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The reliability of a video analysis system (*PnO Clinical Movement Data*TM) and the universal goniometer in the measurement of hip, knee and ankle sagittal plane motion amongst healthy subjects

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Abstract

Throughout the rehabilitation process, measuring joint range of motion (ROM) is essential to understand joint kinematics. The universal goniometer (UG) is the most common tool used in the clinical setting for joint ROM measurement. However, a review of the literature examining the reliability of the UG has demonstrated considerable variation in results and highlighted the necessity of introducing a more reliable tool.

This study aimed to investigate the reliability of a 2-dimensional video analysis system, *PnO Clinical Movement Data*TM (*PnO CMD*TM) compared to the UG. Three testers examined range of motion of eight healthy candidates. Passive sagittal plane motion of the hip, knee and ankle joint was measured with and without markers. ICC values >0.60 were considered to be satisfactory.

Most intratester ICC values for *PnO CMD*TM were found to be above the satisfactory limit (ICC=0.60-0.99). Intratester ICC values for the UG ranged considerably (ICC=0.34-0.94), and some values were below the satisfactory limit. Intertester ICC values across all the joints for *PnO CMD*TM with markers were found to be above the satisfactory limits (ICC=0.94-0.99).

*PnO CMD*TM was found to be more reliable than the UG. Use of markers was found to increase the reliability. The present work introduces using advanced technology in joint ROM measurement.

Key words:

Intratester, intertester, joint range of motion, measurement

Introduction

Measurement of passive joint range of motion (ROM) is an important part of physical assessment to determine appropriate treatment. Understanding joint ROM limitations enables the clinicians to recognise the kinematics challenges presented during motion. The universal goniometer (UG) is the most common and inexpensive tool used in clinical settings to record joint ROM during physical assessment. The UG is a 180° or 360° protractor with a single axis joining two arms. One arm is movable around the axis while the other arm is stationary.¹ UGs are available in different sizes to suit the joint being measured (Figure 1). However, a review of the literature examining the reliability of the UG demonstrated considerable variation in results for joint ROM measurements.² Ability to make direct comparison between studies was restricted due to a lack of similarity in the methodologies implemented.² The number of testers, experience level, number of sessions, time between the sessions, and subject position varied across the studies found. The review also highlighted the gap in current research about the reliability of the UG and the requirement for a more reliable measuring tool.

Currently, 3-dimensional (3D) analysis systems such as the *Vicon system*TM (*Vicon Motion Systems Ltd*) have been shown to produce accurate and reliable measurement.³ Additionally, these systems have been employed in several studies as benchmark to assess the feasibility of other potential systems/devices.³⁻⁷ 3D gait analysis systems are often financially and technically inaccessible in clinical environments especially where space is a challenge. A specialist training is required to operate these systems. Additionally, the outcomes produced by these systems are difficult to understand for some clinicians.³ Hence, the use of alternative systems such as 2-dimensional (2D) video analysis systems might be clinically useful. Additionally, these 2D video analysis system provide immediate interpretation which may be useful in the field of prosthetics and orthotics for tuning or alignment of devices.

In this study, the *PnO Clinical Movement Data*TM (*PnO CMD*TM) (previously known as *Siliconcoach*TM) was considered as an example of a 2D video analysis system capable of motion capture and gait analysis (Figure 2). The use of a 2D system in clinical practice may aid in documentation of the fitting process and promote improved communication between clinicians. The *PnO CMD*TM system is affordable, practical and easy to use in clinical environments. A single video camera is required to capture sagittal plane ROM. The video may be uploaded into the *PnO CMD*TM software for joint ROM measurement. The option to play back the video frame by frame may be useful in identification of passive ROM.

The reliability of the measurement of ankle, knee and hip angles at initial contact, midstance and terminal stance phases of gait cycle using *PnO CMD*TM has previously been investigated.

² This study also investigated the use of predefined anatomical markers, with the authors concluding that using predefined anatomical markers increased reliability. The intratester reliability varied across the gait cycle and was found to be best in terminal stance (ICC=1.00).⁸ Additionally, this study concluded high intertester ICC value (ICC=0.86) for measurement of knee angle at initial contact. A further study⁹ aimed to determine the reliability of *PnO CMD*TM in assessing dynamic and static ROM of the knee joint. Acceptable ICC values (ICC>0.6) for dynamic and static motion were found.⁹ A further study¹⁰ investigated the intratester and intertester reliability of measuring resisted isometric knee flexion during single leg squat using *PnO CMD*TM. Intertester reliability was found to be acceptable for all three testers (ICC>0.6).¹⁰ It was concluded that intratester reliability was found to be better than intertester reliability.

This pilot study aims to investigate the intratester reliability and intertester reliability of 2D video analysis system, *PnO CMD*TM, compared to the UG in measuring passive ROM of the

lower limb joints during physical assessment amongst healthy candidates. Additionally, this study aims to establish the effect of markers on measurement reliability. This study was carried out amongst healthy subjects because no evidence was found in the literature examining the reliability of this system for measurement of passive joint range of motion.

Methods

Participants and testers

Appropriate ethical approval was obtained from the Biomedical Engineering Departmental Ethics Committee, University of Strathclyde. Recruitment posters for testers and participants were displayed within the Department of Biomedical Engineering of the University of Strathclyde. Individuals who showed interest were asked to contact the research team, and were provided with additional information and the participant information sheet. A period of three days was given to each individual to make a decision on their participation. Following that, informed consent was obtained from the participants and testers at the introductory session. Inclusion criteria were as follows: Participants were adult (age>18) and did not suffer from any musculoskeletal or neurological conditions, or from any condition resulting in any lower limb sensory deficit. Participants were excluded if they were unable to attend the scheduled measuring and recording sessions or if there was a change in physical status or injury during the trial period.

Testers were required to be a qualified allied health professional or fourth year prosthetics and orthotics student with current experience in measurement of joint ROM. Fourth year prosthetics and orthotics students use the UG throughout the course and have sufficient training in utilising it. Additionally, only students who have completed their clinical placement were included. Testers were excluded if they were unable to attend the scheduled

measuring sessions or were unable to complete the video analysis within given time frame or had no experience in measuring joint ROM.

Study design

Sagittal plane ROM of the hip, knee and ankle joint of the dominant leg during physical assessment was measured with both tools, with and without markers. Markers were applied on the following bony landmarks: shoulder, greater trochanter, lateral femoral condyle of the knee, lateral malleolus and fifth metatarsal head. Markers consisted of bright coloured adhesive *Velcro*TM cut into circular shapes (25mm) and placed by the same researcher to reduce the variability.

Participants

An introductory session was arranged where explanation about the trial was given to the participants. For practical reasons, the participants were divided into two groups. Each group attended two half day sessions; one with markers and one without markers, with approximately one week gap between the sessions. Participants were provided with Lycra suits to wear for all the sessions to minimise the movement of the marker which may occur due to loose clothing. Additionally, each participant was given a time slot to attend for video recording within a separate video recording session. In the video recording session, which lasted for approximately 30 minutes, the camera (Sony Handycam HDR-CX150 Camcorder video camera with 3.1 mega pixels) was positioned using a tripod perpendicular to the examination table where the participant was lying down at an appropriate distance to capture the image of the participant from the shoulder to toe. The researcher moved each joint individually into maximum flexion and extension while a video of the motion is captured. The same procedure was repeated again using markers.

Testers

An introductory session was arranged where a PowerPoint presentation explaining the measuring method with *PnO CMD*TM and UG was given by the researcher in order to standardise the measuring methods. Additional information was provided in a measuring instruction manual. For the purpose of this study, each tester was asked to record the following measurements on the dominant leg using both devices: maximum hip flexion, maximum hip extension, maximum knee flexion, maximum knee extension, maximum ankle plantarflexion and maximum ankle dorsiflexion. The testers were asked to attend four half day sessions; two marker sessions and two no marker sessions with approximately one week gap between each session. In each session, each tester measured the hip, knee and ankle joint ROM of four participants.

Intratester reliability of *PnO CMD*TM

Each participant's joint ROM of the dominant leg was video recorded with and without markers. Following that, each tester was instructed to evaluate each video three times in a time frame of three weeks with approximately one week gap between each evaluation. Each session lasted for approximately two hours. The order of evaluation of the joints (with and without markers) was randomised. Additionally, the videos sequences and the files were randomised between each evaluation. The testers were guided to pause the video at the stage when the researcher holds the joint at the end of the range for 3 seconds and to take the measurement at that position. The order of evaluation of the joints and video sequences was randomised. Special assessment sheets were used to record the ROM measurements using the identification codes provided to each tester and participant for blind analysis.

Intratester reliability of UG:

Prior to each session the inclusion and exclusion criteria were checked for each participant to ensure that the participant's status has not changed. Each tester measured the ROM of each participant (hip, knee and ankle) 3 times in each session. Each session lasted for approximately 3 hours. The order of measuring participants was randomised and the order of each session (marker/no marker) was also be randomised. Each tester had approximately 10 minutes to measure maximum sagittal plane motion of each participant's hip, knee and ankle joints. Special assessment sheets were used to record the ROM measurements using the identification codes provided for each tester and participant for blind analysis.

Intertester *PnO CMD*TM and UG:

The mean of the three repetitions for each device was calculated with and without markers and compared for each joint between the two devices. It should be noted that intertester values were only able to be calculated if intratester values across all the testers were above the satisfactory level.

Statistical analysis

To achieve power of 80% at the 5% level of significance, 3 testers (final year prosthetics and orthotics students) and 8 participants (healthy subjects) were included in the study. ICC model (2, 1) was used after initial summary statistics was produced. This ICC reliability tool was used to assess and compare the reliability of the *PnO CMD*TM and the UG along with Bland & Altman plots and an appropriate paired test assessing the significance of actual differences. ICC values above 0.60 were considered to be satisfactory for research purposes.¹¹

Results

Participants and testers

In this study a total of eight healthy subjects were recruited. Fourth year prosthetics and orthotics students were included as testers and no qualified Allied Health Professionals were recruited.

Intratester reliability

With markers

PnO CMD™

The lowest ICC values found were for ankle dorsiflexion for all the testers. However, the values were above satisfactory limits ($ICC > 0.6$). The highest ICC values for all the testers were found for knee flexion measurements (Table 1). All ICC values were above satisfactory limits and significant. Additionally, all Bland & Altman plots illustrated small dispersion and equal distribution of the points above and below zero confirming the high ICC results found.

Universal goniometer

Some ICC values were found to be below the satisfactory limits ($ICC < 0.06$). The lowest ICC value was found for hip extension for one tester while the highest ICC value was found for ankle plantarflexion for one tester (Table 1). Additionally, the Bland & Altman plots validated the ICC results achieved.

Without markers

PnO CMD™

ICC values for all the joints measured were found to vary from 0.24 to 0.98. ICC values for ankle dorsiflexion for all the testers were found to be lower in comparison to the other motions

measured and below the satisfactory limits ($ICC < 0.6$). Additionally, ICC value for one tester for hip extension was found to be lower than the satisfactory limits (0.53). The highest ICC values for all the testers were found for hip flexion measurements as indicated in Table 1. All the Bland & Altman plots verified the ICC results found.

Universal goniometer

ICC values across all the joints measured were found to vary from 0.39 to 0.93. The lowest ICC value was found for ankle dorsiflexion for one tester while the highest was found for ankle plantarflexion for another tester (Table 1). Furthermore, the Bland & Altman plots illustrated widespread scattering of the points confirming the low ICC results achieved.

Intertester reliability

With markers

PnO CMD™

ICC values for all the joints measured ranged from (0.94 to 0.99) and were above the satisfactory level ($ICC > 0.60$) and significant (Table 1). Additionally, all Bland & Altman plots showed random scattered points equally distributed above and below zero; hence, validating the high ICC values obtained.

Universal goniometer

Only ICC value for ankle plantarflexion was able to be calculated and this was found to be below the satisfactory level ($ICC = 0.39$) (Table 1). The Bland & Altman plot illustrated large dispersion confirming the low ICC result found.

Without markers

PnO CMD™

ICC values for the all the joints measured except ankle dorsiflexion and hip extension were found to range from (0.91 to 0.97). The ICC value for hip extension for one of the tester was below the satisfactory level (ICC=0.53) which prevented the calculation for intertester reliability. All the ICC values across all the testers for ankle dorsiflexion were below the satisfactory levels (ICC<0.6), hence; intertester reliability was not concluded for this joint (Table 1). All Bland & Altman plots confirmed the high ICC values achieved. The plots illustrated small dispersion and equal distribution of the points above and below zero.

Universal goniometer

Only intratester ICC values for ankle plantarflexion across all the testers were above the satisfactory level, but the resulting intertester reliability was lower than the satisfactory level (ICC=0.47) (Table 1). This low ICC value was confirmed by the Bland & Altman plot.

Discussion

All intratester and the intertester ICC values obtained using *PnO CMD™* with markers for all testers were found to be above the satisfactory limit (ICC>0.60) with small variations in values, which demonstrates the reliability of using this tool with markers (Table 1) (Figure 3, 4, 4 and 6). Furthermore, it was observed in this study that all intratester and intertester ICC values for the UG (with/without markers) across all joints ranged considerably, and in some cases, were below the satisfactory limits (ICC<0.60) (Table 1) (Figure 3, 4 and 5). This demonstrates the unreliability of using this tool in comparison to *PnO CMD™* (Table 1) (Figure 6).

Intratester ICC values for ankle plantarflexion were the only values found to be above satisfactory limits ($ICC > 0.6$) for both tools across all the testers (Figure 3, 4 and 5). The resulting intertester reliability for ankle plantarflexion for *PnO CMD*TM was found to be higher than intratester reliability (Table 1) (Figure 6). On the other hand, the intertester reliability for ankle plantarflexion for the UG was found to be lower than intratester reliability (Table 1) (Figure 6). *PnO CMD*TM (with/without marker) ICC values for ankle dorsiflexion for all testers were found to be lower in comparison to the other motions measured (Table 1).

To the best of our knowledge, only ICC values of the UG can be compared to the results previously found in the literature, as no study was found investigating the reliability of *PnO CMD*TM for passive motion of hip, knee and ankle joint. One study, Kilgour et al.¹² was found which investigated the intratester reliability for the measurement of hip, knee and ankle motion using the UG with markers amongst healthy candidates. ICC values reported for hip extension, knee extension and ankle dorsiflexion using similar testing position were all above the satisfactory limits which does not agree with the findings of this study (Table 1). Peters et al.¹³ used a similar testing position as in the current study to investigate intratester reliability of the UG without markers for measurements of knee joint motion amongst healthy candidates. Again, reported ICC values were higher than the values reported in this study. As recommended in the literature, subject's position and measurement procedure were standardised in this study with both tool. Rothstein et al.¹⁴ and Youdas et al.¹⁵ reported an increase in ICC values for the UG when subject's position was standardised. Another source of error stated in the literature is the variance found between the clinicians in the identification of bony landmarks.¹⁶ Markers proved to be useful with *PnO CMD*TM as it increased the reliability. However, the effect of marker on the UG reliability was not clear. It

was noted that the ICC values for the UG (with/without markers) ranged from weak to excellent with no pattern observed making it hard to draw any conclusions. A possible explanation is the unequal manual force applied while measuring. Testers were instructed in each UG session to move each joint to maximum ROM, which may have resulted in different force applied between the testers and sessions. On the other hand, this variance was not present with *PnO CMD*TM as all the joints were moved by the same researcher and the same video captured on a single occasion was used for all the evaluation.

This study represents an initial step in using advanced technology (*PnO CMD*TM) in clinical practice to measure passive joint ROM. High reliability has been illustrated for sagittal plane passive ROM of hip, knee and ankle joint and this increases with the use of markers. Markers can be created from cheap available material such as *Velcro*TM and used effectively. This study has established a methodology which can now be applied and tested in the prosthetic and orthotic populations (for example amputees or subjects with cerebral palsy).

Additionally, as this study only involved fourth year prosthetics and orthotics students, this may have affected the ICC values obtained using the UG and *PnO CMD*TM. It will be beneficial to investigate if experience or professional background has an effect on reliability of *PnO CMD*TM and UG as this has not been reported sufficiently in the literature.² Test-retest design (intra-session intratester) was applied in this study where all the repeated measurements were taken in the same session. Kilgour et al.¹² and Wakefield et al.¹⁷ reported lower inter-session intratester reliability in comparison to intra-session intratester reliability for the UG of hip, knee and ankle joint. Thus, investigating the intersession intratester for *PnO CMD*TM is recommended as clinicians typically measure on different occasions. This study only investigated the reliability of both tools for a single testing position used for hip, knee and ankle motion. Investigation of reliability of *PnO CMD*TM is

required using different test positions for joint ROM. Further research will be required to examine the accuracy of this system in measurement of passive joint ROM.

Conclusion

In conclusion, *PnO CMD*TM was found to be more reliable than the UG in measuring passive sagittal ROM of the lower limb joints motion amongst healthy candidates. In addition, it was found that using markers increased the intratester and intertester reliability of *PnO CMD*TM. The present work opens up possibilities for using new technology in joint ROM measurements to achieve more reliable measurements.

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Figure Captions

Figure 1: *PnO Clinical Movement Data*TM Hub including Software and 2 Video cameras

Figure 2: Universal goniometer

Figure 3: Intratester ICC values for tester 1 for all the motion measured using both tools with/without markers.

Figure 4: Intratester ICC values for tester 2 for all the motion measured using both tools with/without markers.

Figure 5: Intratester ICC values for tester 3 for all the motion measured using both tools with/without markers.

Figure 6: Intertester ICC values for all testers for all the motion measured using both tools with/without mark

Figures:

Figure 1

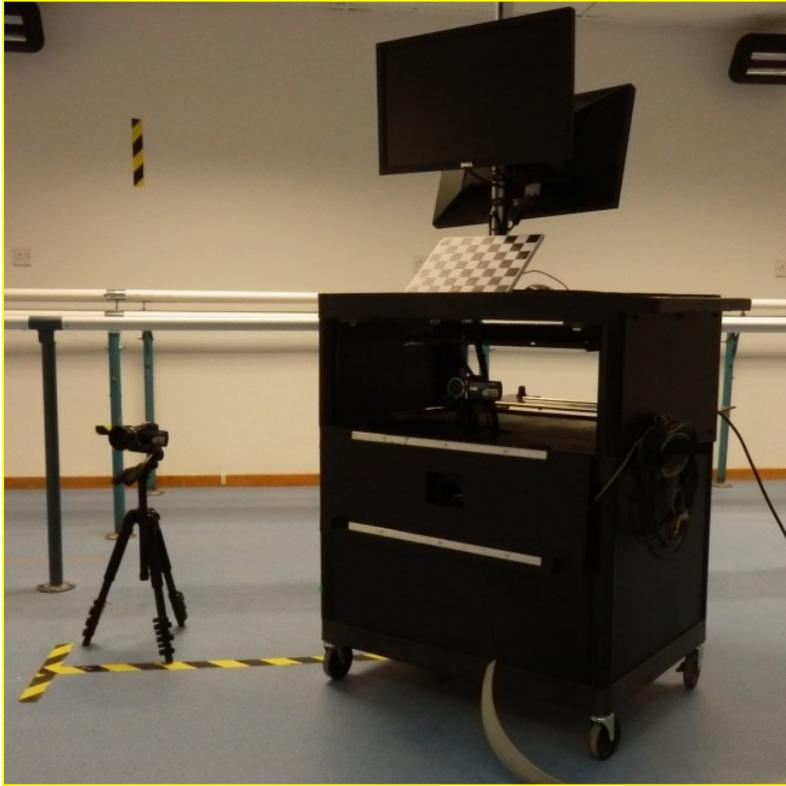


Figure 2

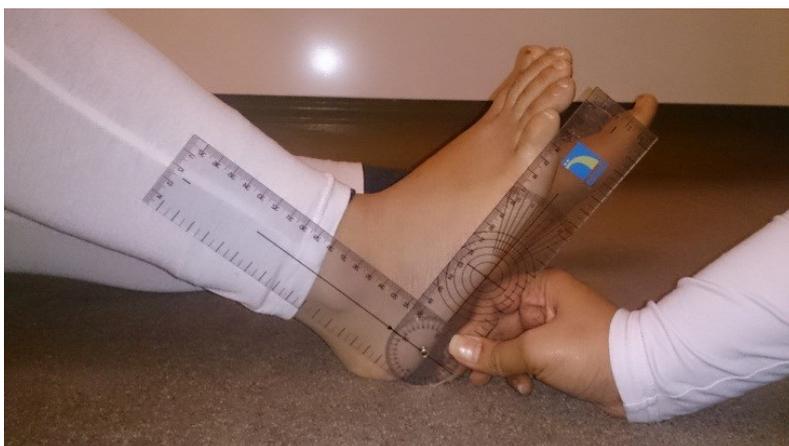


Figure 3

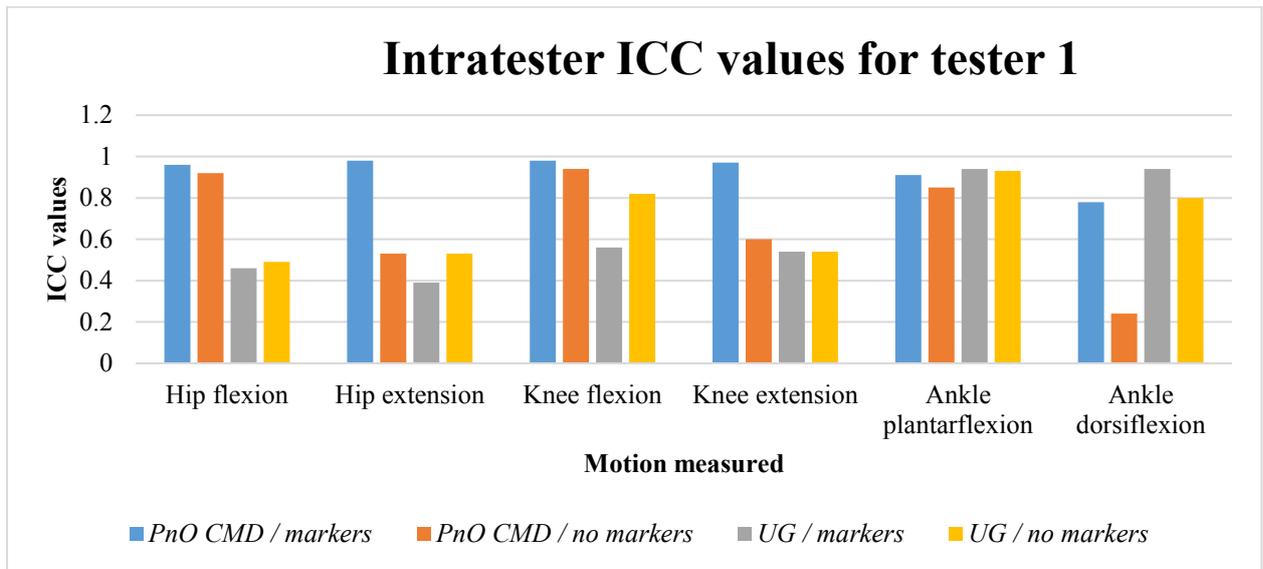


Figure 4

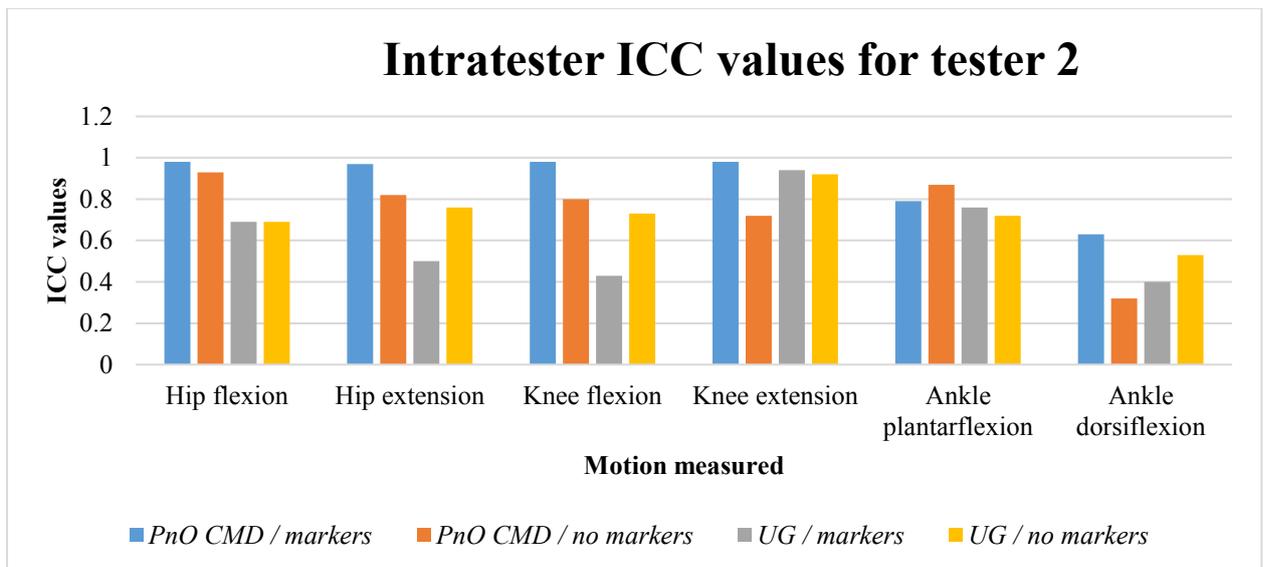


Figure 5

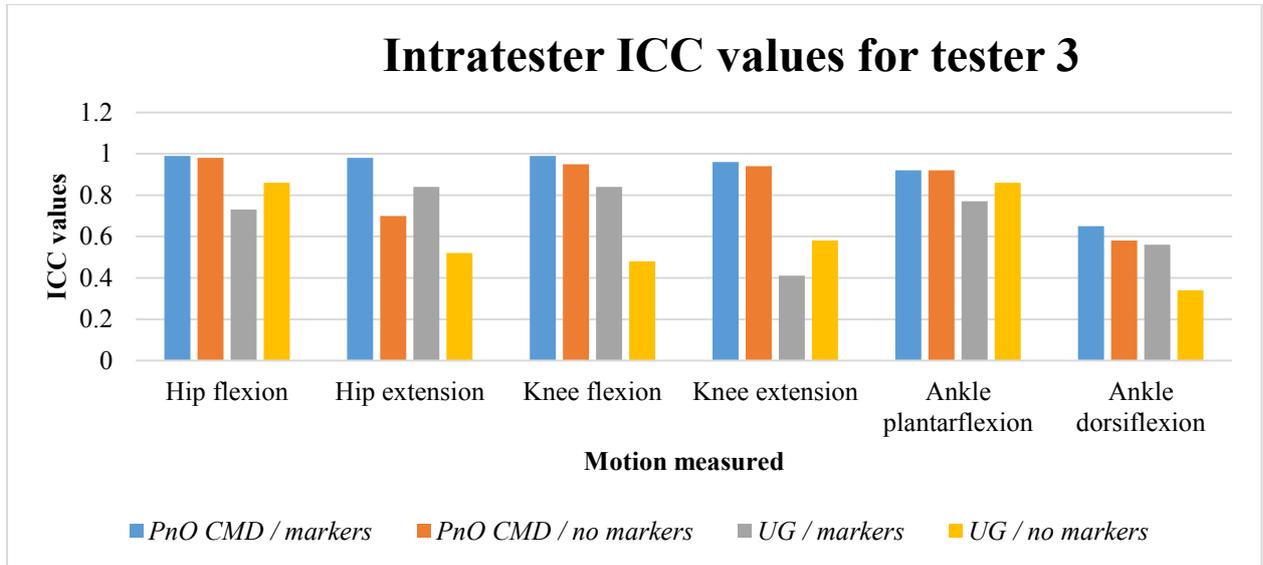
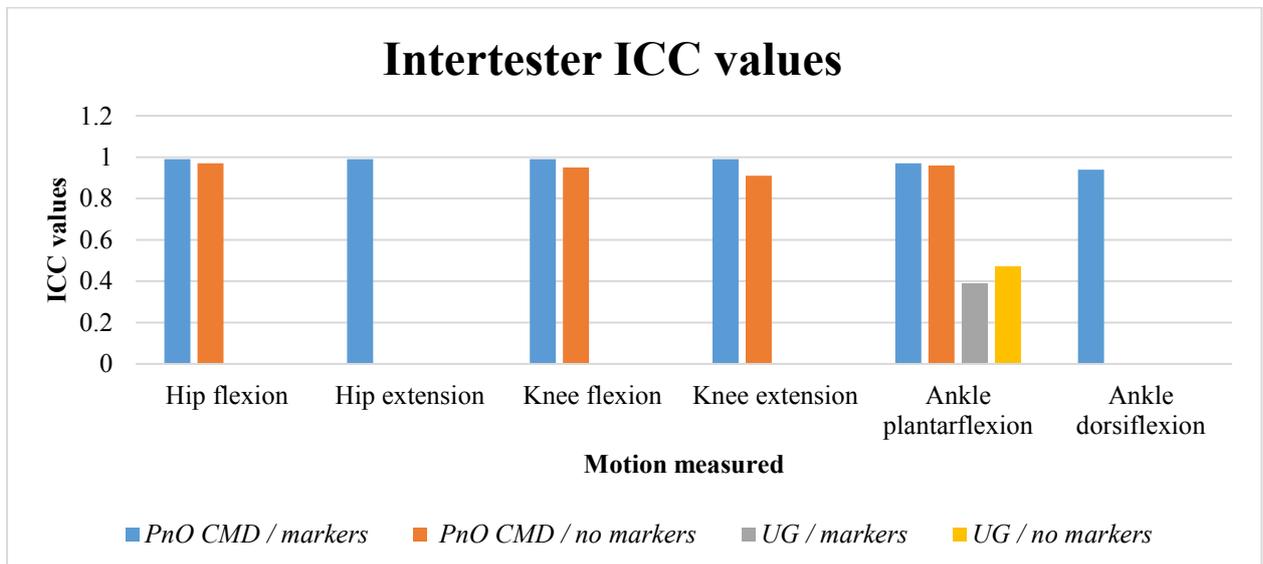


Figure 6



Tables:

Table 1: Intratester and intertester ICC values, p-values and 95% CI across all the testers for both tools with/without markers

Motion/ Tester	Tester 1				Tester 2				Tester 3				Tester 1, 2 & 3			
Reliability	Intratester												Intertester			
	ICC	95% CI		P-value	ICC	95% CI		P-value	ICC	95% CI		P-value	ICC	95% CI		P-value
		Lower bound	Upper bound			Lower bound	Upper bound			Lower Bound	Upper bound			Lower bound	Upper bound	
<i>PnO CMD™/markers</i>																
Hip flexion	0.96	0.88	0.99	<0.001	0.98	0.94	0.99	<0.001	0.99	0.97	0.99	<0.001	0.99	0.98	0.99	<0.001
Hip extension	0.98	0.94	0.99	<0.001	0.97	0.90	0.99	<0.001	0.98	0.94	0.99	<0.001	0.99	0.97	0.99	<0.001
Knee flexion	0.98	0.96	0.99	<0.001	0.98	0.96	0.99	<0.001	0.99	0.98	0.99	<0.001	0.99	0.99	1.00	<0.001
Knee extension	0.97	0.91	0.99	<0.001	0.98	0.93	0.99	<0.001	0.96	0.89	0.99	<0.001	0.99	0.98	0.99	<0.001
Ankle plantarflexion	0.91	0.76	0.98	<0.001	0.79	0.47	0.94	<0.001	0.92	0.77	0.98	<0.001	0.97	0.91	0.99	<0.001
Ankle dorsiflexion	0.78	0.461	0.94	<0.001	0.63	0.29	0.91	<0.001	0.65	0.26	0.90	<0.001	0.94	0.82	0.98	<0.001
<i>PnO CMD™/no markers</i>																
Hip flexion	0.92	0.76	0.98	<0.001	0.93	0.80	0.98	<0.001	0.98	0.93	0.99	<0.001	0.97	0.91	0.99	<0.001
Hip extension	0.53*	0.13	0.86	<0.001	0.82	0.53	0.95	<0.001	0.70	0.33	0.92	<0.001	-	0.46	0.97	<0.001
Knee flexion	0.94	0.82	0.98	<0.001	0.80	0.23	0.95	<0.001	0.95	0.86	0.99	<0.001	0.95	0.44	0.99	<0.001
Knee extension	0.60	0.15	0.89	<0.001	0.72	0.37	0.92	<0.001	0.94	0.7	0.98	<0.001	0.91	0.35	0.98	<0.001
Ankle plantarflexion	0.85	0.60	0.96	<0.001	0.87	0.60	0.97	<0.001	0.92	0.77	0.98	<0.001	0.96	0.88	0.99	<0.001
Ankle dorsiflexion	0.24*	-0.19	0.73	0.15	0.32*	-0.10	0.77	0.07	0.58*	0.18	0.88	<0.001	-	-	-	-

Motion/ Tester	Tester 1				Tester 2				Tester 3				Tester 1, 2 & 3					
Reliability	Intratester												Intertester					
	ICC	95% CI		P- value	ICC	95% CI		P- value	ICC	95% CI		P- value	ICC	95% CI		P- value		
		Lower bound	Upper bound			Lower bound	Upper bound			Lower Bound	Upper bound			Lower bound	Upper bound			
UG/markers																		
Hip flexion	0.46*	0.071	0.83	0.01	0.69	0.27	0.92	<0.001	0.73	0.37	0.93	<0.001	-	-	-	-		
Hip extension	0.39*	-0.05	0.81	0.045	0.50*	0.05	0.85	0.01	0.84	0.56	0.96	<0.001	-	-	-	-		
Knee flexion	0.56*	0.15	0.87	0.005	0.43*	0.02	0.82	0.02	0.84	0.59	0.96	<0.001	-	-	-	-		
Knee extension	0.54*	0.08	0.87	0.01	0.94	0.82	0.98	<0.001	0.41*	-0.04	0.81	0.04	-	-	-	-		
Ankle plantarflexion	0.94	0.84	0.98	<0.001	0.76	0.44	0.94	<0.001	0.77	0.45	0.94	<0.001	0.39*	-0.07	0.80	<0.001		
Ankle dorsiflexion	0.94	0.82	0.98	<0.001	0.40*	-0.05	0.81	0.04	0.56*	0.16	0.87	<0.001	-	-	-	-		
UG/no markers																		
Hip flexion	0.49*	0.04	0.85	0.01	0.69	0.31	0.92	<0.001	0.86	0.60	0.97	<0.001	-	-	-	-		
Hip extension	0.53*	0.08	0.86	0.01	0.76	0.41	0.94	<0.001	0.52*	0.08	0.86	0.01	-	-	-	-		
Knee flexion	0.82	0.54	0.95	<0.001	0.73	0.36	0.93	<0.001	0.48*	0.04	0.84	0.01	-	-	-	-		
Knee extension	0.54*	0.11	0.86	<0.001	0.92	0.76	0.98	<0.001	0.58*	0.19	0.88	<0.001	-	-	-	-		
Ankle plantarflexion	0.93	0.79	0.98	<0.001	0.72	0.36	0.92	<0.001	0.86	0.64	0.96	<0.001	0.47*	-0.22	0.86	0.07		
Ankle dorsiflexion	0.80	0.51	0.95	<0.001	0.53*	0.09	0.86	0.01	0.34*	-0.11	0.79	0.075	-	-	-	-		

ICC: intraclass correlation coefficient, CI: confidence interval, ICC values marked with an asterisk* are below satisfactory level (ICC<0.60). P-values in red font are significant values.