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Gait & Posture 92 (2022) 77–82

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

The SWING test: A more reliable test than passive clinical tests for assessing sagittal plane hip mobility

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A R T I C L E I N F O

Keywords:
Hip mobility
Clinical test
Range of motion
Thomas test
Straight-Leg-Raise

A B S T R A C T

Background: Clinical assessment of sagittal plane hip mobility is usually performed using the Modified Thomas Test (for extension) and the Straight-Leg-Raise (for flexion) with a goniometer. These tests have limited reliability, however. An active swinging leg movement test (the SWING test), assessed using 3D motion analysis, could provide an alternative to these passive clinical tests.

Research question: Is the SWING test a more reliable alternative to evaluate hip mobility, in comparison to the clinical extension and flexion tests?

Methods: Ten asymptomatic adult participants were evaluated by two investigators over three sessions. Participants performed 10 maximal hip extensions and flexions, with both legs straight and no trunk movement (the SWING test). Hip kinematics was assessed using a 3D motion analysis system. Maximal and minimal hip angles were calculated for each swing and represented maximal hip flexion (SWING flexion) and extension (SWING extension), respectively. The Modified Thomas Test and Straight-Leg-Raise were repeated 3 times for each leg. On the first day, both investigators performed all the tests (SWING + Modified Thomas Test + Straight-Leg-Raise). A week later, a single investigator repeated all the tests. Inter-rater, intra-rater, within-day and between-day reliability were evaluated using intra-class correlation.

Results: Intra-class correlation coefficients for all the tests were superior to 0.8, except for the Modified Thomas Test's intra-rater, between-day (intra-class correlation 0.673) and the Straight-Leg-Raise's inter-rater, within-day (intra-class correlation 0.294). The SWING test always showed a higher intra-class correlation coefficient than the passive clinical tests. The only significant correlation found was for the Straight-Leg-Raise and SWING flexion ($r = 0.48$; $P < 0.001$).

Significance: The SWING test seems to be an alternative to existing passive clinical tests, offering better reliability for assessing sagittal plane hip mobility.

1. Introduction

Hip mobility is important for many everyday activities, and reduced mobility affects subjects' quality-adjusted life years [1]. Reduced hip mobility is related to many low back disorders by inducing compensatory movements in the lumbar spine [2]. In the sagittal plane, lumbo-pelvic flexion–extension requires coordination of the lumbar spine and hips via the pelvis [3]. Hip mobility assessment could provide useful information and aid clinical decision-making and recommendations for people with LBP [2]. In clinical contexts, hip mobility in extension and flexion are often evaluated using the Modified Thomas Test (MTT) and the Straight-Leg-Raise (SLR), respectively [4].

The MTT allows clinicians to measure the hip's maximal extension and is used to identify a lack of extensibility in the hip. The limb hangs off the edge of a table, allowing the investigator to observe knee and hip angles. However, the MTT has several limitations, especially when measurements do not control for pelvic tilt. Intra-rater, between-day, and inter-rater, within-day reliabilities have been reported to be moderate to low, with intra-class correlation (ICC) coefficients ranging from 0.51 to 0.54 and from 0.30 to 0.64, respectively [5].

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https://doi.org/10.1016/j.gaitpost.2021.11.014
Received 29 June 2021; Received in revised form 6 October 2021; Accepted 8 November 2021
Available online 17 November 2021

The SLR is used to evaluate hamstring flexibility [6] and detect lumbosacral nerve root irritation [7] by measuring the angle between the iliotibial band and the horizontal while the patient is lying on their back with a passive straight leg [8]. In an asymptomatic population, SLR inter-rater, within-day reliability has been reported to be moderate, with ICC coefficients ranging from 0.48 to 0.54 [9]. Intra-rater, between-day reliability was reported to be good, with Pearson's correlation coefficients ranging from 0.79 to 0.81 [9]. However, several differences in test methodologies (measurement tools, patient positioning, and/or pelvis stabilising), or in the LBP populations involved (nonspecific or specific LBP), limited interpretations of the SLR's reliability [7,8,10].

Both tests have shown moderate inter-rater reliability, suggesting that test measurements were influenced by the rater. An alternative to these passive clinical tests could be active assessments that have shown good intra-rater and inter-rater reliability [11–13]. One explanation could be that active tests are less dependent on the rater. A movement's quantification method might also influence its measurement. These clinical tests are characteristically performed using a goniometer [4], which has the advantages of being easy to use and cost-effective. But goniometric measurements have generally only shown low-to-moderate reliability, especially with passive movements [14], which may explain the merely moderate reliability of the MTT and SLR. In parallel, several studies have used other measurement tools, such as pendular goniometers or 3D motion analysis systems, to quantify the flexibility of hip flexors and hip extensors, and they have reported good-to-excellent reliability [12,15].

The present study aimed to 1) develop an alternative test to the classic, passive clinical MTT and SLR used for managing and monitoring hip mobility, and indirectly assess muscle extensibility; 2) evaluate this new test's inter-rater and intra-rater, between-day and within-day reliability; and 3) compare its reliability against the classic passive clinical MTT and SLR. The research hypothesis was that a lack of extensibility could be assessed during an active leg movement and that this test's reliability would be better than the classic passive clinical MTT and SLR.

2. Methods

2.1. Study design

The present prospective study was approved by the Research Ethics Cantonal Commission of Geneva University Hospitals (Geneva, Switzerland) (reference CER: 14–126), and all participants gave their written informed consent before their inclusion.

2.2. Participants

The sample size calculation was based on the ICC reported by Neto et al. for SLR (ICC=0.92) [16] and Clapis et al. for MTT (0.48 <ICC<0.54) [17] which who used the same methodology that we were going to apply in the present study. Based on the recommendations of Bujang et al. [18], with an ICC of 0.51 (0.48 <MMTICC<0.54), a power of 80%, an alpha error of 0.05, and three trials, the sample size must be greater than 11 participants. In the present study, each leg has been analyzed separately. So, with 10 participants, we have a sample size of 20. The study population consisted of ten asymptomatic participants aged 20–40 years old. Inclusion criteria included no back pain in the last 6 months and no other existing injuries during the experimental period. Potential participants presenting with a history of back surgery, a body mass index over 30 kg/m^2, were unable to understand French, or were pregnant were excluded from the experiment.

2.3. Raters

Two raters performed the range of movement (ROM) measurements independently. Rater *A* had 6 years of experience in human movement analysis and performing clinical tests. Rater *B* was a medical student with little experience in this field. Both were trained in how to perform the measurements.

2.4. Equipment

The clinical tests used a two-arm, 360°-scale goniometer to assess maximal hip angles. To measure the hip kinematics using the alternative test (SWING test, see Procedure section), the trajectories of 18 reflective markers (14 mm diameter), placed on each subject's skin according to the Conventional Gait Model [19], were recorded using a 12-camera motion analysis system (Oqus7 +, Qualisys, Göteborg, Sweden) set to a sampling frequency of 100 Hz.

2.5. Experimental procedure

Three evaluations of 45 min per participant were carried out on two different days, one week apart (Fig. 1). The first two evaluations were performed consecutively, on the same day and on the same participant, one by rater *A* and one by rater *B*. The order of the raters' evaluations was randomised. The third evaluation was performed one week later by rater *A* alone. Each session included:

2.5.1. Familiarisation

Participants were equipped with the retro-reflective markers and asked to walk a hundred meters in the laboratory at a self-selected normal speed to become familiar with the equipment.

2.5.2. Swing test

The proposed alternative was a SWING test of the leg. Participants were asked to take a one-legged standing position on the floor with one hand on a handrail to maintain balance and perform 10 consecutive maximal flexions and extensions of the hip in a swinging leg motion (Fig. 2). Each participant was instructed to flex and extend their hip as far as possible and at a self-selected speed while keeping both knees extended and their back erect. No instruction was given to participant about foot position. Several trials were performed before the test itself, to help participants familiarise themselves with the requested movement until the instructions were met.

2.5.3. Straight Leg Raise (SLR)

The SLR test was used to assess the participant's hip flexion RoM (Fig. 3A) Three measures were taken for each leg. The leg was raised until the pelvis started to incline. The goniometer was placed on the great trochanter. Its proximal branch was aligned with the lateral midline of the pelvis, from the pelvis to the head, and its distal branch was aligned on the iliotibial band to the lateral femoral condyle as described by Clapis et al. [17].

2.5.4. Modified Thomas Test (MTT)

The MTT was used to assess the participants' hip extension RoM (Fig. 3B). Each rater performed three measurements of each participant's legs (right and left alternately) using a goniometer placed on the great trochanter. The goniometer's proximal branch was aligned with the lateral midline of the pelvis, and its distal branch was aligned with the lateral femoral condyle, on the medial line [4]. The first leg measured was randomised for each participant.

2.6. Data processing

Hip kinematics for the SWING test was calculated using Visual3D (C-Motion, Inc, Germantown, MD, USA) in accordance with the placement of markers used in the Conventional Gait Model [19]. Maximal and minimal hip angles were calculated for each swing movement and represent the SWING flexion (maximal hip flexion) and the SWING extension (maximal hip extension), respectively. To limit the influence of lower inertia during the initial swinging movements and any potential

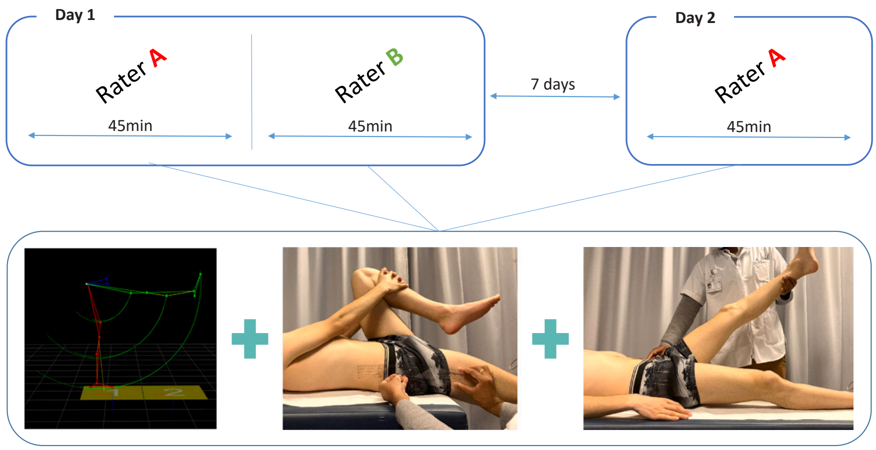

Fig. 1. Summary of the complete protocol.

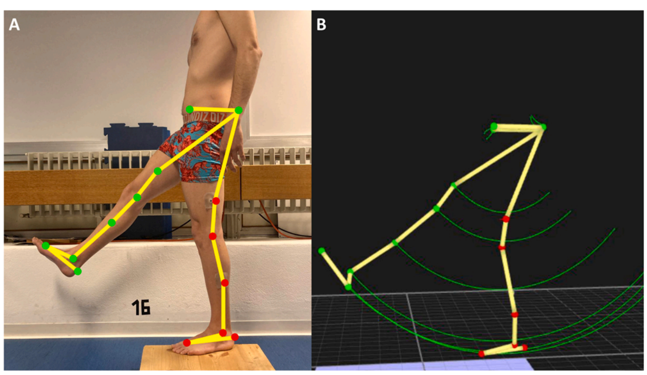

Fig. 2. Illustration of the SWING Test in (A) 2D and (B) sagittal view in the 3D environment of the software.

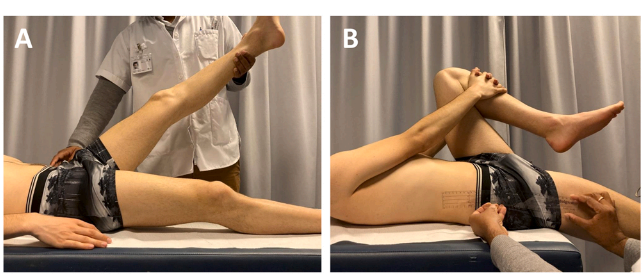

Fig. 3. (A) Straight Leg Raise (SLR) for measuring the length of the hamstring muscles; (B) Modified Thomas Test (MTT) with goniometer alignment for measuring the length of the hip flexors.

muscle fatigue during the last movements, our statistical analysis only used the angles calculated for the fifth to seventh cycles.

2.7. Statistical analysis

All statistical analyses were performed using R software (v.3.1.3) and the RStudio interface (version 1.2.5019). A *P*-value < 0.05 was taken to be a significant level, with a 95% confidence interval (95% CI).

Firstly, to evaluate inter-rater, within-day reliability between the mean values of the measurements made by raters *A* and *B* on the same day, an ICC coefficient with a 95% CI was calculated using an ICC equation described by Rankin and Stokes (equation 3.1; [20]). This equation was described in the context of inter-rater, within-day reliability.

Secondly, to evaluate the intra-rater, within-day reliability between three repeated measurements made by the same rater on the same day, an ICC coefficient with a 95% CI was calculated using an ICC equation described by Rankin and Stokes (equation 1.1; [20]). This equation was described in the context of intra-rater, within-day reliability.

Thirdly, to evaluate the intra-rater, between-day reliability between the mean values of the initial measurements and those made one week later by the same rater, an ICC coefficient with a 95% CI was calculated using an ICC equation described by Rankin and Stokes (equation 1.3; [20]) This equation was described in the context of intra-rater, between-day reliability.

Finally, the standard error of measurement (SEM), associated percentage (SEM%), and the mean of the difference between each repeated measure (MeanDiff) were calculated, and absolute reliability was assessed with minimal detectable change (MDC) with a 95% CI [21].

The Pearson's correlation coefficient and its associated *P*-value were used to quantify the relationship between the clinical tests and the SWING test.

3. Results

Ten asymptomatic participants were recruited for this study (age 32.1 ± 6.1 years; weight 68.9 ± 9.7 kg; height 172.6 ± 8.7 cm; BMI 23.0 ± 1.6 kg/m^2). Only leg presenting values for all the tests were included in the analysis. Due to gaps (marker occlusions) in the trajectory of pelvis markers during the SWING test, 4 legs have to be excluded from the analysis. Reliability results are presented in Table 1. All the ICC coefficients for the SWING test and clinical tests showed excellent intra-rater, within-day reliability. Intra-rater, between-day reliability was excellent for both the SWING test and the SLR but only moderate for the MTT (ICC = 0.673). Inter-rater, within-day reliability was excellent for the SWING test and the MTT but only weak for the SLR (ICC = 0.294).

No significant correlation was found between SWING extension and the MTT (r = 0.16; *P* = 0.23) (Fig. 4). However, a significant but poor correlation was found between SWING flexion and the SLR (r = 0.48; *P* = 0.00021) (Fig. 5).

4. Discussion

The present study aimed to evaluate the potential and reliability of a new test of sagittal plane hip mobility as an alternative to the clinical MTT and the SLR. Indeed, the active SWING test seems to be a good alternative to those clinical tests in terms of reliability, with better inter-rater and intra-rater, between-day and within-day reliability. The SWING test's ICC coefficients were always higher than those of the clinical tests.

Table 1
Reliability of the SWING test, SLR and MTT.

	n	ICC (95% Confidence Interval)	*P*-value	SEM (°)	%SEM	MDC (°)	MeanDiff (°)
Intra-rater, within-day							
SWING Extension	48	0.989 (0.983–0.993)	< 0.001	0.95	5.68	2.65	0.07
Modified Thomas Test	48	0.937 (0.902–0.962)	< 0.001	2.77	58.70	7.68	0.81
SWING Flexion	48	0.903 (0.848–0.942)	< 0.001	4.93	5.74	13.68	-0.30
Straight Leg Raise	48	0.886 (0.825–0.930)	< 0.001	5.12	3.56	14.19	0.06
Intra-rater, between-day							
SWING Extension	16	0.918 (0.757–0.972)	< 0.001	3.05	17.68	8.45	-0.48
Modified Thomas Test	16	**0.673 (0.033–0.887)**	0.022	7.64	163.13	21.19	0.62
SWING Flexion	16	0.885 (0.618–0.965)	< 0.001	7.66	9.014	21.24	0.70
Straight Leg Raise	16	0.809 (0.465–0.933)	0.001	8.75	6.17	24.25	-2.02
Inter-rater, within-day							
SWING Extension	16	0.954 (0.869–0.984)	< 0.001	2.14	12.35	5.95	-0.75
Modified Thomas Test	16	0.939 (0.821–0.979)	< 0.001	2.82	54.50	7.83	1.62
SWING Flexion	16	0.956 (0.878–0.984)	< 0.001	2.80	3.24	7.76	-1.16
Straight Leg Raise	16	**0.294 (0–0.724)**	0.209	11.44	7.94	31.72	-6.93

ICC: intra-class correlation; SEM: Standard Error of Measurement; MDC: Minimum Detectable Change; Mean Diff: mean difference.

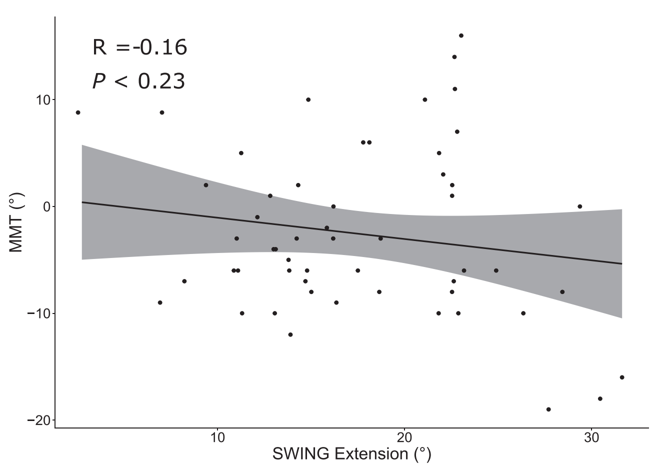

Fig. 4. Relationship between the clinical MTT and SWING test extension. Measures are in degrees (°). MTT: maximal value of MTT for each participant and rater. SWING Extension: maximal value of SWING test extension for each participant and rater. R is the coefficient of correlation.

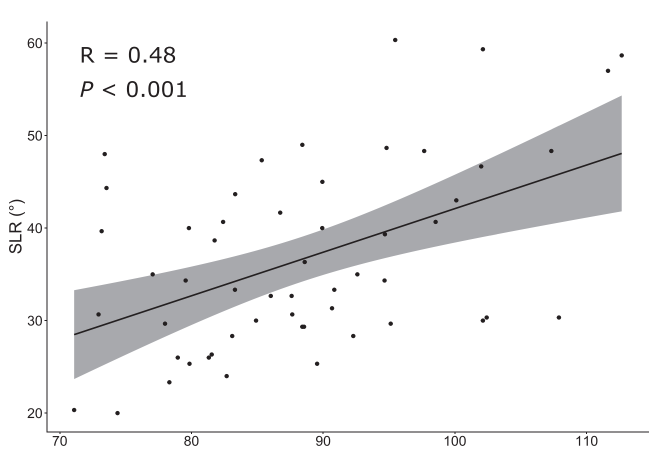

Fig. 5. Relationship between the clinical SLR and SWING test flexion. Measures are in degrees (°). SLR: maximal value of SLR for each participant and rater. SWING Flexion: maximal value of SWING test flexion for each participant and rater. R is the coefficient of correlation.

4.1. Intra-rater, within-day reliability

Both clinical tests and the SWING test showed excellent ICC. The ICC coefficients of our clinical tests were consistent with previous results for the MTT (ICC = 0.91) [17] and the SLR (ICC = 0.97) [8]. From a descriptive point of view, we observed that the ICC values of the SWING test (SWING extension ICC = 0.99, and SWING flexion ICC = 0.9) were always greater than those of the clinical test (MTT ICC = 0.94, and SLR ICC = 0.89).

4.2. Intra-rater, between-day reliability

The SLR and SWING flexion showed excellent intra-rater, between-day reliability (ICC > 0.75) [22], which is consistent with previous findings on the SLR by Neto et al. [16]. Note that the population investigated in their study presented hamstring flexibility deficits but no pain [16]. However, the MTT showed a moderate ICC (ICC 0.40 < ICC < 0.74; [22]). These results were consistent with previous findings of a moderate intra-rater ICC in an MTT assessment (ICC = 0.51–0.54) [5]. Those authors discussed about several conflicting results in the literature, with studies showing both low and excellent intra-rater, between-day reliability. They hypothesised that between-study methodological differences in the MTT settings could have influenced the results, especially the rater's experience (ranging from 4 to 18.5 years). The MTT thus appeared to have limited usefulness for assessing a participant at different sessions. In a clinical setting, clinicians must be able to measure a patient's evolution and monitor the progression in hip mobility. They must be able to assess whether this change is clinically significant or due to measurement error. The MTT's moderate intra-rater, between-day ICC coefficient raised a question about its clinical suitability for patient follow-up if different clinicians perform the tests. Therefore, the SWING test could be a good, reliable alternative to the MTT.

4.3. Inter-rater, within-day reliability

The MTT and SWING extension test's inter-rater, within-day reliability were excellent. However, our results revealed a poor inter-rater, within-day reliability for the SLR (ICC = 0.29) in comparison to the excellent reliability of the SWING flexion test (ICC = 0.96). The SLR's poor reliability was consistent with two previous systematic reviews highlighting that SLR measurement was influenced by the examiner [8, 10]. Poor inter-rater, within-day reliability could be a limitation for patient follow-up. Different clinicians could reach different conclusions and take different decisions regarding the same patient. Several factors might explain the SLR's poor inter-rater, within-day reliability. Correctly measuring the SLR requires close observation of the pelvis to detect its movement but excludes its compensatory movements. Measurement is therefore influenced by the rater's perceptions, which influence inter-rater, within-day reliability. More generally, it has been shown that goniometric measurements are less reliable than other methods, such as 2-D trigonometric measurement [5]. Some authors have underlined the difficulty of measuring with a goniometer, especially when the horizontal line is involved [23]. Finally, raters with different levels of experience could also influence results. We nevertheless deliberately chose raters with different levels of experience to better reflect this realistic clinical context in patient follow-up. Besides, the rater's experience could also be one of the limiting factors in the quality of SLR measurements, which seem to be less present in the SWING flexion test.

Considering the literature and the present results, it appears that the MTT and the SLR are influenced by rater factors such as experience or perception. The better reliability results of the SWING test could therefore be explained by a very low involvement of the rater in the measurement.

4.4. Correlation

SWING flexion had a moderately significant correlation with the SLR ($R = 0.48$, $P < 0.001$)). However, no significant correlation was found between the MTT and the SWING extension test ($R = -0.16$, $P = 0.230$). These results could be due to different factors. One could be the difference between dynamic and static movements. Muscle elasticity and extensibility could be different during dynamic and passive movements. It also might be interesting to investigate the influence of different movement velocities in the SWING test. Moreover, the distance between the muscle anatomic insertion points influences muscle length independently of its elastic components. Some authors have shown that the MTT is not valid if pelvic tilt is uncontrolled [24], because the distance between the insertion points will vary. This component is eliminated by using the SWING test because the calculation of hip kinematics considers the pelvis's movement. However, the angulation of the knee was not taken into account, even though participants were instructed to keep the knee extended. This may have affected the results, allowing greater hip flexion and extension, and parasite movement. One solution to ensure full control over this parameter would be to block the knee completely, e.g. with a splint, and observe potential differences in measurement.

4.5. Study limitations

The present study had several limitations. Firstly, some of the authors were involved in proposing and assessing this new test, which can create a potential for bias in the results. Secondly, although the SWING test enables a reduction in extrinsic variability, its dynamic muscle solicitation is influenced by intrinsic components such as motivation, force, and velocity. Thirdly, some extrinsic variability remains because marker placement can influence hip kinematics [25]. Fourthly, placing markers on the skin exposes the kinematics to soft-tissue artefacts, which can influence the SWING test's hip angle value. Finally, the use of the SWING test with an optoelectronic system is limited because this system is expensive and not easily accessible to all clinicians. Therefore, this study is a feasibility study towards validating the SWING test as a routine clinical hip RoM assessment. Subsequent work could aim to provide low cost, accessible and easy-to-use assessment tools for performing the SWING test in a clinical context, such as the inertial measurement units [26] or single camera markerless motion capture system [27]. Future studies will also evaluate the SWING test's reliability on pathological populations such as LBP patients.

5. Conclusion

We have described a new test—the SWING test—for the assessment of hip range of motion in both flexion and extension. SWING test results suggested that it would be a good alternative to the clinical Modified Thomas Test and the Straight Leg Raise. Indeed, it proved to be more reliable. Nevertheless, SLR presented a low inter-rater within-day reliability (high variability between rater on the same day) and MTT presented a moderate intra-rater between-day reliability (variability between days for the same rater) which questions their use in clinical follow-up. The main future perspective for the SWING test as a hip mobility assessment tool is the use of inertial measurement units or a single camera markerless motion capture system, which are low-cost and easier to use than the present setup and thus better adapted for use in a clinical context.

Funding

This work was partly supported by the "Fondation Privée des HUG" (Switzerland).

Conflict of interest statement

None.

References

[1] J.F. Konopka, Y. Lee, E.P. Su, A.S. McLawhorn, Quality-adjusted life years after hip and knee arthroplasty, JBJS Open Access. 3 (2018), e0007, https://doi.org/10.2106/jbjs.oa.18.00007.

[2] H. Prather, L. van Dillen, Links between the hip and the lumbar spine (hip spine syndrome) as they relate to clinical decision making for patients with lumbopelvic pain, PM R. 11 (2019), https://doi.org/10.1002/pmrj.12187.

[3] M. Zawadka, M. Skublewska-Paszkowska, P. Gawda, E. Lukasik, J. Smolka, M. Jablonski, What factors can affect lumbopelvic flexion-extension motion in the sagittal plane?: a literature review, Hum. Mov. Sci. 58 (2018) 205–218, https://doi.org/10.1016/j.humov.2018.02.008.

[4] C. Norkin, D. White, Measurement of joint motion: a guide to goniometry, (2016). ⟨https://books.google.ch/books?hl=fr&lr=&id=TSluDQAAQBAJ&oi=fnd&pg=PR1&dq=fingertip-to-thigh+test&ots=2g5Qvczjy3&sig=lXApNaoct4IiDh0jJUml3rfPGDU⟩ (accessed November 6, 2018).

[5] C.B. Wakefield, A. Halls, N. Difilippo, G.T. Cottrell, Reliability of goniometric and trigonometric techniques for measuring hip-extension range of motion using the modified Thomas test, J. Athl. Train. 50 (2015) 460–466, https://doi.org/10.4085/1062-6050-50.2.05.

[6] L. López López, J.R. Torres, A.O. Rubio, I. Torres Sánchez, I. Cabrera Martos, M. C. Valenza, Effects of neurodynamic treatment on hamstrings flexibility: a systematic review and meta-analysis, Phys. Ther. Sport. 40 (2019) 244–250, https://doi.org/10.1016/j.ptsp.2019.10.005.

[7] F. Capra, C. Vanti, R. Donati, S. Tombetti, C. O'Reilly, P. Pillastrini, Validity of the straight-leg raise test for patients with sciatic pain with or without lumbar pain using magnetic resonance imaging results as a reference standard, J. Manip. Physiol. Ther. 34 (2011) 231–238, https://doi.org/10.1016/j.jmpt.2011.04.010.

[8] J.K. Dixon, J.L. Keating, Variability in straight leg raise measurements: Review, Physiotherapy 86 (2000) 361–370, https://doi.org/10.1016/S0031-9406(05)60630-X.

[9] D.G. Hunt, O.A. Zuberbier, A.J. Kozlowski, J. Robinson, J. Berkowitz, I.Z. Schultz, R.A. Milner, J.M. Crook, D.C. Turk, Reliability of the lumbar flexion, lumbar extension, and passive straight leg raise test in normal populations embedded within a complete physical examination, Spine 26 (2001) 2714–2718, https://doi.org/10.1097/00007632-200112150-00018.

[10] R. Rebain, G.D. Baxter, S. McDonough, A systematic review of the passive straight leg raising test as a diagnostic aid for low back pain (1989 to 2000), Spine 27 (2002), https://doi.org/10.1097/00007632-200209010-00025.

[11] M.S.A. Hamid, M.R. Mohamed Ali, A. Yusof, Interrater and intrarater reliability of the active knee extension (AKE) test among healthy adults, J. Phys. Ther. Sci. 25 (2013) 957–961, https://doi.org/10.1589/jpts.25.957.

[12] O. Olivencia, G.M. Godinez, J. Dages, C. Duda, K. Kaplan, M.J. Kolber, Kaplan Kolber, The reliability and minimal detectable change of the ely and active knee extension tests, Int. J. Sports Phys. Ther. 15 (2020) 776–782, https://doi.org/10.26603/ijspt20200776.

[13] R. Gajdosik, Rectus femoris muscle tightness: Intratester reliability of an active knee flexion test, J. Orthop. Sports Phys. Ther. 6 (1985) 289–292, https://doi.org/10.2519/jospt.1985.6.5.289.

[14] E. van Trijffel, R.J. van de Pol, R.A.B. Oostendorp, C. Lucas, Inter-rater reliability for measurement of passive physiological movements in lower extremity joints is generally low: a systematic review, J. Physiother. 56 (2010) 223–235, https://doi.org/10.1016/S1836-9553(10)70005-9.

[15] F. Medina-Mirapeix, R.M.S. Agustín, G. Cánovas-Ambit, J.A. García-Vidal, M. Gacto-Sánchez, P. Escolar-Reina, An optoelectronic system for measuring the range of motion in healthy volunteers: a cross-sectional study, Medicine 55 (2019), https://doi.org/10.3390/medicina55090516.

[16] T. Neto, L. Jacobsohn, A.I. Carita, R. Oliveira, Reliability of the active-knee-extension and straight-leg-raise tests in subjects with flexibility deficits, 2014–0220, J. Sport Rehabil. Tech. (2015), https://doi.org/10.1123/jsr.2014-0220.

[17] P.A. Clapis, S.M. Davis, R.O. Davis, Reliability of inclinometer and goniometric measurements of hip extension flexibility using the modified Thomas test, Physiother. Theory Pract. 24 (2008) 135–141, https://doi.org/10.1080/09593980701378256.

[18] M.A. Bujang, N. Baharum, A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation coefficient: a review, Arch. Orofac. Sci. 12 (2017) 1–11.

[19] F. Leboeuf, R. Baker, A. Barré, J. Reay, R. Jones, M. Sangeux, The conventional gait model, an open-source implementation that reproduces the past but prepares for the future, Gait Posture 69 (2019) 126–129, https://doi.org/10.1016/j.gaitpost.2019.01.034.

[20] G. Rankin, M. Stokes, Reliability of assessment tools in rehabilitation: an illustration of appropriate statistical analyses, Clin. Rehabil. 12 (1998) 187–199, https://doi.org/10.1191/026921598672178340.

[21] L. Portney, M.M. Watkins, L. Gross Portney, M.M. Watkins, Foundations of Clinical Research: Applications to Practice (3rd Edition), 2015. https://www.pearson.com/us/higher-education/program/Portney-Foundations-of-Clinical-Research-Applications-to-Practice-3rd-Edition/PGM274308.html (accessed December 18, 2020).

[22] P.E. Shrout, J.L. Fleiss, Intraclass correlations: uses in assessing rater reliability, Psychol. Bull. 86 (1979) 420–428, https://doi.org/10.1037/0033-2909.86.2.420.

[23] M.R. Anderson, B.S. Ho, J.F. Baumhauer, Current concepts review, 247301141876446, Foot Ankle Orthop. 3 (2018), https://doi.org/10.1177/2473011418764461.

[24] A.D. Vigotsky, G.J. Lehman, C. Beardsley, B. Contreras, B. Chung, E.H. Feser, The modified Thomas test is not a valid measure of hip extension unless pelvic tilt is controlled, PeerJ 4 (2016), e2325, https://doi.org/10.7717/peerj.2325.

[25] X. Gasparutto, J. Wegrzyk, K. Rose-Dulcina, D. Hannouche, S. Armand, Can the fusion of motion capture and 3D medical imaging reduce the extrinsic variability due to marker misplacements? PLoS One 15 (2020), e0226648 https://doi.org/10.1371/journal.pone.0226648.

[26] A.J. Fenato, L.M. Garcia, G. da, S.C. Perdoná, D.A. Maranho, Measurement of pelvic retroversion during hip flexion: evaluation with accelerometers, Acta Ortop. Bras. 28 (2020) 69–73, https://doi.org/10.1590/1413-785220202801227237.

[27] A. Schmitz, M. Ye, R. Shapiro, R. Yang, B. Noehren, Accuracy and repeatability of joint angles measured using a single camera markerless motion capture system, J. Biomech. 47 (2014) 587–591, https://doi.org/10.1016/J.JBIOMECH.2013.11.031.