Test-re-test reliability and inter-rater reliability of a digital pelvic inclinometer

Chris Beardsley, Tim Egerton, Brendon Skinner

Objective: The purpose of this study was to investigate the reliability of a digital pelvic inclinometer (DPI) for measuring pelvic tilt. **Method:** The inter-rater reliability and test-re-test reliabilities of the DPI for measuring pelvic tilt on both the right and left sides of the pelvis were measured by two raters carrying out two rating sessions of the same subjects on separate occasions. **Results:** For measuring pelvic tilt, inter-rater reliability was designated as good on both sides (ICC = 0.81 – 0.88), test-re-test reliability within a single rating session was designated as good on both sides (ICC = 0.88 – 0.95), and test-re-test reliability between two rating sessions was designated as moderate on the left side (ICC = 0.65) and good on the right side (ICC = 0.85). **Conclusion:** The inter-rater reliability and test-re-test reliability within a single rating session of the DPI were good, while the test-re-test reliability was moderate-to-good. Further research is required to establish the validity of the DPI in measuring pelvic tilt.

TITLE: Test-re-test reliability and inter-rater reliability of a digital pelvic inclinometer

CORRESPONDING AUTHOR

Chris Beardsley, Suite 34, New House, 67-68 Hatton Garden, Holborn, London, EC1N 8JY,
Telephone: +44 1159 320056. Email: chrisabeardsley@gmail.com

AUTHOR NAMES

Chris Beardsley, Strength and Conditioning Research Limited, Holborn, London, UK

Tim Egerton, England, UK

Brendon Skinner, Department of Sports Therapy, Staffordshire University, UK

ABSTRACT

Objective

The purpose of this study was to investigate the reliability of a digital pelvic inclinometer (DPI) for measuring pelvic tilt.

Method

The inter-rater reliability and test-re-test reliabilities of the DPI for measuring pelvic tilt on both the right and left sides of the pelvis were measured by two raters carrying out two rating sessions of the same subjects on separate occasions.

Results

For measuring pelvic tilt, inter-rater reliability was designated as good on both sides (ICC = 0.81 – 0.88), test-re-test reliability within a single rating session was designated as good on both sides (ICC = 0.88 – 0.95), and test-re-test reliability between two rating sessions was designated as moderate on the left side (ICC = 0.65) and good on the right side (ICC = 0.85).

Conclusion

The inter-rater reliability and test-re-test reliability within a single rating session of the DPI were good, while the test-re-test reliability was moderate-to-good. Further research is required to establish the validity of the DPI in measuring pelvic tilt.

Several methods are available for measuring pelvic tilt. Early studies often used radiography (Clayson et al. 1962; Flint, 1963) and this method continues to be used in relation to surgery affecting the hip and pelvis (Blondel et al. 2009; Lazennecet al. 2011) or when a standard is required against to validate other methods (Burdett et al. 1986; Crowell et al. 1994; Petrone et al. 2003; Sprigle et al. 2003; Lazennecet al. 2011). Other methods include the Iowa Anatomical Position System (Day et al. 1984), the Metrecom Skeletal Analysis System (Barakatt et al. 1996), the antenna method (Moes, 1998), goniometers (Burdett et al. 1986; Sprigle et al. 2003), calipers (Sanders and Stavrakas, 1981; Gajdosik et al. 1985; Alviso et al. 1988), inclinometers (Walker et al. 1987; Crowell et al. 1994; Levine et al. 1997; Hagins et al. 1998; Petrone et al. 2003; Preece et al. 2008; Gnat et al. 2009; Herrington, 2011), low-dose digital stereoradiography (Lazennecet al. 2011; Guenoun et al. 2012), and magnetic resonance imaging (MRI) scans (Lalonde et al. 2006).

Increased anterior pelvic tilt has been associated with greater lumbar lordosis angle during standing (Day et al. 1984; Levine and Whittle, 1996; Youdas et al. 2000), although not all investigators have reported such associations (Walker et al. 1987; Youdas et al. 1996). Increased lumbar lordosis angle is a risk factor for developing low back pain during extended periods of standing (Sorensen et al. 2015) and may increase the risk of musculoskeletal injury during running (Schache et al. 1999; Schache et al. 2000), possibly by causing repetitive impingement of the vertebral facets (Schache et al. 1999) or by producing excessive lengthening of the hamstring, leading to strain injury (Schache et al. 1999). On this basis, some clinicians may decide to measure anterior pelvic tilt in their patients and clients.

Pelvic tilt can be measured either with a single measurement, at the center line, or with two measurements at either lateral border. Measurements taken in cadavers have shown that differences in bony anatomy lead to significant between-side differences in anterior pelvic tilt (Preece et al. 2008) and significant differences in pelvic tilt between sides have also been reported in live subjects (Herrington, 2011). The difference in pelvic tilt between sides has been taken as a measurement of pelvic torsion, which some investigations have associated with leg length discrepancy (Cummings et al. 1993; Young et al. 2000; Betsch et al. 2012; Wild et al. 2014). It has been variously suggested that pelvic torsion occurs as a natural adaptation to leg length discrepancy (Krawiec et al. 2003), that greater anterior pelvic tilt occurs on the side of the shorter leg compared to the contralateral leg (Knutson et al. 2005), and that this biomechanical feature may be common to both symptomatic and asymptomatic individuals alike (Herrington, 2011). Even so, the precise relationships between leg length discrepancy and pelvic torsion, as well as between leg length discrepancy and musculoskeletal injury risk, are contentious and remain poorly understood (Gurney, 2002; Juhl et al. 2004; Knutson, 2005; Cooperstein and Lew, 2009).

Previously, the reliability of calliper-based inclinometers for measuring iliac crest height differences (Walker et al. 1987; Hagins et al. 1998; Petrone et al. 2003; Krawiec et al. 2003) and also for measuring pelvic tilt (Crowell et al. 1994; Gnat et al. 2009; Herrington, 2011; Fourchet et al. 2014) has been found to be good. Calliper-based inclinometers have also been found to display good convergent criterion reference validity by reference to radiography (Crowell et al. 1994; Petrone et al. 2003). Furthermore, these devices also have several practical advantages to the clinician, being quickly and easily utilized (Crowell et al. 1994), as well as being small, portable, relatively safe compared to radiography, and comparatively inexpensive in comparison with low-dose digital stereoradiography and MRI scanning devices. Calliper-based inclinometers also permit measurements to be taken on both sides of the pelvis, which may be important given the differences between sides that have previously been observed (Preece et al. 2008; Herrington, 2011).

Different models of calliper-based inclinometer have been investigated in the literature. The Palpation Meter (PALM, Performance Attainment Associates, St. Paul, MN) is the calliper-based inclinometer that has been extensively explored (Hagins et al. 1998; Petrone et al. 2003; Krawiec et al. 2003; Gnat et al. 2009; Lee et al. 2011; Herrington, 2011; Fourchet et al. 2014). Other models that have been investigated include those developed and modified by Walker et al. (1987) and Crowell et al. (1994). The model used and developed by Crowell et al. (1994) included a spirit level to permit readings relative to the ground, finger-tip rings to allow superior palpation of the bony prominences, and a digital read-out for ease and speed of reading the output. The Digital Pelvic Inclinometer (DPI, Sub-4 Limited, UK) is a newly commercially-available calliper-based inclinometer that is very similar to the model developed by Crowell et al. (1994) (Figure 1). Like the model developed by Crowell et al. (1994), the DPI uses a digital display, which allows the clinician to see the output of the device while simultaneously performing the measurement procedure; it has recessed calliper ends, which allow simultaneous palpation of the bony prominences with the hands and the calliper arms; and it contains a spirit level to facilitate measurements of pelvic angles relative to the ground as well as relative to the other side of the pelvis.

The purpose of this study was to investigate the inter-rater reliability and test-re-test reliability of the DPI in young, healthy males and females across two rating sessions with experienced, trained raters. The first hypothesis for this study was that inter-rater reliability for the DPI between two raters would be good. The second hypothesis was that test-rest reliability for the DPI would be good by reference to three separate measurements taken on a single rating session. The third hypothesis was that test-re-test reliability for the DPI would be good by reference to the mean of the measurements taken on each of two rating sessions on separate occasions.

Method

Experimental approach

The inter-rater reliability and test-re-test reliabilities of the DPI for measuring pelvic tilt on both the right and left sides of the pelvis were measured by two raters carrying out two rating sessions of the same subjects on separate occasions. The dependent variables were the two angles of pelvic tilt (right and left sides). The independent variables were the test number (3 tests per session), the session (2 sessions), and the rater (2 raters).

Measurement procedures

The subjects arrived at the laboratory wearing athletic clothing. The subjects were tested by both raters in 2 sessions on 2 separate days, 3 weeks apart. The subjects were measured while wearing loose clothing and socks on a level floor in the same room of the same building, at the same time of day on each occasion. The raters used a DPI to take measurements for pelvic tilt on each side of the pelvis (right and left). The DPI is a hand-held, calliper-based inclinometer with a digital readout (Figure 1).

[Figure 1 about here]

The DPI comprises two precision arms, which are mounted upon a main body. The main body contains a tri-axial accelerometer, which records the angle of pelvic tilt across the two precision arms. The output from the tri-axial accelerometer is shown as an angle in degrees, in numerical form on a liquid crystal display.

For each measurement of pelvic tilt, standard instructions were used per the manufacturer's guidelines, as follows: "the practitioner places the index finger and thumb on each hand on each finger grip at the end of the DPI arms. With each index finger slightly prominent ready for concurrent palpation of the posterior superior iliac spine (PSIS) and anterior superior iliac spine (ASIS), the practitioner positions the DPI on the side of the innominate bone and takes a reading. The practitioner moves their index finger over the most prominent point of the iliac crests until the apex is established for the measuring. The practitioner then reads off the degree of inclination from the LCD."

Subjects and raters

Following a power analysis as described by Wolak et al. (2012), a convenience sample of 18 healthy subjects (12 males and 6 females) were recruited from a university physical therapy program. Of the 18 subjects, only 16 were included in the test-retest reliability assessment between sessions (for subject characteristics relevant to each assessment see Table 1).

[Table 1 here]

Subjects qualified for the study if they met the following criteria: were $\geq$ 18 years of age, were able to stand unsupported for the duration of the measurement process ($<$10 minutes), were free from existing low back injuries, had not experienced any low back injuries within the previous 3 months, and had no medical condition leading to clinically meaningful leg length inequality (e.g. total hip replacement). In accordance with ethical requirements, the subjects received an explanation of the nature, purpose, and risks of the study and were given the opportunity to ask questions. All subjects signed an informed consent document prior to participating in the study.

Written ethical approval for the study was granted by the [BLANK FOR PEER REVIEW] ethics panel of [BLANK FOR PEER REVIEW].

A convenience sample of two raters with similar experience in using the DPI were recruited. They completed the DPI measurements for all subjects. The first rater was a sports podiatrist with 26 years experience in clinical practice, and 4 years of experience with using the DPI. The second rater was a podiatrist with 15 years experience in clinical practice, and 6 months of experience with using the DPI.

Statistics

Intra-class correlation coefficients (ICC) were used to assess the inter-rater, intra-rater (between sessions) and intra-rater (within sessions) reliability of pelvic tilt measured using the DPI for both right and left sides. ICCs are suitable for use in fully-crossed study designs assessing reliability of interval variables (Hallgren, 2012). Since the raters were not randomly selected for each subject but were the same for all subjects, a two-way Analysis of Variance (ANOVA) model was used (Shrout and Fleiss, 1979). Since absolute rather than ranked values of pelvic tilt are of interest, the ICC model type was set to require absolute agreement (McGraw and Wong, 1996). The unit of measurement used in the model differed between the statistics calculated. Since clinical practice commonly involves taking multiple measurements and recording the mean, the mean of the three ratings taken for each subject in a single session was used for hypothesis testing for inter-rater reliability and test-retest reliability between sessions. In contrast, for test-retest reliability within single sessions, reliability of the single, individual ratings was assessed (Shrout and Fleiss, 1979). Before commencing the trial, it was decided that interpretation of the reported values for each ICC would be based upon the following criteria: <0.50 = poor, 0.50 - 0.75 = moderate, and >0.75 = good (Walmsley and Amell, 1996; Batterham and George, 2003; Portney and Watkins, 2008). To enhance clinical interpretation of the results, the standard error of measurement (SEM) and minimum difference to be considered real (MD) were estimated (Weir, 2005). Descriptive statistics were calculated as means with standard deviation. Statistical significance was set a priori at $p < 0.05$. All statistical analysis was performed using R, using the irr (Gamer et al. 2007) and ICC (Wolak, 2012) packages.

Results

Descriptive statistics

Descriptive statistics (mean ± standard deviation) for pelvic tilt on the right and left sides are presented in table 2.

[Table 2 here]

Reliability

The ICC, SEM, and MD reported when measuring inter-rater reliability, test-re-test reliability (within sessions) and test-re-test reliability (between sessions) are presented in table 3.

[Table 3 here]

Discussion

The purpose of this study was to investigate the inter-rater reliability and test-re-test reliability of the DPI for measuring pelvic tilt angle on both right and left sides of the pelvis in young, healthy males and females. The first hypothesis for this study was that inter-rater reliability for the DPI would be good. The second hypothesis was that test-re-test reliability for the DPI would be good within a single rating session. The third hypothesis was that test-re-test reliability for the DPI would be good between two rating sessions.

By reference to pre-determined criteria for assessing reliability by reference to the magnitude of the ICC, the inter-rater reliability of the DPI for measuring pelvic tilt was designated as good on both sides (ICC = 0.81 – 0.88), the test-re-test reliability of the DPI for measuring pelvic tilt within a single rating session was designated as good on both sides (ICC = 0.88 – 0.95), and the test-re-test reliability for the DPI for measuring pelvic tilt between two rating sessions was designated as moderate on the left side (ICC = 0.65) and good on the right side (ICC = 0.85).

For inter-rater and test-rest reliability, our findings (ICC = 0.65 – 0.95; SEM = 1.9 – 3.4 degrees; MD = 2.9 – 9.4 degrees) are broadly in line with those of other investigations in similar devices measuring pelvic tilt. In their trial of a very similar type of caliper-based inclinometer to the DPI, Crowell et al. (1994) reported good intra-rater reliability (ICC = 0.92; SEM = 0.93 degrees; MD = 2.6 degrees) and good inter-rater reliability (ICC = 0.95; SEM = 0.78 degrees; MD = 2.2 degrees), Preece et al. (2008) reported good intra-rater reliability (albeit in cadavers) (ICC = 0.98; SEM = 1.1 degrees; MD = 3.1 degrees), Gnat et al. (2009) reported good intra-rater reliability (ICC = 0.99; SEM and MD not reported), Herrington (2011) reported good intra-rater reliability (ICC = 0.87; SEM = 1.1 degrees; MD = 2.5 degrees), and Fourchet et al. (2014) reported good inter-rater and intra-rater reliability (coefficient of variation = 15.8%). The reliability of the PALM in assessing linear differences in iliac crest height has also been found to be good (Hagins et al. 1998; Petrone et al. 2003) but whether such findings can be considered as directly comparable with the measurement of pelvic tilt angle is unclear. The reliability of a three-dimensional (3D) camera-based motion capture system reported by Levine and Whittle (1996) was also found to be good but interestingly no better than the PALM (ICC = 0.95; SEM = 0.96 degrees; MD = 2.7 degrees) and the caliper-based system used by Gajdosik et al. (1985) also displayed similar reliability (ICC = 0.88; SEM = 1.4 degrees; MD = 4.0 degrees).

Regarding pelvic tilt, our descriptive statistics (means of 10.5 – 10.6 degrees) are in line with the findings of other investigations, across various measurement devices. Using a PALM device, Herrington (2011) measured pelvic tilt in a population of 120 young, healthy subjects (65 males and 55 females, aged 23.8 years). It was reported that 85% of males and 75% of females displayed an anteriorly rotated pelvis, in the range of 6 – 7 degrees. Also using a PALM device, Lee et al. (2011) measured pelvic tilt in a population of 40 young, healthy subjects (23 males aged 23.8 years and 17 females aged 21.4 years) and found that anterior pelvic tilt was 7 – 8 degrees. Gajdosik et al. (1985) measured pelvic tilt in a population of 20 healthy males, aged 25.2 years, and reported a mean anterior pelvic tilt angle of 8.5 ± 4.1 degrees. Using a 3D camera-based motion capture system, Levine and Whittle (1996) measured pelvic tilt angle in a population of 20 healthy female subjects, aged 23.4 years, and reported a mean anterior pelvic tilt angle of 11.3 ± 4.3 degrees. Using radiography, Vaz et al. (2002) measured pelvic tilt angle in 100 healthy students from medical professions, aged 27 years, and reported a mean anterior pelvic tilt angle of 12.3 ± 5.9 degrees. From this very brief review, it seems that calliper or calliper-inclinometer systems (Gajdosik et al. 1985; Herrington, 2011; Lee et al. 2011) tend to report slightly lower values of anterior pelvic tilt (6 – 8 degrees vs. 11 – 12 degrees) than those found using more sophisticated methods (Levine and Whittle, 1996; Vaz et al. 2002). It is interesting that the values reported here using the DPI (means of 10.5 – 10.6 degrees) are at the higher end of the spectrum reported in the literature and closer to those observed using more sophisticated methods. Whether this is a feature of the population measured, the presence of a spirit level in the DPI to standardize measurements relative to the ground, systematic bias in the DPI, or systematic bias in the raters is unclear.

Regarding differences between right and left sides, this investigation reported descriptive statistics (mean of 0.1 degrees greater anterior pelvic tilt on the right side) that are within the range of values observed by others. The literature is conflicting regarding whether the left or right sides tend to be more anteriorly rotated, or whether no difference is the norm. In respect of the prevailing direction of greater anterior tilt, some studies have reported very small differences that are likely within the bounds of measurement error (Gnat et al. 2009; Lee et al. 2011). Other investigators have reported greater mean anterior tilt on the right side (Krawiec et al. 2003), which has been predicted based upon the apparent tendency for the right leg to be shorter in many populations (Knutson et al. 2005). However, greater mean anterior tilt on the left side has also been reported (Barakatt et al. 1996). In respect of the magnitude of difference between sides, as noted above, some studies have reported very small differences (Gnat et al. 2009; Lee et al. 2011), while others have reported differences of around 2 degrees (Barakatt et al. 1996; Krawiec et al. 2003). It is noteworthy that Gnat et al. (2009) reported low mean values for the difference between sides in quiet standing (<0.5 degrees) but much greater values after exercise, particularly jumping (4.65 ± 1.56 degrees).

Limitations

There are several key limitations to this investigation. The study design and consequently the forms of ICC used for statistical analysis do not permit the extrapolation of these results to any rater but rather limit their application to experienced and trained raters (Shrout and Fleiss, 1979). Different results might therefore be observed in untrained or in trained but inexperienced raters. In addition, the subjects who were assessed comprised young, healthy physical therapy students and investigations in other populations might yield differing findings. Care should therefore be taken in drawing inferences about the use of the DPI in the general population based on these results. There were also two key controls in which the study protocol was deficient. Firstly, the raters were not blinded to the values displayed on the DPI for each measurement, unlike some other studies assessing reliability in similar devices (Gnat et al. 2009). Secondly, the activities of the subjects immediately prior to the measurements being taken were not controlled. Since mechanical loading has been found to affect pelvic tilt angle (Gnat and Saulicz, 2008; Gnat et al. 2009), this may have affected the reliability of the measurements taken between sessions.

In respect of the validity of the DPI, there are three substantial limitations of the present study. Firstly, criterion reference validity of the DPI for assessing anterior pelvic tilt on either side of the pelvis was not assessed. Future studies could explore this by correlating measurements taken using the DPI with measurements taken using gold standard methods (such as radiography) in the same group of subjects, as other investigators have done (Crowell et al. 1994; Petrone et al. 2003). Therefore, while the DPI displays good reliability between raters and between ratings taken in the same session, it may not produce valid measurements of pelvic tilt in comparison with values recorded using radiography or MRI. Secondly, the extent to which the measurements of anterior pelvic tilt on either side of the pelvis or the difference between these (pelvic torsion) might be predictive of increased injury risk or low back pain was not assessed. Thirdly, the extent to which measurements of anterior pelvic tilt on either side of the pelvis or the difference between these (pelvic torsion) might provide useful information about the extent of any existing leg length inequality was not explored.

Conclusions

The inter-rater reliability and test-re-test reliability of the DPI for measuring pelvic tilt angle on both right and left sides of the pelvis were assessed, in a convenience sample of young, healthy males and females. The inter-rater reliability of the DPI for measuring pelvic tilt was designated as good on both sides (ICC = 0.81 – 0.88); the test-re-test reliability of the DPI for measuring pelvic tilt within a single rating session was designated as good on both sides (ICC = 0.88 – 0.95); and the test-re-test reliability for the DPI for measuring pelvic tilt between two rating sessions was designated as moderate on the left side (ICC = 0.65) and good on the right side (ICC = 0.85). While these results indicate that the DPI produces acceptably reliable measurements, further research is required to establish the validity of the DPI in measuring pelvic tilt.

References

1. Alviso, D. J., Dong, G. T., & Lentell, G. L. (1988). Intertester reliability for measuring pelvic tilt in standing. *Physical Therapy*, *68*(9), 1347-1351.

2. Barakatt, E., Smidt, G. L., Dawson, J. D., Wei, S. H., & Heiss, D. G. (1996). Interinnominate motion and symmetry: comparison between gymnasts and nongymnasts. *Journal of Orthopaedic & Sports Physical Therapy*, *23*(5), 309-319.

3. Batterham, A. M., & George, K. P. (2003). Reliability in evidence-based clinical practice: a primer for allied health professionals☆. *Physical Therapy in Sport*, *4*(3), 122-128.

4. Betsch, M., Wild, M., Große, B., Rapp, W., & Horstmann, T. (2012). The effect of simulating leg length inequality on spinal posture and pelvic position: a dynamic rasterstereographic analysis. *European Spine Journal*, *21*(4), 691-697.

5. Blondel, B., Parratte, S., Tropiano, P., Pauly, V., Aubaniac, J. M., & Argenson, J. N. (2009). Pelvic tilt measurement before and after total hip arthroplasty. *Orthopaedics & Traumatology: Surgery & Research*, *95*(8), 568-572.

6. Burdett, R. G., Brown, K. E., & Fall, M. P. (1986). Reliability and validity of four instruments for measuring lumbar spine and pelvic positions. *Physical Therapy*, *66*(5), 677-684.

7. Clayson, S. J., Newman, I. M., Debevec, D. F., Anger, R. W., Skowlund, H. V., & Kottke, F. (1962). Evaluation of mobility of hip and lumbar vertebrae of normal young women. *Archives of physical medicine and rehabilitation*, *43*, 1.

8. Cooperstein, R., & Lew, M. (2009). The relationship between pelvic torsion and anatomical leg length inequality: a review of the literature. *Journal of Chiropractic Medicine*, *8*(3), 107-118.

9. Crowell, R. D., Cummings, G. S., Walker, J. R., & Tillman, L. J. (1994). Intratester and intertester reliability and validity of measures of innominate bone inclination. *Journal of Orthopaedic & Sports Physical Therapy*, *20*(2), 88-97.

10. Cummings, G., Scholz, J. P., & Barnes, K. (1993). The effect of imposed leg length difference on pelvic bone symmetry. *Spine*, *18*(3), 368-373.

11. Day, J. W., Schmidt, G. L., & Lehmann, T. (1984). Effect of pelvic tilt on standing posture. *Physical Therapy*, *64*(4), 510.

12. Flint, M. M. (1963). Lumbar posture: A study of roentgenographic measurement and the influence of flexibility and strength. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *34*(1), 15-20.

13. Fourchet, F., Materne, O., Rajeb, A., Horobeanu, C., & Farooq, A. (2014). Pelvic tilt: Reliability of measuring the standing position and range of motion in adolescent athletes. *British Journal of Sports Medicine*, *48*(7), 594-594.

14. Gajdosik, R., Simpson, R., Smith, R., & DonTigny, R. L. (1985). Pelvic tilt intratester reliability of measuring the standing position and range of motion. *Physical Therapy*, *65*(2), 169-174.

15. Gamer, M., Lemon, J., Fellows, I., & Singh, P. (2007). IRR: various coefficients of interrater reliability and agreement. *R package v. 0.70. See http://www.r-project. org*.

16. Gnat, R., & Saulicz, E. (2008). Induced static asymmetry of the pelvis is associated with functional asymmetry of the lumbo-pelvo-hip complex. *Journal of Manipulative and Physiological Therapeutics*, *31*(3), 204-211.

17. Gnat, R., Saulicz, E., Biały, M., & Kłaptocz, P. (2009). Does pelvic asymmetry always mean pathology? Analysis of mechanical factors leading to the asymmetry. *Journal of Human kinetics*, *21*, 23-32.

18. Guenoun, B., Zadegan, F., Aim, F., Hannouche, D., & Nizard, R. (2012). Reliability of a new method for lower-extremity measurements based on stereoradiographic three-dimensional reconstruction. *Orthopaedics & Traumatology: Surgery & Research*, *98*(5), 506-513.

19. Gurney, B. (2002). Leg length discrepancy. *Gait & posture*, *15*(2), 195-206.

20. Hagins, M., Brown, M., Cook, C., Gstalder, K., Kam, M., Kominer, G., & Strimbeck, K. (1998). Intratester and intertester reliability of the palpation meter (PALM) in measuring pelvic position. *Journal of Manual & Manipulative Therapy*, *6*(3), 130-136.

21. Hallgren, K. A. (2012). Computing inter-rater reliability for observational data: An overview and tutorial. *Tutorials in Quantitative Methods for Psychology*, *8*(1), 23.

22. Herrington, L. (2011). Assessment of the degree of pelvic tilt within a normal asymptomatic population. *Manual Therapy*, *16*(6), 646-648.

23. Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1-15.

24. Juhl, J. H., Cremin, T. M. I., & Russell, G. (2004). Prevalence of frontal plane pelvic postural asymmetry—part 1. *Journal of the American Osteopathic Association*, *104*(10), 411-421.

25. Knutson, G. A. (2005). Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. *Chiropractic & Manual Therapies*, *13*(1), 11.

26. Krawiec, C. J., Denegar, C. R., Hertel, J., Salvaterra, G. F., & Buckley, W. E. (2003). Static innominate asymmetry and leg length discrepancy in asymptomatic collegiate athletes. *Manual Therapy*, *8*(4), 207-213.

27. Lazennec, J. Y., Rousseau, M. A., Rangel, A., Gorin, M., Belicourt, C., Brusson, A., & Catonné, Y. (2011). Pelvis and total hip arthroplasty acetabular component orientations in sitting and standing positions: measurements reproductibility with EOS imaging system versus conventional radiographies. *Orthopaedics & Traumatology, Surgery & Research*, *97*(4), 373.

28. Lee, J. H., Yoo, W. G., & Gak, H. B. (2011). The immediate effect of anterior pelvic tilt taping on pelvic inclination. *Journal of Physical Therapy Science*, *23*(2), 201-203.

29. Levine, D., & Whittle, M. W. (1996). The effects of pelvic movement on lumbar lordosis in the standing position. *Journal of Orthopaedic & Sports Physical Therapy*, *24*(3), 130-135.

30. Levine, D., Walker, J. R., & Tillman, L. J. (1997). The effect of abdominal muscle strengthening on pelvic tilt and lumbar lordosis. *Physiotherapy Theory and Practice*, *13*(3), 217-226.

31. McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological methods*, *1*(1), 30.

32. Moes, C. C. M. (1998). Measuring the tilt of the pelvis. *Ergonomics*, *41*(12), 1821-1831.

33. Petrone, M. R., Guinn, J., Reddin, A., Sutlive, T. G., Flynn, T. W., & Garber, M. P. (2003). The accuracy of the palpation meter (PALM) for measuring pelvic crest height difference and leg length discrepancy. *Journal of Orthopaedic & Sports Physical Therapy*, *33*(6), 319-325.

34. Portney, L. G., & Watkins, M. P. (2008). Foundations of clinical research: applications to practice. *Prentice Hall, Upper Saddle River, NJ.*

35. Preece, S. J., Willan, P., Nester, C. J., Graham-Smith, P., Herrington, L., & Bowker, P. (2008). Variation in pelvic morphology may prevent the identification of anterior pelvic tilt. *Journal of Manual & Manipulative Therapy*, *16*(2), 113-117.

36. Sanders, G., & Stavrakas, P. (1981). A technique for measuring pelvic tilt. *Physical Therapy*, *61*(1), 49-50.

37. Schache, A. G., Bennell, K. L., Blanch, P. D., & Wrigley, T. V. (1999). The coordinated movement of the lumbo–pelvic–hip complex during running: a literature review. *Gait & Posture*, *10*(1), 30-47.

38. Schache, A. G., Blanch, P. D., & Murphy, A. T. (2000). Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. *British Journal of Sports Medicine*, *34*(4), 279-283.

39. Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychological bulletin*, *86*(2), 420.

40. Sorensen, C. J., Norton, B. J., Callaghan, J. P., Hwang, C. T., & Van Dillen, L. R. (2015). Is lumbar lordosis related to low back pain development during prolonged standing?. *Manual Therapy*. Published Online: January 14, 2015.

41. Sprigle, S., Flinn, N., Wootten, M., & McCorry, S. (2003). Development and testing of a pelvic goniometer designed to measure pelvic tilt and hip flexion. *Clinical biomechanics*, *18*(5), 462-465.

42. Vaz, G., Roussouly, P., Berthonnaud, E., & Dimnet, J. (2002). Sagittal morphology and equilibrium of pelvis and spine. *European Spine Journal*, *11*(1), 80-87.

43. Walker, M. L., Rothstein, J. M., Finucane, S. D., & Lamb, R. L. (1987). Relationships between lumbar lordosis, pelvic tilt, and abdominal muscle performance. *Physical Therapy*, *67*(4), 512-516.

44. Walmsley, R. P., & Amell, T. K. (1996). The application and interpretation of intraclass correlations in the assessment of reliability in isokinetic dynamometry. *Isokinetics and Exercise Science*, *6*(2), 117-124.

45. Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *The Journal of Strength & Conditioning Research*, *19*(1), 231-240.

46. Wild, M., Kühlmann, B., Stauffenberg, A., Jungbluth, P., Hakimi, M., Rapp, W., & Betsch, M. (2014). Does age affect the response of pelvis and spine to simulated leg length discrepancies? A rasterstereographic pilot study. *European Spine Journal*, *23*(7), 1449-1456.

47. Wolak, M. E., Fairbairn, D. J., & Paulsen, Y. R. (2012). Guidelines for estimating repeatability. *Methods in Ecology and Evolution*, *3*(1), 129-137.

48. Wolak, M. (2012). Functions facilitating the estimation of the intraclass correlation coefficient. *R package v. 2.2.1. See http://www.r-project. org.*

49. Youdas, J. W., Garrett, T. R., Harmsen, S., Suman, V. J., & Carey, J. R. (1996). Lumbar lordosis and pelvic inclination of asymptomatic adults. *Physical Therapy*, *76*(10), 1066.

50. Youdas, J. W., Garrett, T. R., Egan, K. S., & Therneau, T. M. (2000). Lumbar lordosis and pelvic inclination in adults with chronic low back pain. *Physical Therapy*, *80*(3), 261-275.

51. Young, R. S., Andrew, P. D., & Cummings, G. S. (2000). Effect of simulating leg length inequality on pelvic torsion and trunk mobility. *Gait & posture*, *11*(3), 217-223.

Figure 1: The Digital Pelvic Inclinometer

	Inter-rater	Test-re-test (within sessions)	Test-re-test (between sessions)
Number of subjects	18	18	16
Number of males (m) and females (f)	12m / 6f	12m / 6f	11m / 5f
Age (years)	23.6 ± 4.7	23.6 ± 4.7	24.0 ± 5.0
Bodyweight (kg)	74.7 ± 13.5	74.7 ± 13.5	76.2 ± 14.0
Height (m)	1.74 ± 0.08	1.74 ± 0.08	1.75 ± 0.09

Table 1: Descriptive statistics for the subjects

	Right (degrees)	Left (degrees)	Difference (degrees)
Mean	10.6	10.5	0.1
Standard deviation	5.0	5.8	3.8

Table 2: Descriptive statistics for pelvic tilt

	Inter-rater		Test-re-test (between sessions)		Test-re-test (within sessions)	
	Right	Left	Right	Left	Right	Left
ICC	0.81*	0.88*	0.85*	0.65*	0.88*	0.95*
SEM	2.2	2.0	1.9	3.4	1.7	1.1
MD	6.0	5.5	5.4	9.4	4.8	2.9

Table 3: Inter-rater and test-re-test reliabilities (between sessions and within sessions) of the DPI for measuring pelvic tilt on the right and left sides, as assessed by intra-class correlation coefficient (ICC), standard error of measurement (SEM) and minimum difference (MD) to be considered real (* = significant, $p < 0.05$)