Appendix A (Continued)

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
SEM ICC	8.94	9.86	11.25	9.11	9.08	9.84	7.99
1 × Peak RTD100							
RTD Session A	91.48 ± 29.29	91.51 ± 29.04	91.87 ± 29.19	91.82 ± 29.24	91.82 ± 29.24	91.82 ± 29.24	91.19 ± 29.89
RTD Session B	81.44 ± 31.26	82.26 ± 31.27	82.45 ± 31.15	81.63 ± 31.28	82.18 ± 31.37	82.19 ± 31.25	82.76 ± 30.02
ICC	0.830	0.831	0.832	0.826	0.831	0.833	0.815
95% CI Lower limit	0.531	0.565	0.558	0.522	0.551	0.552	0.566
SEM ICC	12.49	12.41	12.37	12.63	12.47	12.37	12.88
3 × Peak RTD100							
RTD Session A	82.31 ± 29.60	85.08 ± 29.57	85.72 ± 29.23	86.50 ± 28.38	86.37 ± 28.17	86.53 ± 28.06	86.48 ± 28.10
RTD Session B	77.59 ± 30.99	77.73 ± 30.98	78.43 ± 30.33	78.41 ± 30.47	78.53 ± 30.01	78.75 ± 29.79	79.18 ± 29.71
ICC	0.913	0.857	0.879	0.877	0.884	0.887	0.890
95% CI Lower limit	0.792	0.653	0.681	0.644	0.656	0.658	0.683
SEM ICC	8.94	11.45	10.36	10.33	9.91	9.73	9.59
Knee extension - RTD100							
1 × Peak Torque							
RTD Session A	127.49 ± 49.57	128.14 ± 49.27	127.45 ± 51.61	127.15 ± 52.07	127.32 ± 5196	125.52 ± 50.32	125.10 ± 50.69
RTD Session B	121.91 ± 48.22	119.69 ± 49.36	118.9 ± 49.71	118.49 ± 50.14	118.03 ± 49.70	118.82 ± 49.08	119.26 ± 49.89
ICC	0.941	0.934	0.927	0.93	0.945	0.951	0.961
95% CI Lower limit	0.857	0.820	0.813	0.816	0.821	0.871	0.899
SEM ICC	11.88	12.67	13.69	13.52	11.92	11.00	9.93
3 × Peak Torque							
RTD Session A	126.80 ± 48.16	127.40 ± 49.02	127.13 ± 49.04	126.68 ± 47.99	126.43 ± 47.88	125.93 ± 47.84	124.83 ± 47.56
RTD Session B	119.64 ± 48.02	118.93 ± 47.95	118.27 ± 47.81	118.88 ± 48.29	118.60 ± 48.14	118.07 ± 46.94	118.77 ± 46.56
ICC	0.919	0.905	0.898	0.916	0.923	0.917	0.943
95% CI Lower limit	0.804	0.769	0.753	0.795	0.807	0.795	0.859
SEM ICC	13.69	14.94	15.47	13.95	13.32	13.65	11.24
1 × Peak RTD100							
RTD Session A	138.80 ± 48.38	139.63 ± 47.86	140.34 ± 48.68	140.36 ± 48.66	140.36 ± ± 48.66	140.36 ± 48.66	140.40 ± 48.63
RTD Session B	125.92 ± 48.74	126.50 ± 48.30	126.73 ± 48.12	126.99 ± 48.10	127.43 ± 48.17	128.75 ± 47.02	130.39 ± 47.32
ICC	0.855	0.852	0.849	0.850	0.850	0.851	0.847

(Continues)

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
95% CI Lower limit	0.632	0.621	0.610	0.615	0.625	0.644	0.652
SEM ICC	18.49	18.50	18.81	18.74	18.75	18.47	18.77
3 × Peak RTD100							
RTD Session A	126.8 ± 48.18	130.36 ± 48.69	131.69 ± 48.96	132.89 ± 48.01	133.23 ± 47.50	133.47 ± 47.27	133.56 ± 47.21
RTD Session B	119.64 ± 48.02	120.90 ± 48.67	121.95 ± 47.89	122.72 ± 47.84	123.20 ± 47.82	124.21 ± 49.91	125.33 ± 47.08
ICC	0.919	0.870	0.877	0.876	0.876	0.884	0.884
95% CI Lower limit	0.804	0.698	0.708	0.701	0.701	0.721	0.730
SEM ICC	13.69	17.55	16.98	16.88	16.78	16.56	16.06
Knee extension - Peak50							
1 × Peak torque							
RTD Session A	1597.09 ± 641.99	1605.84 ± 628.98	1589.23 ± 656.05	1580.77 ± 669.60	1577.66 ± 672.21	1557.96 ± 661.20	1552.75 ± 663.22
RTD Session B	1530.23 ± 660.59	1482.26 ± 674.32	1459.99 ± 682.29	1448.96 ± 688.12	1454.62 ± 663.76	1456.89 ± 661.42	1448.77 ± 631.56
ICC	0.926	0.904	0.899	0.909	0.937	0.941	0.939
95% CI Lower limit	0.826	0.761	0.749	0.765	0.813	0.843	0.836
SEM ICC	177.19	202.03	212.71	204.81	167.67	160.63	159.94
3 × Peak torque							
RTD Session A	1593.82 ± 626.58	1592.87 ± 625.20	1586.60 ± 319.80	1575.60 ± 600.17	1566.93 ± 601.43	1558.13 ± 602.54	1542.33 ± 600.79
RTD Session B	1492.84 ± 639.67	1479.37 ± 643.15	1472.72 ± 651.19	1468.06 ± 654.82	1456.56 ± 652.34	1439.95 ± 634.37	1444.27 ± 621.82
ICC	0.921	0.904	0.901	0.914	0.926	0.91	0.936
95% CI Lower limit	0.805	0.765	0.760	0.787	0.806	0.769	0.832
SEM ICC	177.96	196.51	200.01	184.19	170.67	185.60	154.67
1 × Peak RTD100							
RTD Session A	1753.38 ± 603.03	1759.50 ± 596.44	1767.24 ± 601.63	1768.35± 600.53	1768.35 ± 600.53	1768.35 ± 600.53	1765.15 ± 603.57
RTD Session B	1561.96 ± 631.98	1570.78 ± 635.17	1575.29 ± 632.05	1564.32 ± 632.34	1576.18 ± 634.51	1583.36 ± 626.14	1594.93 ± 600.56
ICC	0.869	0.865	0.864	0.859	0.863	0.868	0.858
95% CI Lower limit	0.581	0.587	0.578	0.539	0.578	0.596	0.617
SEM ICC	223.56	226.37	227.55	231.55	228.65	222.88	226.88
3 × Peak RTD100							

(Continues)

Appendix A (Continued)

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
RTD Session A	1593.82 ±626.58	1639.35 ±621.40	1654.24 ±618.63	1670.18 ±601.44	1670.47 ±596.11	1674.63 ±593.02	1675.81 ±592.00
RTD Session B	1492.84 ±639.67	1503.94 ±644.18	1514.46 ±633.91	1518.49 ±636.31	1522.32 ±630.92	1529.50 ±624.73	1538.58 ±624.20
ICC	0.921	0.878	0.889	0.888	0.892	0.895	0.896
95% CI Lower limit	0.805	0.703	0.714	0.691	0.699	0.706	0.721
SEM ICC	177.96	221.10	208.67	207.20	201.70	197.36	196.18

Appendix B

Intraclass Correlation Coefficients and RTD Measures in Knee Flexion

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
Knee flexion- RTD50							
1×Peak torque							
RTD Session A	29.81±11.17	29.55±12.00	29.59±11.97	30.53±12.24	30.96±12.42	30.96±12.42	31.38±12.16
RTD Session B	33.28±14.40	33.11±14.00	32.48±15.33	32.91±16.28	32.96±16.29	33.12±16.27	34.14±16.38
ICC	0.468	0.805	0.762	0.792	0.787	0.781	0.772
95% CI Lower limit	0.056	0.557	0.499	0.553	0.542	0.533	0.516
SEM ICC	9.40	5.76	6.71	6.57	6.69	6.77	6.89
3×Peak torque							
RTD Session A	30.15±12.53	30.51±11.53	29.68±11.07	30.33±12.10	29.99±12.59	30.51±12.75	30.46±12.15
RTD Session B	32.9±13.83	31.46±14.38	31.8±14.75	31.79±15.12	31.81±15.21	31.71±14.78	31.77±13.98
ICC	0.674	0.725	0.789	0.831	0.870	0.863	0.878
95% CI Lower limit	0.350	0.424	0.548	0.626	0.706	0.690	0.721
SEM ICC	7.53	6.83	5.99	5.63	5.03	5.11	4.57
1×Peak RTD100							
RTD Session A	32.44±13.12	33.40±12.78	33.64±13.08	34.26±13.43	34.26±13.59	34.34±13.70	34.86±13.81
RTD Session B	34.64±15.28	34.64±15.12	34.54±15.45	34.96±16.42	35.72±16.14	35.71±15.96	36.51±15.99
ICC	0.655	0.652	0.681	0.684	0.757	0.761	0.831
95% CI Lower limit	0.314	0.302	0.348	0.352	0.484	0.49	0.625
SEM ICC	8.36	8.26	8.08	8.43	7.35	7.27	6.14
3×Peak RTD100							
RTD Session A	30.15±12.54	31.75±12.75	32.39±13.28	32.78±13.36	32.98±13.58	32.70±13.29	33.05±13.25
RTD Session B	32.90±13.83	33.12±14.03	33.68±14.59	33.96±14.83	34.20±14.72	34.16±14.61	34.14±14.58
ICC	0.674	0.694	0.727	0.730	0.793	0.820	0.847

(Continues)

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
95% CI Lower limit	0.350	0.372	0.429	0.433	0.555	0.604	0.655
SEM ICC	7.54	7.42	7.29	7.33	6.44	5.93	5.45
Knee Flexion - RTD100							
1 × Peak torque							
RTD Session A	59.5 ± 22.26	59.1 ± 21.65	59.46 ± 21.47	60.7 ± 23.08	61.31 ± 23.74	61.31 ± 23.74	61.97 ± 23.63
RTD Session B	65.7 ± 24.47	66.31 ± 25.19	66.09 ± 27.62	66.67 ± 28.43	66.82 ± 28.44	67.06 ± 28.50	67.11 ± 28.88
ICC	0.881	0.881	0.835	0.841	0.859	0.854	0.856
95% CI Lower limit	0.66	0.583	0.604	0.633	0.672	0.659	0.671
SEM ICC	8.07	8.10	10.05	10.33	9.84	10.02	10.01
3 × Peak torque							
RTD Session A	57.99 ± 23.65	59.4 ± 23.39	59.8 ± 22.54	60.54 ± 23.19	60.87 ± 23.58	61.23 ± 24.53	61.5 ± 24.01
RTD Session B	63.74 ± 25.00	62.93 ± 24.77	63.97 ± 25.95	64.48 ± 26.68	64.99 ± 26.60	65.32 ± 26.41	65.20 ± 26.32
ICC	0.905	0.920	0.907	0.912	0.912	0.916	0.917
95% CI Lower limit	0.714	0.808	0.774	0.788	0.787	0.795	0.801
SEM ICC	7.50	6.81	7.41	7.42	7.46	7.39	7.26
1 × Peak RTD100							
RTD Session A	62.14 ± 24.18	63.74 ± 23.42	64.19 ± 23.53	65.00 ± 24.31	65.60 ± 24.62	65.97 ± 25.07	66.49 ± 25.07
RTD Session B	66.82 ± 24.89	67.59 ± 25.02	68.34 ± 26.85	69.03 ± 27.58	69.47 ± 27.68	69.62 ± 27.55	69.96 ± 27.67
ICC	0.928	0.926	0.915	0.917	0.929	0.934	0.944
95% CI Lower limit	0.795	0.816	0.792	0.799	0.825	0.838	0.859
SEM ICC	6.58	6.59	7.36	7.49	6.98	6.77	6.25
3 × Peak RTD100							
RTD Session A	58.00 ± 23.65	60.62 ± 23.75	61.67 ± 23.78	62.64 ± 24.13	63.44 ± 24.63	63.82 ± 24.96	64.32 ± 24.10
RTD Session B	63.74 ± 24.40	64.91 ± 25.13	65.76 ± 26.03	66.43 ± 26.35	66.99 ± 26.44	67.49 ± 26.56	67.91 ± 26.95
ICC	0.905	0.921	0.915	0.922	0.934	0.933	0.940
95% CI Lower limit	0.714	0.796	0.792	0.81	0.837	0.835	0.849
SEM ICC	7.41	6.87	7.27	7.06	6.56	6.67	6.26
Knee Flexion - Peak50							
1 × Peak torque							
RTD Session A	698.68 ± 288.24	697.64 ± 275.34	705.78 ± 268.19	716.99 ± 275.23	721.32 ± 280.89	721.32 ± 280.89	727.49 ± 281.78
RTD Session B	791.85 ± 310.85	794.95 ± 311.19	796.76 ± 336.81	805.35 ± 344.04	808.41 ± 343.27	810.67 ± 344.53	800.68 ± 340.0
ICC	0.88	0.843	0.832	0.834	0.845	0.839	0.854

(Continues)

Selection criteria	3 REPS	4 REPS	5 REPS	6 REPS	7 REPS	8 REPS	9 REPS
95% CI Lower limit	0.574	0.538	0.573	0.59	0.609	0.595	0.653
SEM ICC	103.84	116.42	124.78	126.93	123.48	126.12	119.31
3 × Peak torque							
RTD Session A	689.01 ± 306.15	701.76 ± 301.46	706.46 ± 281.00	713.52 ± 284.13	722.47 ± 284.39	726.5 ± 287.57	725.28 ± 289.43
RTD Session B	763.29 ± 297.41	773.45 ± 308.26	782.5 ± 325.73	774.39 ± 328.50	780.75 ± 325.25	786.44 ± 320.89	782.28 ± 321.85
ICC	0.892	0.906	0.89	0.892	0.904	0.904	0.9
95% CI Lower limit	0.694	0.720	0.687	0.735	0.760	0.756	0.0754
SEM ICC	99.19	93.47	100.89	100.93	94.66	94.40	96.79
1 × Peak RTD100							
RTD Session A	725.57 ± 302.46	742.65 ± 295.09	749.44 ± 293.75	754.26 ± 299.45	765.62 ± 305.31	767.43 ± 306.63	771.66 ± 304.43
RTD Session B	807.23 ± 311.69	813.59 ± 312.82	816.33 ± 326.33	826.18 ± 332.45	821.30 ± 325.86	826.04 ± 327.09	828.34 ± 328.09
ICC	0.909	0.927	0.919	0.895	0.911	0.904	0.906
95% CI Lower limit	0.663	0.728	0.758	0.718	0.78	0.762	0.77
SEM ICC	92.64	82.16	88.36	102.52	94.20	98.23	97.03

Appendix C

Results From Mixed Linear Model on RTD in Knee Extension

Knee extension	Estimate	Sig.	95% confidence interval	
			Lower bound	Upper bound
RTD50				
Session				
Session 1	4.74	≤ 0.000	2.15	7.32
Session 2	—	—	—	—
Selection criteria				
1 × Peak torque	−5.80	≤ 0.000	−9.07	−2.52
3 × Peak torque	−5.33	0.001	−8.60	−2.05
1 × Peak RTD100	2.78	0.096	−0.50	6.05
3 × Peak RTD100	—	—	—	—
Session × Selection criteria				
1 × Peak torque × session 1	2.20	0.063	−0.12	4.51
3 × Peak torque × session 1	−1.01	0.392	−3.33	1.31
1 × Peak RTD100 × session 1	1.79	0.130	−0.53	4.10

(Continues)

Knee extension	Estimate	Sig.	95% confidence interval Lower bound	Upper bound
3 × Peak RTD100 × session 1	—	—	—	—
1 × Peak torque × session 2	—	—	—	—
3 × Peak torque × session 2	—	—	—	—
1 × Peak RTD100 × session 2	—	—	—	—
3 × Peak RTD100 × session 2	—	—	—	—
RTD100				
Session				
Session 1	3.31	0.029	0.34	6.29
Session 2	—	—	—	—
Selection criteria				
1 × Peak torque	−5.93	0.002	−9.69	−2.17
3 × Peak torque	−6.24	0.001	−10.00	−2.48
1 × Peak RTD100	4.22	0.027	0.46	7.98
3 × Peak RTD100	—	—	—	—
Session × Selection criteria				
1 × Peak torque × session 1	1.79	0.178	−0.870	4.447
3 × Peak torque × session 1	−0.22	0.869	−2.882	2.435
1 × Peak RTD100 × session 1	3.08	0.023	0.420	5.737
3 × Peak RTD100 × session 1	—	—	—	—
1 × Peak torque × session 2	—	—	—	—
3 × Peak torque × session 2	—	—	—	—
1 × Peak RTD100 × session 2	—	—	—	—
3 × Peak RTD100 × session 2	—	—	—	—
Peak 50				
Session				
Session 1	82.93	≤ 0.000	39.70	126.16
Session 2	—	—	—	—
Selection criteria				
1 × Peak Torque	−96.59	0.001	−151.27	−41.91
3 × Peak Torque	−91.81	0.001	−146.49	−37.12
1 × Peak RTD100	40.52	0.146	−14.16	95.20
3 × Peak RTD100	—	—	—	—
Selection criteria				
1 × Peak torque × session 1	23.43	0.235	−15.23	62.10
3 × Peak torque × session 1	−16.61	0.399	−55.28	22.05
1 × Peak RTD100 × session 1	48.10	0.015	9.43	86.76
3 × Peak RTD100 × session 1	—	—	—	—

(Continues)

Appendix C (Continued)

Knee extension	Estimate	Sig.	95% confidence interval	
			Lower bound	Upper bound
1 × Peak torque × session 2	—	—	—	—
3 × Peak torque × session 2	—	—	—	—
1 × Peak RTD100 × session 2	—	—	—	—
3 × Peak RTD100 × session 2	—	—	—	—

Appendix D

Results From Mixed Linear Model in RTD in Knee Flexion

Knee flexion	Estimate	Sig.	95%confidence interval	
			Lower bound	Upper bound
RTD50				
Session				
Session 1	−1.81	≤ 0.000	−2.48	−1.14
Session 2	—	—	—	—
Selection criteria				
1 × Peak torque	−1.23	0.011	−2.18	−0.28
3 × Peak torque	−1.94	≤ 0.000	−2.89	−0.99
1 × Peak RTD100	1.57	0.001	0.62	2.52
3 × Peak RTD100	—	—	—	—
RTD100				
Session				
Session 1	−4.58	≤ 0.000	−5.27	−3.89
Session 2	—	—	—	—
Selection criteria				
1 × Peak torque	−0.61	0.220	−1.59	0.36
3 × Peak torque	−1.84	≤ 0.000	−2.82	−0.86
1 × Peak RTD100	2.59	≤ 0.000	1.61	3.57
3 × Peak RTD100	—	—	—	—
Number of trials				
RTD1	−3.35	≤ 0.000	−4.65	−2.06
RTD2	−2.48	≤ 0.000	−3.77	−1.19
RTD3	−1.90	0.004	−3.19	−0.61
RTD4	−1.12	0.089	−2.41	0.17
RTD5	−0.62	0.346	−1.9	0.67
RTD6	−0.33	0.615	−1.62	0.96
RTD7	—	—	—	—
Peak 50				
Session				

(Continues)

Knee flexion	Estimate	Sig.	95%confidence interval	
			Lower bound	Upper bound
Session 1	−70.30	≤0.000	−78.89	−61.70
Session 2	—	—	—	—
Selection criteria				
1×Peak torque	−0.91	0.883	−13.07	11.24
3×Peak torque	−13.04	0.036	−25.19	−0.89
1×Peak RTD100	28.92	≤0.000	16.77	41.08
3×Peak RTD100	—	—	—	—
Number of trials				
RTD1	−32.74	≤0.000	−48.82	−16.66
RTD2	−22.46	0.006	−38.54	−6.38
RTD3	−15.78	0.054	−31.86	0.30
RTD4	−8.80	0.283	−24.88	7.28
RTD5	−3.77	0.646	−19.85	12.31
RTD6	−1.03	0.9	17.11	15.05
RTD7	—	—	—	—