Primerjava največjega navora med izokinetičnima dinamometroma SMM iMoment in Biodex System Pro 4

Peak Torque Comparison between SMM iMoment and Biodex System Pro 4 Isokinetic Dynamometers

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Izvleček

Namen: *Primerjati meritev največjih navorov pri koncentričnem mišičnem krčenju iztega in upogiba kolena med izokinetičnima dinamometroma SMM iMoment in Biodex System Pro 4.*

Metode: *Petindvajset študentov (14 moških, 11 žensk, starost 24.35 (1.41) let) je sodelovalo v študiji. Na dveh ločenih obiskih smo izmerili največji navor (PT) in kot pri največjem navoru (APT) iztegovalk in upogibalk kolenskega sklepa pri hitrosti 60 °/s and 180 °/s. Parni t-test, medrazredni korelacijski koeficient (ICC), standardna napaka meritve (SEM), koeficient variacije (CVmed) in Bland Altman metodo smo uporabili za preverjanje razlik, relativne in absolutne zanesljivosti, ter ujemanje meritev med napravami.*

Rezultati: *Zaznali smo statistično značilne razlike med napravama v PT med upogibom kolena pri hitrosti 60 °/s (p = 0.027). ICC vrednosti so pokazale viso-*

Abstract

Purpose: *To compare peak torque of knee extensors and flexors during muscle contractions between the SMM iMoment and Biodex System Pro 4 isokinetic dynamometers (inter-machine reliability).*

Methods: *Twenty-five students (14 men and 11 women, age 24.35 (1.41) years) took part in a crossover study. Peak torque (PT) and angle of peak torque (APT) for knee extensors and flexors were assessed at the velocity of 60°/s and 180°/s on two visits. Paired t-test, intraclass correlation coefficient (ICC), standard error of measurement (SEM), coefficient of variation (CV-med) and Bland-Altman plots were used to determine significant differences, relative and absolute reliability and agreement between devices.*

Results: *There were statistically significant differences in PT between machines at the velocity of 60°/s for the right* *ko do zelo visoko relativno zanesljivost pri nalogah izvedenih z levo nogo (0.84 - 0.93) in srednjo do zelo visoko zanesljivost pri nalogah izvedehih z desno nogo (0.79 - 0.91). V primerjavi z drugimi sorodnimi študijami, so vrednosti absolutne zanesljivosti razkrile večjo variabilnost podatkov (CVmed: 4.84% - 9.36%, SEM: 9.62 Nm - 26.11 Nm). Bland Altman metoda je pokazala dobro primerljivost pri nalogah izvedenih z levo nogo in rahlo slabšo primerljivost pri nalogah izvedenih z desno nogo (4-6 Nm). Ugotovili smo statistično značilne razlike med napravama v APT pri vseh pogojih merjenja.*

Zaključek: *Vrednosti največjega navora mišic iztegovalk in upogibalk kolena so bile podobne na obeh napravah. Poudariti gre večjo razpršenost rezultatov izmerjenih s pomočjo naprave iMoment.*

leg knee flexion (p = 0.027). ICC values revealed high to very high relative reliability for the left leg (0.84 - 0.93) and moderate to very high for the right leg (0.79 - 0.91). Values of absolute reliability revealed more substantial differences between dynamometers compared to other similar studies (CVmed: 4.84% - 9.36%, SEM: 9.62 Nm - 26.11 Nm). Bland-Altman plots revealed no specific bias in exercise performed with the left leg and small bias (4-6 Nm) in exercises performed with the right leg. There were significant differences in APT between dynamometers in all conditions.

Conclusion: *Mean peak torque values of knee extensors and flexors were similar between machines; however, data collected using the iMoment dynamometer were substantially more variable.*

INTRODUCTION

Isokinetic dynamometry is a widely accepted procedure in clinical, rehabilitation and research environments. The isokinetic device allows the assessment of joint and muscle maximal eccentric (ECC), concentric (CON) and isometric (ISO) strength under controlled constant velocities throughout specified range of motion. Even though dynamometers are developed to measure muscle strength in several joints (e.g., shoulder, torso, knee, ankle, etc.), the most measured muscles in practice, are the knee extensor and flexor muscles (1). As well as measuring muscle strength, the isokinetic dynamometers allow us to conduct a proper progressive rehabilitation protocol, such as hamstring and knee injuries (2). It is a recognised diagnostic tool that helps make more accurate decisions about patient progress, readiness and return-to-play evaluation (3). Some authors have suggested that preseason screening of unilateral and bilateral strength imbalance in healthy athletes can allow medical staff to identify the ones at a higher risk of incurring lower limb injuries during training or competition (4).

Because there are many isokinetic machines present on the market, it is critical to establish the validity and reliability of these measuring devices. This allows confident assessment of the instrument output data in clinical and experimental environments. Existing devices are regularly updated and upgraded in the isokinetic market. New devices are also introduced. So far, the market is led mainly by the Biodex brand, which has a long history of producing valid and reliable isokinetic dynamometers and is considered a gold standard (5,6). However, other brands can produce reproducible and valid dynamometers like Cybex Norm (now Humac Norm), IsoMed 2000, REV9000 and iSAM 9000 (7, 8, 2, 9). In general, the results of these studies indicate good to excellent intra-machine reliability (repeatability of data within machine) and inter-machine (comparison of data between machines) reliability for measuring maximum knee strength performance (8).

A newer, less known isokinetic dynamometer on the market is the iMoment dynamometer. The SMM Company (SMM d. o. o., Maribor, Slovenia) has developed the device in a joint venture with members of the Faculty of Sport at the University of Ljubljana. At the time of writing this paper, only two working prototypes have so far been developed and extensively tested at two important locations in Slovenia (Faculty of Sport, Ljubljana and Faculty of Medicine, Maribor). The manufacturer wanted to develop a modern, robust and reliable device. Excellent intra-machine repeatability and reliability for the iMoment peak torque has already been proven (10). Even though the device has been developed as a versatile platform capable of measuring muscle torque in several joints and body positions, only the knee flexion-extension and shoulder internal-external rotation measurements were fully functional at the time of writing this article. Machine settings (sitting position, dynamometer positioning and lever arm velocity) are fully automatized using controlled electric motors. This can be user-controlled on the main console of the software. It also allows storing patient positions and protocol settings (pictures of both dynamometers in Figure 1). This study aimed to compare peak torque measurements (inter-machine reliability) between the SMM iMoment and the Biodex System Pro 4 isokinetic dynamometers for knee extensor and flexors. The tests were conducted at velocities of 60°/s and 180°/s during concentric muscle contractions.

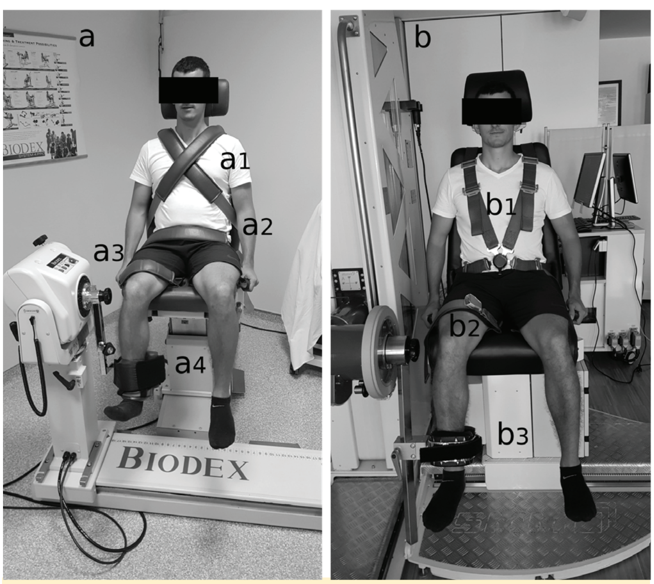

Figure 1. *Pictures of both machines and differences between fixation systems: a) Biodex System Pro 4, a1) chest fixation, a2) pelvis fixation, a3) thigh fixation, a4) lever arm fixation and b) SMM iMoment, b1) torso fixation, b2) thigh fixation, b3) lever arm fixation.*

MATERIALS AND METHODS

Twenty-five healthy students (14 men and 11 women, age 24.35 (1.41) years) attending the Faculty of Medicine at the University of Maribor without any known history in locomotor or nerve injuries were recruited for the study. The volunteers were acquainted with the experimental procedure and their voluntary cooperation was confirmed by written consent on the day of the first testing. Subjects were instructed to maintain their daily exercise routine but were asked not to perform vigorous exercise 48 hours before the testing session. All procedures were in accordance with the latest version of the Helsinki declaration and were approved by the Research Ethics Committee at the University Medical Centre Maribor (UKC-MB-KME-14/19).

Two isokinetic dynamometers were used in this study: iMoment isokinetic device and the System Pro 4 (Biodex Medical Systems, Shirley, NY, USA). The inter-machine reliability was assessed by performing knee extension and flexion exercises on both legs at separate velocities of 60°/s and 180°/s. A crossover experimental design was constructed to allow assessment of inter-machine reliability. All the subjects repeated the measurements twice, on two different visits. Each visit comprised the assessment on one machine (iMoment and Biodex respectively). There were at least 7 days rest between visits in order to minimise potential learning effects, fatiguing or potentiation effects of the neuromuscular system. The order of devices was randomised across subjects.

Before data collection, the machines were calibrated according to the manufacturer instructions. The Biodex dynamometer calibration is automatic during machine start up. The calibration procedure for the iMoment dynamometer requires manual operation. The iMoment dynamometer was manually calibrated at the beginning of each measuring day. At the beginning of each visit, the subjects carried out a standardised 10-minute warm-up which consisted of stepping on a 30 cm high box at a frequency of 0.5 Hz. After the warm-up, the first of the two legs were selected and the subjects were positioned on the isokinetic device. The positioning was carefully carried out following the manufacturer instructions, that is, the knee joint axis was aligned with the centre of the machine rotational axis. The appropriate hip, thigh and chest straps were tightened in order to secure the body position and to minimise hip and knee movement. Biodex and iMoment fixation straps differ in position, width and fixation mechanism (Figure 1). However, the dynamometer lever arm was fixed at a similar length for both machines. The ankle stabilisation strap was fixed just above the ankle joint (5 cm above the external malleolus). The knee flexion and extension protocols were carried out in 60° range, between 90° and 30° angle (where the fully extended knee represented 0°).

After aligning the subject to the correct position, a short familiarisation routine was carried out with the machine. The researcher verbally explained the experimental procedure and an additional warm-up consisting of 15 repetitions of knee extension and flexion at a velocity of 60°/s was conducted asking the subject to progressively increase the torque per repetition. Three maximum concentric contractions were executed in knee extension and flexion at a velocity of 60°/s. After a 2-minute rest, three maximum contractions were then executed in knee extension and flexion at a velocity of 180°/s. After a five-minute break, the subjects were repositioned on the machine to repeat the same procedure on the opposite leg. The experiment was carried out by an experienced researcher, who has taken more than 300 measurements on each machine.

The gravitational moment (GET) was determined by the iMoment and Biodex start up procedure by measuring the leg weight at a position of 30° knee extension. Torque data were automatically GET corrected by individual machine software and used in further analysis. The repetition with the highest PT from each velocity (60°/s and 180°/s) and leg (left and right) were further analysed. Data were checked for normality of distribution using the Shapiro-Wilk test and by visual inspection of Q – Q plots. Paired Student's t-tests (Biodex vs iMoment) were used to assess statistical differences in PT and angle of peak torque (APT) between machines. All statistical analyses were performed using the R statistical software (11). P-values lower than 0.05 were considered statistically significant. The relative magnitude of the association between measures was assessed using the intraclass correlation coefficient (ICC 2, 1). To the best of our knowledge there is no consensus for which correlation values for use in reliability studies (12). For this reason, we adopted the classification proposed by Sole et al., in which correlations of 0.50 – 0.69 are "moderate", 0.70 – 0.89 are "high" and higher than 0.90 are "very high" (13). Absolute reliability (variability of the score from trial to trial in original units) was assessed using the standard error of measurement (SEM) and the coefficient of variability as proposed by Bardis et al. (1):The coefficient of variation was calculated by the following formula:

$$SEM = SD\sqrt{1 - ICC}.$$

where *di* is the difference between two results in each individual and $\bar{x}i$ is the mean of the two results. Median (CV_{med}), 10th and 90th percentiles CV% were calculated in order to obtain the coefficient of variation 80% central range ($CV_{80\%}$). CV_{med} and $CV_{80\%}$ represents the central range to give information about the distribution of the variation (14). The standard error of measurement (SEM) was calculated with the formula:

$$CV\% = 100\sqrt{(1/2)di^2 xi},$$

The SEM is a calculation of how much measured test scores are spread around a "true" score, and it uses the same units as the test (peak torque in Nm in this study) (16). Bland-Altman plots and "lines of equality" were visually inspected and evaluated in order to define the agreement between the two measurements (15).

Table 1. *Mean and standard deviation of peak torque (Nm)*

	Peak Torque Nm (SD) Left			**Peak Torque Nm (SD) Right**		
	Biodex	iMoment	*p*	Biodex	iMoment	*p*
60°/s						
Extension	192.1 (55.8)	194.8 (61.6)	0.835	191.3 (48.5)	189.2 (59.5)	0.081
Flexion	100.9 (29.7)	101.6 (34.7)	0.191	100.8 (28.8)	99.9 (28.9)	0.027*
180°/s						
Extension	128.4 (45.7)	129.2 (47.4)	0.848	129.5 (43.5)	128.9 (40.9)	0.421
Flexion	71.2 (23.8)	72.8 (24.3)	0.920	72.7 (23.9)	70.9 (19.8)	0.161

**Statistically significant differences.*

RESULTS

Means, standard deviations and paired Student's t-test p – values for knee extension and flexion PT at 60 °/s and 180 °/s velocities are shown in Table 1. There were statistically significant differences in PT between machines at the velocity of 60°/s for the right leg knee flexion exercise ($p = 0.027$). There were no significant differences in PT between machines at a velocity of 180 °/s. ICCs involving all assessments performed with the left leg were close to or higher than 0.90, indicating a high to very high relative reproducibility (Table 2). ICC coefficients on the right leg were slightly lower (compared to the left leg) for all measurements, reaching only moderate reproducibility in the knee extension at 180°/s velocity (Table 2). Coefficient of variation (CV_{med}) for the PT parameter of knee extensors and flexors showed moderate differences between dynamometers (see Table 2).

Table 2. *Relative (ICC) and absolute (CV and SEM) reliability for peak torque data*

	Peak Torque Left			Peak Torque Right		
	ICC (95% CI)	CV_{med} ($CV_{80\%}$)	SEM	ICC (95% CI)	CV_{med} ($CV_{80\%}$)	SEM
60°/s						
Extension	0.835 (0.722 – 0.930)	9.36 (1.86 – 19.80)	23.70	0.847 (0.700 – 0.925)	6.79 (0.99 – 18.60)	26.11
Flexion	0.929 (0.778 – 0.945)	7.01 (1.86 – 15.10)	10.44	0.911 (0.805 – 0.959)	7.40 (1.17 – 13.30)	9.62
180°/s						
Extension	0.859 (0.681 – 0.918)	6.69 (1.24 – 23.20)	18.18	0.788 (0.600 – 0.894)	4.84 (1.04 – 27.30)	24.52
Flexion	0.889 (0.856 – 0.966)	8.41 (4.03 – 23.70)	11.31	0.892 (0.785 – 0.948)	6.02 (2.00 – 17.40)	9.70

ICC = intraclass correlation coefficient; CI = confidence interval, CV_{med} = coefficient of variation (in %); $CV_{80\%}$ = CV 80% range from 10^{th} to 90^{th} percentile; SEM = standard error of measurement (in Nm).

A random relationship was observed between the individual differences for Biodex and iMoment assessments, as shown in Bland-Altman plots, which represents the differences against mean calculatins between machines at 60°/s (left sides of Figure 2 and Figure 3) and 180°/s (left sides of Figure 4 and Figure 5), respectively. There was no explicit bias in PT between exercise performed with the left leg, but small bias was present in exercise performed with the right leg at both velocities (4-6 Nm less for iMoment measurements). In addition, line of equality demonstrates similarities between dynamometers at 60°/s (right sides of Figure 2 and Figure 3) and 180°/s (right sides of Figure 4 and Figure 5), respectively.

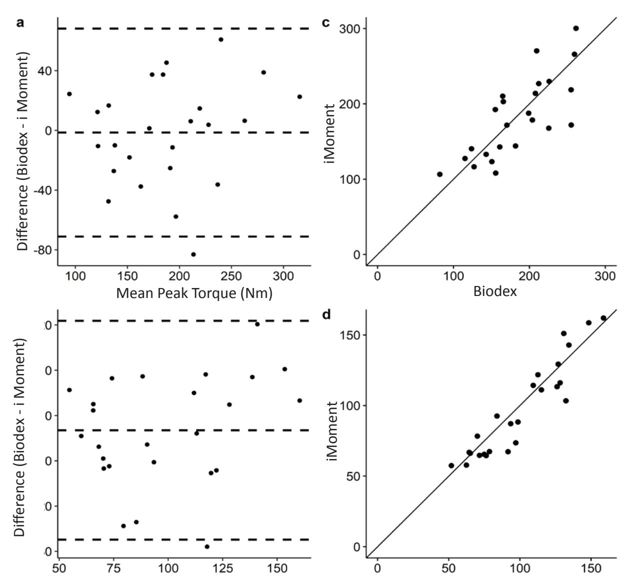

Figure 2. *Difference against mean for left leg PT at 60°/s for a) knee extension, b) knee flexion; and line of equality between two dynamometers c) knee extension, d) knee flexion (Biodex - iMoment).*

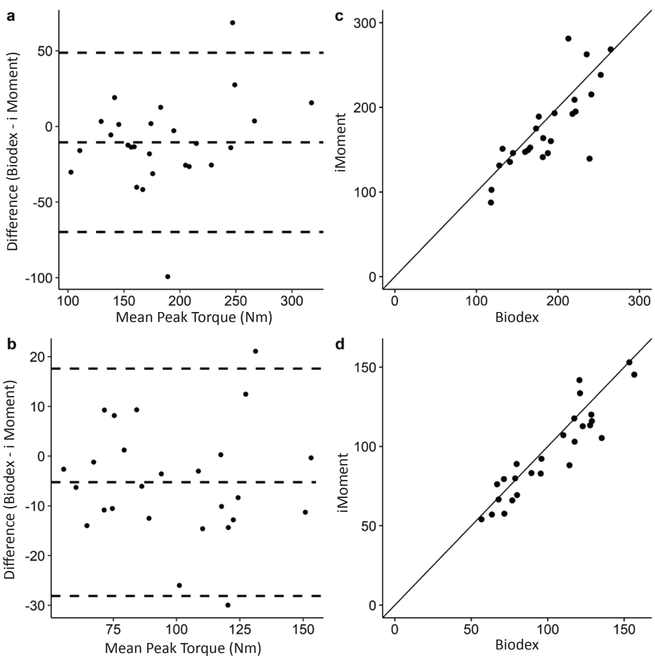

Figure 3. Difference against mean for right leg PT at 60°/s for a) knee extension, b) knee flexion; and line of equality between two dynamometers c) knee extension, d) knee flexion (Biodex - iMoment).

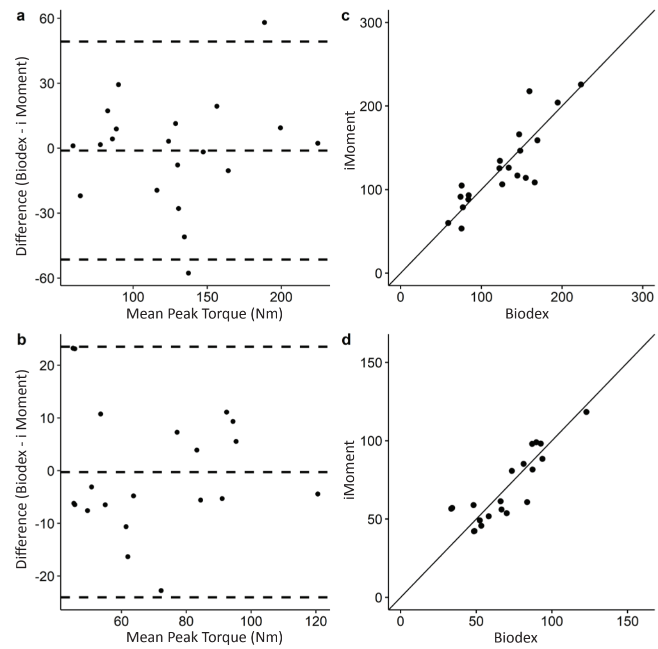

Figure 4. Difference against mean for left leg PT at 180°/s for a) knee extension, b) knee flexion; and line of equality between two dynamometers c) knee extension, d) knee flexion (Biodex - iMoment).

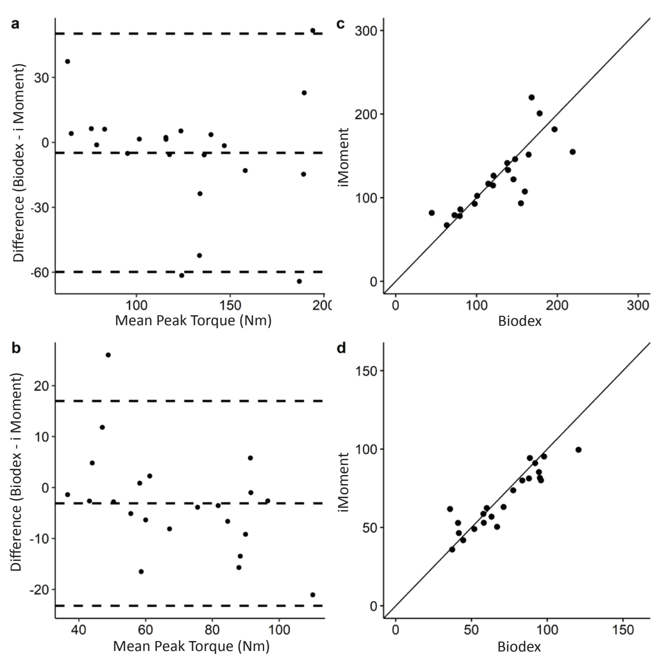

Figure 5. Difference against mean for right leg PT at 180°/s for a) knee extension, b) knee flexion; and line of equality between two dynamometers c) knee extension, d) knee flexion (Biodex - iMoment).

There were significant differences in APT between machines in knee extension and flexion for both legs at both velocities (data for 60 °/s are displayed in Figure 6).

DISCUSSION

The aim of this study was to determine the inter-machine reliability of the SMM iMoment and the Biodex System Pro 4 for knee extensor and flexor PT measurement at velocities of 60°/s and 180°/s during concentric muscle contractions.

Because the SMM iMoment dynamometer is a new machine on the isokinetic market, there are no reliability studies published in the literature. However, it is possible to compare the results of this study with other similar studies, that were used for other brands of machines. To the best of our knowledge, only a few other machines have been compared to the Biodex standard. Various Cybex (now Humac Norm) machines have been compared to different Biodex machines several times (16–19), and iSAM9000 dynamometer has been compared to Biodex once (3). In addition, it is difficult to compare studies due to differences in exercise protocols and methodology. Gross et al. reported data for velocities of 60°/s and 180°/s (19). While Thompson et al. and Keilani et al. reported data for velocities of 240°/s as well (17, 20). De Araujo Ribeiro Alvares et al. reported data for one velocity setting of 60°/s (18). However, they reported isometric and eccentric data as well. Substantial methodological differences across studies make it difficult to compare the outcomes of different studies directly. Smith et al. compared the results only using repeated measures ANOVA (3). Thompson et al. used paired student t-test and simple correlation to compare results between machines (17). De Araujo Ribeiro Alvares et al. and Gross et al. used a similar methodology as adopted in our study (Table 3) (18—19). The studies mentioned above have found similar relative reliability as that presented in this paper for ICC, ranging between 0.71 to 0.96 in knee extension and flexion at 60 °/s velocity (17–19). Compared to our study Gross et al. and Thompson et al. additionally found significant differences between peak torques assessed via Biodex and Cybex (19, 17). We found statistically significant differences only in the right knee flexion at 180 °/s velocity.

Table 3. *Relative and absolute reliability of the present study compared with studies with similar methodology*

Author	Biodex vs	Knee extension			Knee flexion		
		ICC	CV	SEM	ICC	CV	SEM
Gross et al., 1991 (19)	Cybex II	0.93	-	-	0.82	-	-
de Araujo Ribeiro Alvares et al., 2015 (18)	Humac Norm	0.89	7.19	9.98	0.91	6.22	3.72
This study	SMM iMoment	0.84	9.36	23.70	0.93	7.0	11.31

ICC = intraclass correlation coefficient; CV = coefficient of variation (in %); SEM = standard error of measurement (in Nm).

$CV_{med,}$ CV80% and SEM reflect the magnitude of the differences between two measurements (13). Coefficients of variation (CV_{med}) for all measurements registered in our study were below 9.36 (left knee extension at 60°/s) and as low as 4.84 (right knee extension at 180 °/s). Moreover, CV_{med} was comparable with the study conducted by de Araujo Ribeiro Alvares et al. for 60°/s velocity (Table 3) (18). However, SEM values ranged from 9.62 Nm (right knee flexion at 60°/s) to 26.11 Nm (right knee extension at 60°/s) and were much more varied compared to other studies (Table 3).

There was good agreement between the machines, as the Bland-Altman plots show no systematic bias (left side of Figures 2-5) and most of the points were close to the line of equality (right side of Figures 2-5). However, some large differences (up to 100 Nm) between machines were recorded during right knee extension at slow velocity (60 °/s). Compared to other studies, the limits of agreement in Bland-Altman plots seem narrower (1,17). For example, left knee extension at 60°/s ranged from -71 Nm to 68 Nm in our study compared to results ranging from -32 Nm to 39 Nm in de Araujo Ribeiro Alvares et al. study (18).

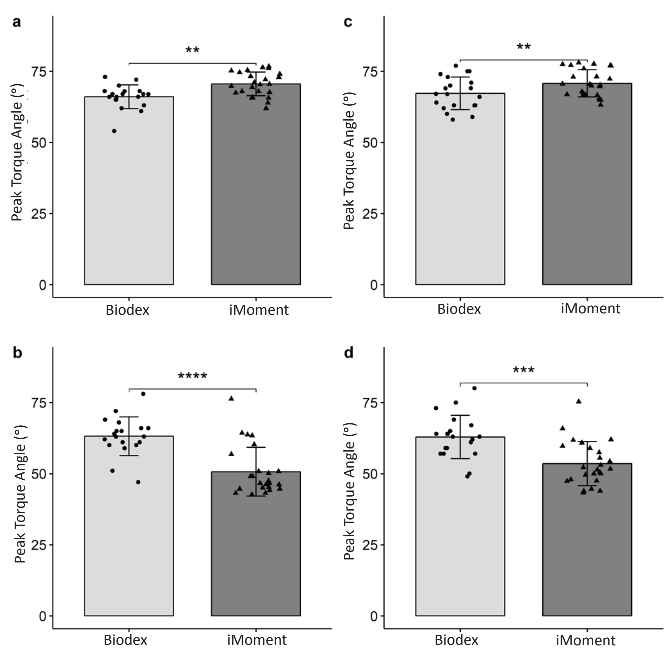

Figure 6. *Angle of peak torque (APT) comparison between Biodex and iMoment.at 60°/s velocity a) left leg extension, b) left leg flexion, c) right leg extension, d) right leg flexion. Asterisks denote statistical significant differences in paired t-test.* $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.0001$.

The differences between the machines examined in this study did not display a worrying variation. Relative reliabilities were ranging from high to very high for most assessments and absolute reliabilities were slightly worse, but overall comparable to the results reported in other studies. This study demonstrated that most of the differences should be attributed to biological differences and the inability of a subject to repeat the same performance on two different occasions. However, differences in the machine design, such us body fixation system, seat cushioning and lever arm cushioning, could all play an important role (Figure 1). During the experiment, we visually noticed that it was difficult for subjects to maintain a fixed position during the exercise. It encouraged us to search further into the data to eventually find significant differences between the APT in all assessments (Figure 6). One of the possible reasons for such differences was the increased softness of the iMoment seat, especially in the front part of the seat near the knee joint. By visual observation it was noticed that when extending the knee on the iMoment machine, the soft seat collapsed more than on the Biodex machine. If this thesis is correct (increase seat softness), the APT should diminish as the exerted torque increases. However, the correlations between APT and PT were not significant for knee extension at the velocity of 60°/s for both iMoment ($r = -0.087$, $p = 0.55$) and Biodex ($r = -0.015$, $p = 0.93$) machines. Differences in APT could also be related to the differences in the fixation system. Both machines provided a strong shoulder and torso fixation system. However, the iMoment machine lacked a pelvis fixation system (Figure 1). This kind of fixation can play a key role in maintaining the position of the pelvis and preventing upward hip movements in knee extension exercises, forward hip and knee movement in knee flexion exercise. However, the study was not designed to find the reasons for differences in APT.

This study showed high inter-machine reliability between SMM iMoment and Biodex System Pro 4 isokinetic dynamometer for knee flexion and extension at velocities of 60°/s and 180°/s. The results of this study showed high to very high relative reliability and moderate absolute reliability. Compared to other similar studies, which compared different devices to the Biodex standard, there was more significant variation in the data. The data collected in this study will inform the SMM manufacturer in order to improve their product. Apart from technical differences that were discovered in this study, in order to place a competitive product on the market, it is suggested that the manufacturer improve software and simplify movement and fixation system of the machine.

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