



# Reliability and validity of a novel Isokinetic Knee Dynamometer System

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*Purpose:* The aim of this work was to determine the intersession reliability and validity of a recently developed prototype Isokinetic Knee Dynamometer to assess isokinetic knee extension and flexion peak moments compared to a Biodex System 4 dynamometer. *Methods:* Thirty-five healthy participants performed two sessions (48-h separation) of bilateral concentric isokinetic knee extension and flexion on both isokinetic devices at 60 °/s (6 repetitions), 180 °/s (10 repetitions) and 240 °/s (15 repetitions). Dynamometer and limb order were randomized among participants while peak moment of each set was used for data analysis. *Results:* The Isokinetic Knee Dynamometer had excellent relative reliability, comparable to the System 4, and both systems displayed acceptable absolute reliability. Proportional biases were observed favoring the System 4 during knee extension of both limbs at 60 °/s and the dominant limb at 180 °/s, and fixed biases favoring the Isokinetic Knee Dynamometer in seven conditions. Relative agreement between systems was good across all test conditions with the majority demonstrating excellent agreement. *Conclusions:* These data support the Isokinetic Knee Dynamometer as a reliable and valid knee isokinetic testing system. Due to its reduced system complexity, space requirements, and production cost, the Isokinetic Knee Dynamometer may increase the clinical utilization of isokinetic knee assessments. Finally, these data fill an existing isokinetics literature void with the results supporting similar and acceptable measurement properties jointly for dominant and non-dominant limbs and at the higher testing velocities considered.

*Key words:* peak moment, strength assessment, lower extremity, peak torque

## 1. Introduction

Measurement of dynamic muscle performance characteristics, such as strength, power and endurance, through isokinetic dynamometry has a 40 year history [7] and is considered to be the gold standard in clinical populations [3], [7], [12], [37]. Isokinetic assessment methods evaluate dynamic muscle performance through a predefined range of motion (ROM) at a preset constant velocity, with currently available commercial systems ranging from 1 °/s to 300 °/s [7]. Because velocity is held constant, the resistance provided by the isokinetic dynamometer system accommodates to the active muscle force produced by the participant. This scenario is an advantage for muscle performance testing, exercise in clinical populations, and is sup-

ported by the plethora of studies demonstrating reliability and validity in both healthy and clinical populations [2], [8]–[11], [14], [19], [28]–[30], [35]–[38].

Currently available commercial isokinetic dynamometer systems are not portable, require a significant amount of dedicated space, and are seemingly complex. The large size and complexity are mostly attributable to being designed to accommodate the assessment and exercise of multiple joints, including knees, shoulders, ankles, hips, elbows, and wrists. Despite the capability to be used at multiple joints, the vast majority of clinically utilized isokinetic assessments and exercise are conducted at the knee joint. Numerous studies have demonstrated the importance of quadriceps strength and power and its relationship to prevention of re-injuries and return to pre-morbid levels of performance [13], [20], [21], [23], [24].

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A prototype Isokinetic Knee Dynamometer (IKD) has been recently developed to assess solely dynamic knee extension and flexion muscle performance, thereby reducing space requirements, system complexity and cost as utilization barriers. Additionally, the prototype was designed to operate with typical electrical supply circuits and be controlled from a tablet computer. As the IKD is solely for assessment and exercise of the knee joint, the dynamometer-patient attachment is fixed to the actuator. Thus, while the IKD design simplifies the time and steps needed to prepare for use, the smaller and lighter patient positioning system and reduced joint axis/dynamometer alignment capabilities could influence dynamic knee muscle performance compared to the traditional stationary systems. Therefore, the primary purpose of this study was to determine the intersession reliability and validity of the IKD to assess dynamic knee extension and flexion peak moment in comparison to a traditional commercially available isokinetic dynamometer system in healthy young adults. We hypothesized the results would demonstrate the IKD to have excellent reliability and validity. Based on previous literature not considering the possibility for bilateral differences (dominant versus nondominant knees) in reliability and validity, as well as a void examining the higher testing velocities often used in clinical situations ( $>180$  °/s) [7], secondary purposes were to conduct separate analyses for each limb as well as to consider the measurement properties of  $180$  °/s and  $240$  °/s testing velocities. We hypothesized that similar and acceptable measurement properties would be realized for both limbs and at the higher testing velocities.

## 2. Materials and methods

### 2.1. Participants

Participants included 19 male ( $84.3 \pm 12.3$  kg,  $1.79 \pm 0.08$  m,  $24.9 \pm 3.4$  years) and 16 female ( $72.6$

$\pm 14.7$  kg,  $1.64 \pm 0.07$  m,  $23.9 \pm 4.8$  years) volunteers aged 18 to 35 years. All participants were in good health, met minimum standards for exercise as determined by the Physical Activity Readiness Questionnaire [1], met American College of Sports Medicine criteria for being physically active [33] and were also free from lumbar spine or lower extremity orthopedic and neurological conditions that could affect knee muscle function. This experiment was undertaken with the understanding and written consent of each participant. This study conforms with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the Georgia Southern University Institutional Review Board (protocol: H19030, approved 9/24/2019).

### 2.2. Study design

This study utilized a randomized, cross over, repeated measures, research design. Study participation required two testing sessions 48 hours apart. Testing sessions were scheduled at near identical times each day [15] and participants were asked to avoid vigorous physical activity 24 hours prior to each session. At each session, participants completed identical protocols: knee extension and flexion at three isokinetic velocities using both dynamometer systems with both limbs. Each participant was randomly allocated a dynamometer and limb testing order (Fig. 1) which was replicated on day two.

### 2.3. Device descriptions

The IKD (Fig. 2) prototype used in the current investigation consisted of a  $0.41$  m wide seat plate ( $12^\circ$  posterior tilt) and adjustable (fore/aft in  $0.35$  m intervals) backrest secured to an elevated platform. The participant’s pelvis and thigh were secured to the seat plate with padded straps, while a padded cuff secured the shank to the distal end of an adjustable three-link interface that was connected to a custom rotary actua-

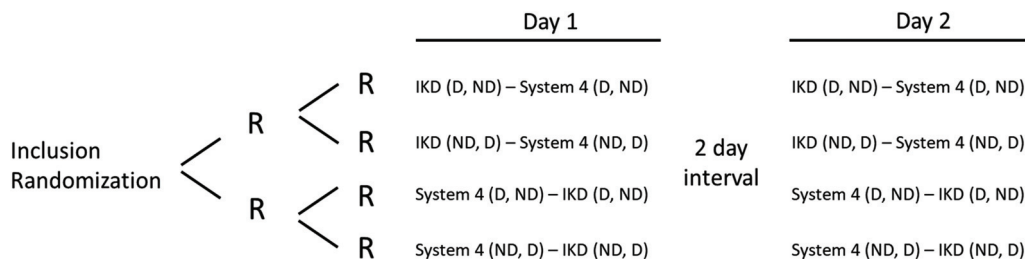


Fig. 1. Illustration of research study design in which participants were randomly assigned to starting on the Isokinetic Knee Dynamometer (IKD) or System 4 Dynamometer with either the dominant (D) or non-dominant (ND) limb

tor. The rotary actuator, which allows for motor-controlled motion, attaches to either side of the seat plate to allow for testing of both knees. The actuator employs a commercial off-the-shelf brushless direct current motor (Parker model K089075, Parker-Hannifin Corp., Cleveland, OH, USA; rated output power 548 W), and an incremental position encoder manufactured by US Digital (Vancouver, WA, USA). The transmission from motor speed and torque to output speed and torque was accomplished with a strain wave-type gearbox (Cone Drive CBC-25, Cone Drive, Transverse City, Michigan, USA) with an 80:1 gear ratio equipped with a custom strain gauge torque sensor. A system control board performed safety monitoring, motor control, moment, position and temperature sensor processing, and communication between the actuator and a tablet computer. Mechanical hardstops limited the ROM from 100° knee flexion to 10° knee hyperextension. At 60 °/s, the dynamometer was demonstrated to resist and remain at the target velocity against a 329.5 Nm torque load imposed by another dynamometer.



Fig. 2. The Isokinetic Knee Dynamometer prototype used in the current investigation

The Biodex System 4 Dynamometer (S4) (Biodex Medical Systems, Shirley, NY, USA), released commercially in 2007, is a fixed system dynamometer capable of providing isokinetic and isotonic, both concentric and eccentric, and isometric muscle strength and endurance assessments. The patient positioning

system has padded straps that cross the chest, pelvis and thigh. A padded cuff at the distal end of the knee attachment secures the shank. Both the chair (width: 0.44 m, seat pan tilt: 12° posterior) and dynamometer can be moved to allow for knee joint axis alignment with the dynamometer shaft. Additionally, the precise fore/aft position of the seatback is adjustable by a crank mechanism. Several studies have demonstrated the Biodex Dynamometers to be valid and reliable [10], [22], [41].

Computers operating the Biodex Advantage BX (version 5.0.33) software were interfaced with each dynamometer system, controlled the dynamometers during the testing, and recorded moment, position and velocity data. The peak moments attained during each set of repetitions were exported for statistical analysis.

## 2.4. Bilateral isokinetic testing procedures

Participants underwent concentric-concentric isokinetic assessments at three velocities (60 °/s, 180 °/s, 240 °/s) on both the IKD and S4 dynamometer systems for knee extension and flexion. Participants were positioned in each dynamometer according to the Instruction for Use documentation, particularly with regards to knee joint axes alignment. The starting position was established with the shank plumb, while active extension ROM or full knee extension, whichever was less, was used end of ROM limit.

At each velocity, progressive gradient warm-ups were used followed by a maximum effort consisting of 6 repetitions at 60 °/s, 10 repetitions at 180 °/s and 15 repetitions at 240 °/s. Thirty seconds rest was given between sets. Three minutes rest was provided between limbs and 5-min rest was given between dynamometer systems. Prior to each set of repetitions at each testing velocity, participants were encouraged to “push and pull as hard and fast as possible”. Identical testing procedures were utilized during each participant’s second testing session.

## 2.5. Statistical analysis

Separate, but similar, statistical analyses were conducted on the knee extension and flexion peak moments from the dominant and nondominant limbs. In-depth exploratory analyses on the peak moment data were conducted to identify potential outliers or erroneous data. All statistical procedures were conducted using

IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, NY, USA) and Microsoft Excel, version 16 (Microsoft Corporation, Redmond, WA, USA).

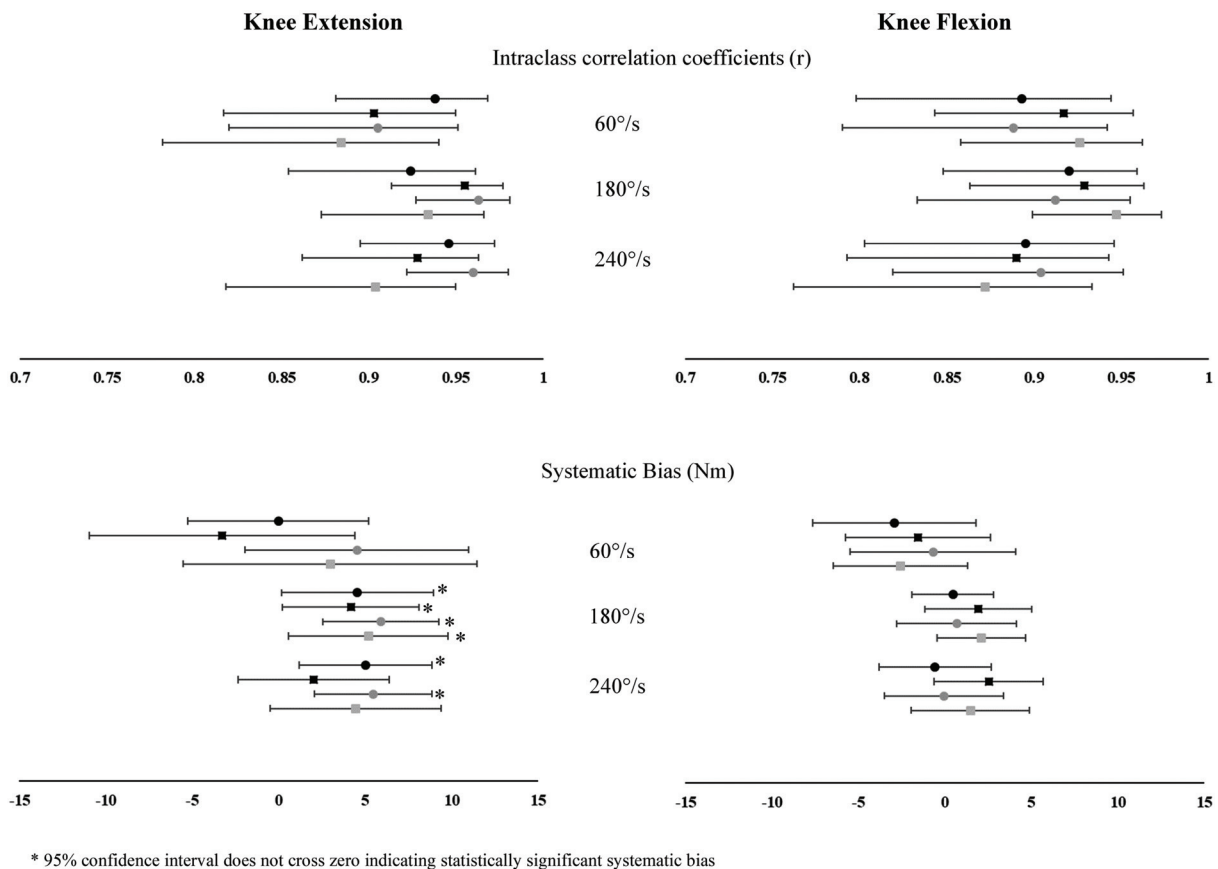
Heteroscedasticity was examined by using the Bland–Altman method [4]. Next, relative reliability was computed using intraclass correlation coefficients (ICC, model: 2,1). The magnitude for the ICC were interpreted as follows: less than 0.40 – *poor*, between 0.40 and 0.59 – *fair*, between 0.60 and 0.74 – *good*, and between 0.75 and 1.00 – *excellent* [6]. Then, systematic bias between testing sessions were evaluated using dependent *t*-tests. Finally, absolute reliability was determined by computing standard error of measurement (SEM) [39] and coefficient of variation (CV) [16]. To facilitate the comparison of reliability between the two dynamometer systems, 95% confidence intervals (CI) were computed around the point estimates for systematic bias, ICC, SEM and CV. These were then plotted for each measure by direction of motion to facilitate comparison of the point estimates, degree of CI overlap, and width (precision) of the reliability estimates.

Agreement between the IKD and S4 dynamometer were assessed by ordinary least products (OLP) re-

gression analysis [26]. The slope and intercept parameters from the OLP regression, along with their 95% CI, were used to determine the presence of fixed and proportional biases between dynamometer systems. Proportional error was examined by inspection of residual plots against the predicted values. In circumstances where proportional error were detected, weighted least products regression was used [26]. The 95% CI containing the value of 1 for the slope and 0 for the intercept provides for a rejection of the hypothesis of proportional and fixed biases, respectively. Additionally, relative agreement between the IKD and S4 dynamometer was evaluated by Lin’s concordance coefficient (LCC) [25] and ICC (model: 2,1). The magnitude of these statistics were interpreted identical to the ICC reliability.

### 3. Results

The results of the exploratory analysis for heteroscedasticity yielded only nondominant knee extension at 60 °/s (Kendall’s Tau = 0.271) and 240 °/s (Ken-



\* 95% confidence interval does not cross zero indicating statistically significant systematic bias

Fig. 3. Comparison of the intraclass correlation coefficient (top graphs) and systematic bias (bottom graphs) results between peak moment recorded by the Isokinetic Knee Dynamometer (round markers) and System 4 Dynamometer (square markers). Black markers denote the dominant limb and gray markers denote non-dominant limb. Error bars represent 95% confidence intervals

dall's Tau = 0.264) on the IKD to be statistically significant. In both cases, the same participant was largely responsible for this occurrence. During the first session, they exhibited relatively high peak moment in comparison with the rest of the participants, but they then also demonstrated substantially higher peak moments during the second testing, inducing coefficient statistical significance. Because there were only two conditions that reached statistical significance, with one participant largely carrying the issue, we did not conduct data transformations on those conditions to facilitate being able to directly compare the reliability statistics across all conditions.

### 3.1. Reliability results

The results of the relative reliability analysis demonstrated excellent reliability for the IKD and comparable to the S4 dynamometer (Fig. 3). The lowest ICC for the IKD was 0.888 (non-dominant knee flexion at 60 °/s) and the lowest ICC for the S4 dynamometer was 0.872 (non-dominant knee flexion at 240 °/s).

Near identical magnitudes of systematic bias were revealed between the dynamometer systems (Fig. 3). There were no significant differences for knee flexion peak moment between sessions. For knee extension, the dominant and non-dominant peak moments ( $\bar{X}_{diff} = 4.5$  to 5.9 Nm) at 180 °/s and 240 °/s were significantly ( $P = 0.001$  to 0.043) higher during the second testing session for the IKD. For the S4 dynamometer, significantly ( $P = 0.029$  to 0.039) higher peak moments ( $\bar{X}_{diff} = 4.2$  to 5.2 Nm) were recorded for both limbs at 180 °/s.

The SEM (Fig. 4) knee extension results at the two higher testing velocities were  $\leq 10$  Nm and comparable between the two dynamometer systems with the largest difference being 3.0 Nm for non-dominant limb at 240 °/s. The SEM for knee extension at 60 °/s were larger (10.7 to 17.5 Nm) than the higher testing velocities coupled with larger differences between the dynamometer systems (4.5 to 5.0 Nm). The SEM for knee flexion peak moments were all below 10 Nm with near identical results between the dynamometer systems.

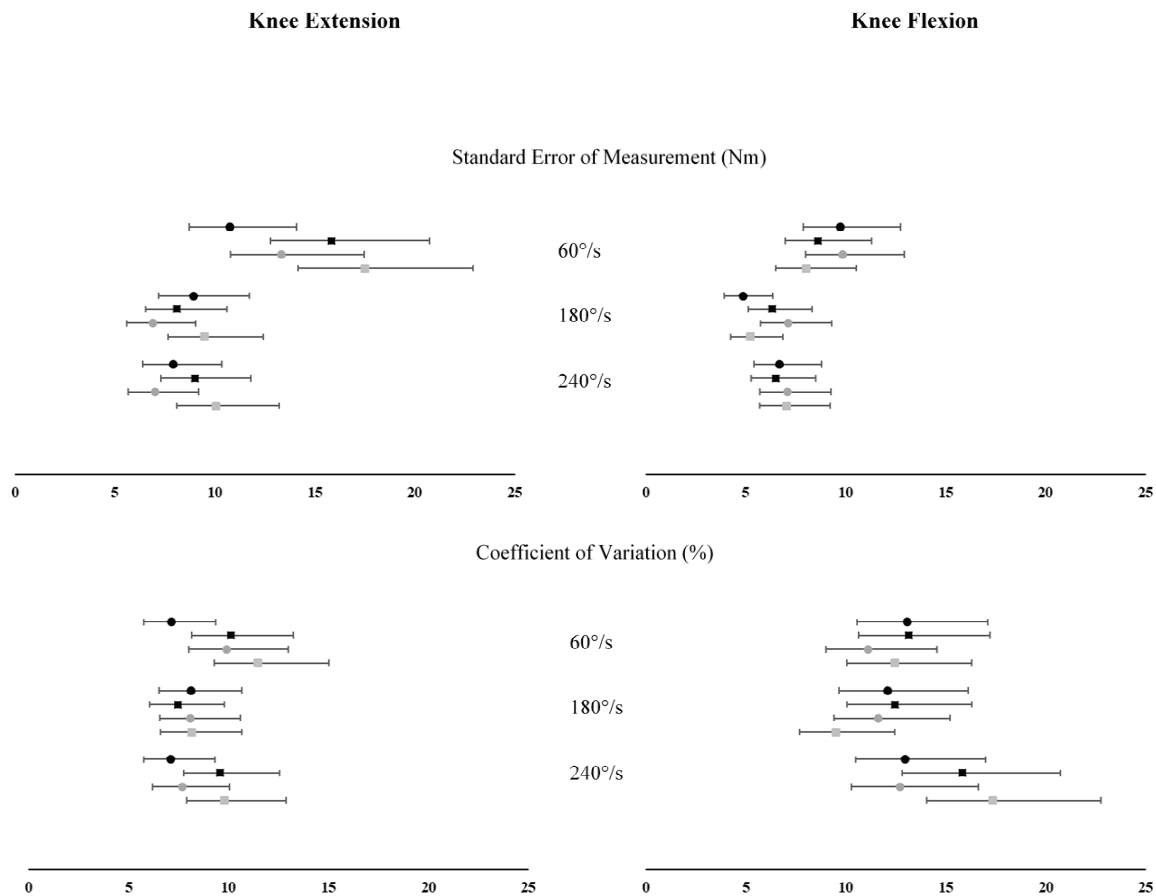


Fig. 4. Comparison of the standard error measurement (top graphs) and coefficient of variation (bottom graphs) results between peak moment recorded by the Isokinetic Knee Dynamometer (round markers) and System 4 Dynamometer (square markers). Black markers denote the dominant limb and gray markers denote non-dominant limb. Error bars represent 95% confidence intervals

The CV (Fig. 4) for knee extension peak moments were <12% with similar magnitudes between the dynamometer systems at the two higher testing velocities. At 60 °/s, the dominant limb CV was 3% greater for the S4 dynamometer compared to the IKD, whereas they were near identical for the non-dominant limb. For knee flexion peak moment, the CV were larger than knee extension but very similar magnitudes between the dynamometer systems at 60 °/s and 180 °/s. At 240 °/s, the dominant limb CV for the S4 dynamometer was by 2.8% higher than the IKD whereas the non-dominant limb the CV was 4.7% higher for the S4 dynamometer compared to the IKD.

### 3.2. Validity results

Validity results are presented in Table 1. Results of the OLP regression revealed statistically significant ( $P < 0.05$ ) proportional bias with the S4 dynamometer values being progressively higher than the IKD as the

magnitude of the peak moments increased for knee extension of both limbs at 60 °/s and the dominant limb at 180 °/s. There were no other statistically significant proportional biases identified. Additionally, there were statistically significant fixed biases revealed for seven of the velocity-limb-direction conditions. In all cases, higher peak moments (range: 8.56 to 23.05 Nm) were recorded on the IKD compared to the S4 dynamometer.

All but one (non-dominant knee flexion at 180 °/s) of the LCC were in the excellent range, with 75% being greater than 0.75. The ICC were all in the excellent range, with the lowest ICC being 0.859 (non-dominant knee flexion at 180 °/s).

## 4. Discussion

The purpose of the current study was to determine the intersession reliability and validity of the IKD to

Table 1. Results of the peak moment comparison conducted between the Isokinetic Knee Dynamometer and System 4 dynamometers. Boxes that are gray denote statistical significance for the slopes (proportional bias) and intercepts (fixed bias) derived from the ordinary least products regression analysis

Velocity	Direction	Limb	Ordinary least products regression			Lin's concordance coefficient (95% CI)	Intraclass correlation coefficient (95% CI)
			$R^2$	Slope (95% CI)	Intercept* (95% CI)		
60°/s	Extension	D	0.91	0.84 (0.76–0.91)	23.05 (10.74–35.36)	0.937 (0.902–0.973)	0.939 (0.882–0.969)
		ND	0.83	0.85 (0.76–0.94)	6.54 (–6.07–19.15)	0.843 (0.757–0.929)	0.902 (0.814–0.949)
	Flexion	D	0.84**	1.01 (0.85–1.17)	7.42 (–3.10–17.94)	0.887 (0.817–0.956)	0.921 (0.849–0.959)
		ND	0.87	0.94 (0.85–1.02)	21.86 (14.80–28.91)	0.782 (0.679–0.884)	0.930 (0.865–0.964)
180°/s	Extension	D	0.94	0.87 (0.81–0.93)	16.55 (9.11–23.99)	0.958 (0.934–0.983)	0.959 (0.920–0.979)
		ND	0.90**	0.92 (0.79–1.04)	–2.35 (–16.37–11.68)	0.898 (0.822–0.951)	0.941 (0.887–0.970)
	Flexion	D	0.77	0.98 (0.76–1.20)	12.32 (0.76–23.89)	0.792 (0.681–0.902)	0.905 (0.819–0.952)
		ND	0.67**	1.17 (0.86–1.49)	10.05 (–6.08–26.18)	0.619 (0.472–0.767)	0.859 (0.738–0.926)
240°/s	Extension	D	0.92	0.95 (0.88–1.02)	10.08 (2.77–17.39)	0.946 (0.911–0.981)	0.972 (0.946–0.986)
		ND	0.87**	0.99 (0.86–1.11)	–5.87 (–16.00–4.24)	0.912 (0.857–0.968)	0.931 (0.869–0.965)
	Flexion	D	0.76	1.06 (0.94–1.18)	8.56 (2.64–14.48)	0.744 (0.620–0.868)	0.880 (0.775–0.937)
		ND	0.79**	1.13 (0.97–1.30)	12.68 (4.62–20.73)	0.702 (0.581–0.823)	0.894 (0.799–0.946)

\* Positive intercepts indicated higher peak moment for the Isokinetic Knee Dynamometer.

\*\* Weighted least products regression used.

95% CI: 95% confidence interval, D: dominant, ND: non-dominant.

assess dynamic knee extension and flexion peak moment in comparison to a traditional commercially available isokinetic dynamometer in healthy young adults. The results of the reliability analysis demonstrated excellent intersession reliability for the IKD and supported our hypotheses. The validity results demonstrated slight, but statistically significant, proportional bias between the systems for knee extension at 60 °/s (both limbs) and significant fixed bias favoring higher peak moments on the IKD for seven of the comparisons; however, the LCC and ICC results largely support excellent relative agreement between the dynamometer systems. Despite the smaller patient positioning system and reduced joint axis/dynamometer alignment capabilities, these results support the capability of the IKD to reliably assess isokinetic knee extension and flexion peak moment in healthy individuals.

It is important to be cognizant of two important factors associated with the current study. First, peak moment is the most common measure considered in both clinical and research settings [2], [7]–[9], [17], [18], [21], [28], [29]; however, from a measurement perspective very volatile, as by definition being the maximum value obtained across a set of repetitions. Thus, in contrast to other measures (e.g., average peak moment, work per repetition), the current peak moment results likely provide a very conservative perspective on the IKD's reliability and validity. Secondly, the reliability and validity results in this study reflect the dynamometer systems (actuators and strain gauges), patient positioning systems, and participants' performance. There are many biological factors that contribute to random fluctuations in voluntary maximal exercise performance, and, although there were controls employed to reduce several biological factors (e.g., exercise, diurnal muscle strength variations), there is no way to ensure that study participants used identical amounts of force on both dynamometer systems [8]. Thus, these results are reflective of both the dynamometer systems and participants, with the participants being a greater source of performance variability compared to the dynamometer systems.

The current research design provided mechanisms to evaluate the reliability of the IKD, as well as conduct a method comparison analysis (validity) between the two systems. Almost all statistical methods used in reliability and method comparison studies have been criticized [40]. For this reason, multiple statistical methods were incorporated into the current study. Unfortunately, while incorporating multiple methods avoids the criticism of being restrained by the limitations associated with a single statistical method [27], simultaneous interpretation of multiple statistics can

be complicated. An additional distinction of the current study compared to the previous reports [2], [8], [11], [28], [29] was that the reliability and validity analyses were conducted in terms of dominant and nondominant limbs. The rationale was because previous research has demonstrated muscle performance differences between limbs in particular healthy subgroups [5], [32].

Surprisingly, based on previous reports of peak moment [2], [31], we did not find strong evidence of heteroscedasticity in our reliability data. Only nondominant knee extension at 60 °/s and 240 °/s on the IKD demonstrated statistically significant heteroscedasticity. It is also noteworthy that the vast majority of previous studies [8], [9], [11], [14], [29] do not describe using heteroscedastic exploratory procedures.

Comparing the current validity and reliability results to previous reports is difficult for several reasons. First, because our participants completed three sets of isokinetic knee extension and flexion using both limbs on two different dynamometer systems during each testing session, our investigation involved participants completing a higher set volume compared to the previous studies that only considered one testing velocity [8], [9], [28] or limb [2], [8], [11], [28], [29]. Furthermore, within each set, we used more repetitions than most of the previous studies [2], [8], [9], [17], [29]. Our repetition protocol was based upon the most commonly used clinical protocols [7]. Although typical clinical utilization of knee isokinetic testing involves an identical bilateral three velocity test protocol with similar repetitions at each velocity, having our participants complete it twice (once on each dynamometer system) likely adversely influenced the consistency of their sustained maximal effort. Additionally, we included 240 °/s, as it is commonly used clinically to better replicate functional activities velocities [7]; however, the majority of recent (within last 20 years) reliability [2], [8], [9], [17], [29] and validity [8], [18], [28] reports have only considered low velocity (i.e., 180 °/s or less) testing protocols thereby inhibiting the comparison of our higher velocity test results. Moreover, while we attempted to duplicate the same statistics as previous isokinetic statistics, there are a variety of computation methods to the same reliability or validity statistic [34]. Furthermore, as reliability of knee isokinetic testing differs among commercially available dynamometer systems [14], it should be noted that direct comparisons to previous works is complicated because of all the various commercially available dynamometer systems used (e.g., Biodex, Cybex, etc.). As a result, in comparing our reliability and validity results, we limited our focus

to literature using more contemporary commercially available dynamometer systems. Finally, adding further complexity to making comparisons between studies are the differences in the data collection and analysis software versions operating the dynamometer systems.

Nevertheless, our reliability results of isokinetic knee extension and flexion testing in young adults yields values that are comparable to previous reports. The ICC and 95% CI reported in the current study (both dynamometer systems) are comparable to previous reports [2], [28] using contemporary Biodex dynamometers (System 3 or 4), although it should be noted that Lund et al. [28] only considered 60°/s and Almosnino et al. [2] conducted assessments at 30°/s and 120°/s through a 60° ROM. The majority of studies examining peak moment relative reliability using older Biodex dynamometer systems [11], [14] or non-Biodex dynamometer systems [9], [14], [17], reported comparable ICC values as the current study at lower testing velocities; only one investigation [11] considered 240°/s with results that largely paralleled the current data.

In contrast to the number of studies that have considered relative reliability, fewer investigations have considered systematic changes (bias) in peak moments across repeated testing sessions. Similar to the Lund et al. [28] (60°/s) and Almosnino et al. [2] (60° ROM at 30°/s and 120°/s), both of which used contemporary Biodex dynamometer systems, we failed to detect significant systematic bias at our slowest testing velocity (60°/s). Comparable to the current results, both Maffiuletti et al. [29] and Impellizzeri et al. [17] also reported significantly greater knee extension peak moments during a second testing session compared to the first session at 180°/s; however, they also reported significantly greater knee flexion peak moment at 180°/s, which are in contrast to the current results. Unfortunately, there is a dearth of previous studies examining systematic bias between sessions at velocities greater than 180°/s, making our 240°/s testing results unique.

Similarly to systematic bias, few studies have reported absolute reliability statistics, with the variety of various statistics reported making comparison and consensus difficult. Lund et al. [28] (60°/s) reported SEM similar to our estimates. Almosnino et al. [2] (30°/s and 120°/s) reported CVs that were about half the magnitude of our results, likely attributable to using a reduced ROM (90° to 30° knee flexion). Similarly to systematic bias, the shortage of investigations considering testing velocities greater than 180°/s make our 240°/s results unique.

We only identified three studies [8], [18], [28] that examined isokinetic knee extension and flexion testing with a comparable Biodex system as used in the current study. Each study reported scaled agreement statistics, either an ICC or Pearson coefficient, although the exact ICC models were not specified. For 60°/s isokinetic knee extension and flexion peak moment, our ICC results are near identical to the comparisons conducted between the Biodex system and both the Cybex [8], [18] and Lido [28] systems. Only one investigation [18] considered system comparisons at testing velocities of 180°/s and 240°/s; the reported agreement coefficients at those velocities were slightly lower compared to our results. The detection of systematic bias between dynamometer systems differs between investigations. While two previous studies [8], [28] reported no significant systematic bias between systems at 60°/s for either knee extension and flexion, Keilani et al. [18] reported significant bias between dynamometer systems (peak moments higher on Biodex compared to Cybex) for both knee extension and flexion at 60°/s, 180°/s, and 240°/s with the exception of knee flexion at 60°/s (both limbs). Our results are more similar to those by Keilani et al. [18], as we revealed significantly higher peak moments on the IKD for several of the conditions. Additionally, with the exception of dominant knee extension (60°/s) and non-dominant knee flexion (60°/s), the significant systematic bias differences in the current study are all smaller than the significant differences previously reported [18]. Keilani et al. [18] also reported significant proportional biases between dynamometer systems in all but four of the limb/velocity/direction conditions, whereas the current data only revealed a proportional bias for knee extension at 60°/s (both limbs) and 180°/s (dominant limb). The similarity, and for some statistics, better agreement, supports a conclusion that the IKD demonstrates a comparability to the Biodex S4 dynamometer.

The biggest discrepancies in reliability and validity between the two dynamometer systems in the current investigation existed at knee extension at 60°/s, the condition associated with the greatest peak moment production. It is likely that the differences in the patient positioning and stabilization systems account for these differences. Moreover, the lack of chest straps on the IKD allowed participants to have more extraneous body movements, which may have permitted compensatory movements which contributed to their peak moment. Nonetheless, although there were the above observed reliability and validity differences between the systems, they were small in magnitude and do not meet a threshold of clinical meaningfulness.



## 5. Conclusions

The IKD is a reliable tool for the assessment of knee extension and flexion peak moment. Direct comparison of isokinetic test performance between the dynamometer systems demonstrated a tendency for greater moment production on the IKD; however, discrimination between individuals (relative agreement) supports the IKD as a valid assessment tool compared to the Biodex S4 dynamometer. The reliability and validity results recorded largely paralleled previous research reports in the literature, thereby providing external validation to the current investigation. Considering peak moment is one of the most volatile isokinetic variables, the current analysis likely provides very conservative perspective on the reliability and validity of the IKD. Coupled with the reduced system complexity, space requirements and likely production cost, given the number of knee pathologies treated in clinical settings, a dedicated knee isokinetic system may become a welcome addition to orthopedic clinical practices. Finally, these data fill an existing literature isokinetic void with the results supporting similar and acceptable measurement properties across both dynamometers jointly for dominant and nondominant limbs and at the higher testing velocities considered.

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