Measuring range of motion: an S&C coach's guide to assessing mobility

By **Louis Howe**[1] and **Mark Waldron**[2,3]
[1]Medical and Sport Sciences, University of Cumbria, [2]College of Engineering, Swansea University
[3]School of Science and Technology, University of New England, New South Wales, Australia

OVERVIEW

Strength and conditioning (S&C) coaches must possess a skill set that allows them to assess the physical preparedness of their athletes. This requires the assessment of numerous physical qualities, with testing procedures that produce objective data that are both reliable and valid. Traditionally, assessments for mobility have necessitated palpatory skills that most S&C coaches do not possess, along with the use of specialised equipment. The aim of this article is to illustrate that neither are essential, by providing coaches with the toolbox to execute range of motion (ROM) assessments that will allow them to perform a thorough gap analysis, along with identifying the success of their programmes for improving an athlete's mobility.

Introduction

Mobility is a key physical quality that underpins athletic movement. In instances where a joint's ROM is impaired, an athlete's movement quality may be diminished.[9] Strength and conditioning (S&C) coaches, in many instances, are responsible for screening an athlete's ROM and delivering strategies to improve mobility to support the development of movement quality. Furthermore, prospective studies demonstrate that limited ROM at joints, such as the shoulder complex,[39,40] thoracic spine,[22] hip joint[10,41] and ankle joint[17] may present as a modifiable risk factor for injury – a key consideration for when coaches are designing injury risk management strategies. In order to identify deficits in mobility, coaches must have the skill set to record objective data that represents a joint's ROM in order to perform a gap analysis – a process whereby a coach compares the athlete's current performance levels against established benchmarks. When discrepancies are identified, coaches must also be able to identify changes in ROM following the completion of a corrective programme to establish the success of the intervention. Therefore, the S&C coach's skill set requires an ability to record objective measures of mobility, while appreciating the reliability of the methods used.

Traditionally, joint ROM assessments have been performed using specialised equipment, such as digital inclinometers and goniometers, which require a certain level of experience to acquire accurate data. When using such equipment, practitioners are often required to possess exceptional anatomical knowledge and advanced palpatory skills in order to identify landmarks relevant for testing. However, with the emergence of relatively new technology, non-specialised equipment may provide coaches with a tool that provides objective data for ROM tests that are both reliable and valid. Smartphones

'with the … relatively new technology, non-specialised equipment may provide coaches with a tool that provides objective data for ROM tests'

equipped with gyroscopes, that determine the orientation of the phone in space, allow for the measurement of angular displacement using free applications (eg, iHandy Level, Slope Angle, Clinometer Bubble Level). Recently, the smartphone apps have been shown to provide valid and reliable measurements of joint ROM across a number of clinical assessments.[3,6,9,11,28,37]

Although smartphones have the potential to measure ROM for almost any given joint, some measures still require competence in palpation that may reside outside of many S&C coaches' skill sets. For example, the use of a smartphone has been shown to provide a reliable and valid measure of spinal mobility.[28] However, in order to collect measures of spinal mobility, this investigation required the palpation of numerous spinal segments that many coaches may not be able to perform with their athletes. This may indicate that due to the skills required for data collection, some measures of joint ROM may be unattainable for S&C coaches. Fortunately, evidence-based techniques to measure spinal mobility using a standard tape measure with no palpatory skills required are available.[29]

With more than 90% of the UK population under the age of 54 owning a smartphone in 2018[23] and tape measures available at low cost (under £5), technology to assess an athlete's ROM is clearly readily accessible for most S&C coaches. Therefore, the aim of this article is to provide coaches with a guide for performing isolated assessments for ROM in order to develop and expand their toolbox. Where possible, typical error values for ROM tests using smartphones or tape measures will be presented to support coaches' interpretation. However, these values should be interpreted as a guide only and coaches are encouraged to produce their own reliability data using the procedures outlined.

Although there is scope for testing ROM for any joint segment using a smartphone or tape measure, this article will focus on the following 11 tests, which underpin most fundamental exercises performed in the weight room and cover many of the key joints throughout the kinetic chain:

1. Supine active shoulder flexion test
2. Supine active shoulder rotation test (internal and external)
3. Thoracic spine extension test
4. Lumbar locked rotation test
5. Supine active hip flexion test
6. Thomas test
7. Modified Thomas test
8. Bent knee fallout test
9. Active hip rotation test (internal and external)
10. Active knee extension test
11. Modified weight-bearing lunge test.

Standardisation

For outcome measures to be accurate and reliable in assessing ROM, it is important that testing procedures are standardised.[31] In order to standardise the use of smartphones as a ROM measurement tool, the following considerations should be given:

1. Athletes should be made familiar with the movement technique to prevent learning effects from affecting results.

2. Phone cases should be removed from the smartphone prior to testing. A phone case may have the potential to alter the contours of the phone and, therefore, affect accuracy of the test.

3. The phone should be calibrated against a vertical or horizontal reference point (eg, wall, door frame, table, etc) prior to testing. Most applications allow the measure to be zeroed prior to testing (eg, iHandy Level). It is also important to note that when using the smartphone for measuring angles, the screen lock should be on to prevent the automatic changing between portrait and landscape.

4. At present, little evidence supports the interchangeable use of different phone models for ROM assessments. However, due to the variety in dimensions between smartphones, the same smartphone may need to be used for each test session to maintain test-retest reliability.

5. Although each application utilises the same built-in technology of the phone, the authors are unaware of evidence for the interchangeable use of different applications. The authors recommend coaches initially trial different applications, with one selected for continuous use.

6. Perform each test three times, using the mean of the three measurements to represent ROM.

Unless otherwise specified, all of the following tests used a smartphone as the measuring equipment.

SUPINE ACTIVE SHOULDER FLEXION TEST

Purpose: Shoulder flexion ROM is fundamental to the performance of all overhead movements.[12]

Start position: The athlete lays supine, with the knees flexed to 90° and the plantar surface of the feet flat against the ground. The athlete is cued to posteriorly rotate the pelvis, so as to flatten the spine and prevent contribution to the movement from the lumbar region. The head should be positioned so that the face is looking towards the ceiling and the cervical spine is in a neutral position. The shoulder is flexed to 90°, with the elbows extended and the palms facing each other (Figure 1a).

Movement: The athlete is cued to maximally flex the shoulder by bringing the thumbs towards the ground above the head. Throughout the test, it is important to maintain sagittal plane alignment. As such, coaches should ensure that compensations (eg, shoulder abduction) do not occur that may inflate scores when an athlete presents with limited ROM. Elbows must remain extended and the lumbar spine maintained in a flexed position (Figure 1b).

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall). The smartphone is placed along the upper-arm (triceps brachii), just below the medial epicondyle (Figure 1c). Typical error values using a smartphone for this test are 1.1°.[39]

SUPINE ACTIVE SHOULDER ROTATION TEST (INTERNAL AND EXTERNAL)

Purpose: Shoulder rotation ROM is a modifiable risk factor for shoulder injury in overhead sports.[38,40]

Start position: The athlete lies supine on a plinth, with the knees flexed to 90° and the plantar surface of the feet flat against the table. The athlete is cued to maintain a neutral spine, with the head resting on the plinth positioned so that the face is looking forwards towards the ceiling and the cervical spine is in a neutral position. The shoulder is abducted to 90° (upper arm rests on the plinth), with the elbow flexed to 90° and palm facing down towards the feet (Figure 2a).

Movement: For glenohumeral internal rotation, the athlete is cued to bring the palm towards the floor as far as possible, while preventing the scapula from coming away from the plinth to minimise scapulothoracic contribution (Figure 2b). For glenohumeral external rotation, the athlete is cued to bring the back of the hand towards the floor as far as possible (Figure 2c).

Figure 1a. *Start position*

Figure 1b. *End range for shoulder flexion*

Figure 1c. *Smartphone placement for measurement*

Figure 2a. *Start position*

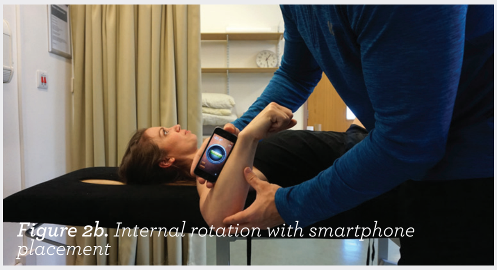


Figure 2b. *Internal rotation with smartphone placement*

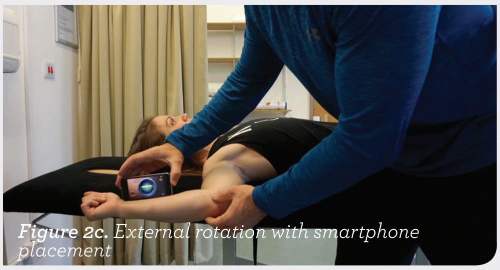


Figure 2c. *External rotation with smartphone placement*

'the use of a smartphone has been shown to provide a reliable and valid measure of spinal mobility'

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall). For internal rotation, the smartphone is placed on the posterior surface of the forearm (extensor side) just below the ulnar styloid process (Figure 2b). For external rotation, the smartphone is placed on the anterior surface of the forearm (flexor side) just below the ulnar styloid process (Figure 2c). Measures of internal and external glenohumeral rotation using a smartphone have a typical error of 6.3° and 3.7°, respectively.[39] These values may be inflated due to a lack of standardisation of phone placement,[39] and therefore coaches following the procedures outlined here may achieve typical error values less than those reported in the literature.

THORACIC SPINE EXTENSION TEST

Purpose: Thoracic spine extension ROM promotes efficient mechanics at the shoulder complex.[7] Reduced thoracic spine extension has also been shown to result in reduced shoulder abduction strength.[15]

Equipment: Tape measure.

Start position: The athlete leans with their back against a bare wall. The feet should be positioned one foot length away from the wall, with the knees slightly flexed. The athlete is cued to posteriorly rotate the pelvis to flatten the spine against the wall and prevent lumbar spine contribution. The head should be touching the wall and the mouth should be closed (Figure 3a).

Figure 3a. Start position

Figure 3b. Measurement of tragus-wall distance

Figure 4a. Start position

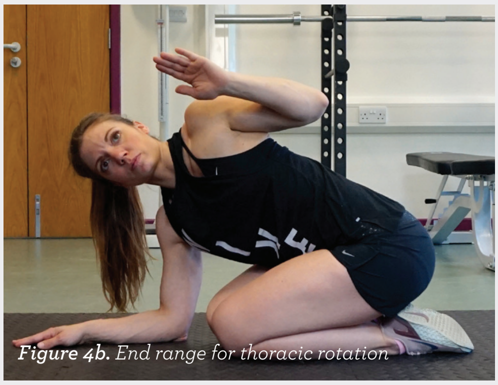


Figure 4b. End range for thoracic rotation

Figure 4c. Smartphone placement for measurement

‘The phone should be calibrated against a vertical or horizontal reference point (eg, wall, door frame, table, etc) prior to testing’

Movement: Maintaining contact between the head and the wall, the athlete is cued to draw the chin towards the chest as far as possible (Figure 3b).

Measurement technique: The distance between the tragus (small pointed eminence covering the auditory meatus (ear canal)) and the wall is measured to the nearest 0.5cm (Figure 3b). Typical error of this test ranges between 0.1 and 0.2cm.[30] Coaches should be aware that this measure will be influenced by periods of maturation and weight gain/loss that do not necessarily relate to thoracic spine mobility, with differences in an athlete's anthropometric dimensions altering the tragus-to-wall distance.[24]

LUMBAR LOCKED ROTATION TEST

Purpose: The lumbar locked rotation test assesses thoracic spine rotation ROM.[3] Axial rotation at the thoracic spine is vital to support shoulder mechanics for athletes competing in rotational sports.[1]

Start position: The athlete kneels with the ankles plantar-flexed so the dorsal surface of the foot contacts the ground. The athlete sits on their heels, while supporting their upper-body mass with their elbows and forearms placed on the ground so the shoulders are flexed to 90°. With the cervical spine in a neutral alignment, the athlete is encouraged to 'lift the chest' to encourage thoracic spine extension. Athletes are instructed to flex the ipsilateral elbow maximally while bringing the forearm off the ground. The elbow is kept by the athlete's side throughout the test (Figure 4a).

Movement: The athlete is cued to rotate as far as possible in the direction to the side with the arm off the floor, whilst maintaining a neutral alignment of the cervical spine (head follows body) and the supporting forearm on the floor (Figure 4b). To prevent thoracic spine rotation ROM from being inhibited due to poor spinal positioning in the sagittal plane, coaches should ensure that athletes maintain an extended thoracic spine alignment ('keep the chest lifted') during the movement.

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall). The smartphone is placed on the spine at the level of C7-T1 (Figure 4c). Although palpating C7-T1 may present as a challenge for S&C coaches, C7-T1 is (in the authors' experience) consistently located at the level of the neckline on a traditional crew neck t-shirt. To the authors' knowledge, no reliability data for thoracic rotation testing using a smartphone has been reported. However, there is a strong relationship between inclinometer and smartphone measurements for thoracic spine rotation measurements ($r = 0.98$, $p < 0.05$).[3] As a result, the typical error of 2.3° reported by Johnson et al[14] using an inclinometer is likely to be relevant.

SUPINE ACTIVE HIP FLEXION TEST

Purpose: Hip flexion ROM underpins many athletic tasks, such as sprinting,[21] jumping[33] and squatting.[32]

Start position: Laying supine on the ground, with both knees extended and the arms by the athlete's side (Figure 5a).

Movement: The athlete is cued to maximally bring the knee of the test limb towards the ipsilateral shoulder, while bending the knee. It is important also to ensure athletes keep the posterior thigh of the non-test limb in contact with the ground to prevent spinal contribution. The coach must also ensure that the athlete maintains a neutral hip alignment in the frontal and transverse plane throughout the movement (Figure 5b).

Figure 5a. Start position

Figure 5b. End range for hip flexion with smartphone placement

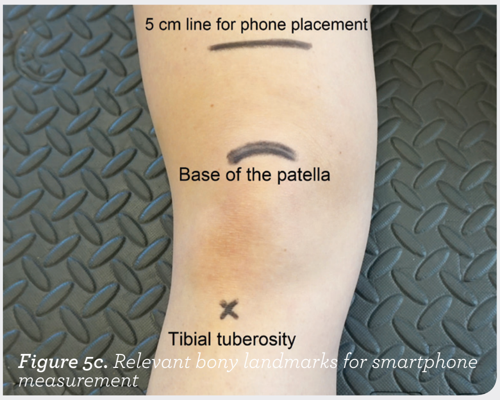


Figure 5c. Relevant bony landmarks for smartphone measurement

'there is a strong relationship between inclinometer and smartphone measurements for thoracic spine rotation measurements'

‘It is therefore recommended that coaches produce their own values of typical error for each test’

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall). In the start position, a horizontal line is marked on the athlete’s thigh, 5 cm above the base of the patella (Figure 5c). The smartphone is placed directly below the marked line at the point of maximal hip flexion. Typical error of this test using a smartphone has been reported to be 2.3°.[6]

THOMAS TEST

Purpose: The Thomas test isolates the uniarticular hip flexor muscles (psoas major, iliacus and tensor fascia latae).

Start position: The athlete lies supine on the ground, with both hips and knees flexed and held in position with each arm. In this position, the athlete should be maximally flexed at both hips to the point that the lumbar spine flexes and the lower back flattens against the ground to ensure a posterior pelvic tilt (Figure 6a).

Movement: While maintaining the hip position for the non-test limb, the athlete is instructed to maximally extend the test limb, as if attempting to lay the leg on the ground. The coach must ensure that the athlete maintains a neutral hip alignment for the test limb, with no abduction/adduction or internal/external rotation allowed at the hip joint. This movement must occur without rotating or shifting the pelvis, which could alter the transverse or frontal plane alignment of the hip joint and lead to reduced accuracy for measuring hip extension.[36]

If coaches are unsure how to check for changes in pelvic alignment, a blood pressure cuff positioned under the athlete’s lumbar spine and inflated to 60 mmHg may be used as a tool for controlling pelvic rotation.[19] During this variation, the athlete must maintain the pressure as they extend the hip.

Measurement technique: Prior to testing, the smartphone is zeroed against a horizontal reference (eg, the top of a door frame). Lying supine with the legs extended, a horizontal line is marked on the athlete’s thigh, 5cm above the base of the patella (Figure 5c). At the point of maximal hip extension, the smartphone is placed directly below the marked line (Figure 6b).

To the authors’ knowledge, there is little evidence for measuring hip extension with the procedures outlined using a smartphone device. However, measures of hip extension during modified Thomas test using a smartphone has previously produced intraclass correlation coefficients for intra-rater reliability as excellent (0.94).[9] Using an inclinometer, typical error of 1° for measures of hip extension Thomas test are commonly found.[5,26]

MODIFIED THOMAS TEST

Purpose: The modified Thomas test attempts to isolate the biarticular rectus femoris muscle. Reduced ROM during the modified Thomas test has been shown to be a risk factor for hamstring strains.[10]

Start position: The athlete lies supine on a

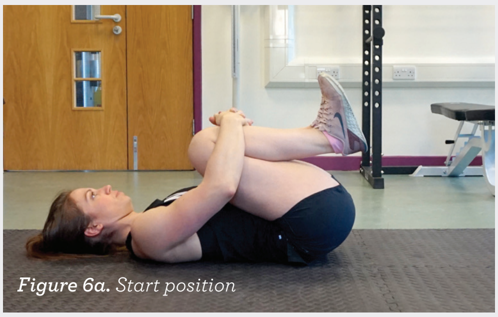


Figure 6a. Start position

Figure 7a. Start position

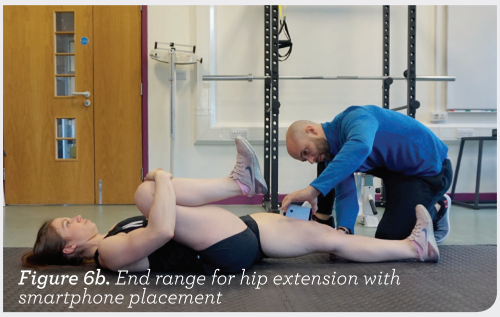


Figure 6b. End range for hip extension with smartphone placement

Figure 7b. End range for knee flexion with smartphone placement

plinth so that when the hips are extended, the back of the thighs are supported by the table but the knee does not make contact with the table. Both hips begin in a flexed position, flattening the lumbar spine and preventing spinal contribution. The athlete is instructed to lower the test limb down into hip extension, with the knee extended until the back of the thigh contacts the table (Figure 7a).

Movement: While maintaining hip alignment for both limbs, the athlete is instructed to flex the knee on the test limb as far as possible, while maintaining hip alignment (Figure 7b). Coaches must monitor pelvic alignment and ensure that no rotation occurs, which may lead to reduced accuracy in measuring hip extension.[36]

Measurement technique: Prior to testing, the smartphone is zeroed against a horizontal reference (eg, the top of a door frame). The smartphone is placed on the anterior border of the tibia below the tibial tuberosity at the point of maximal knee flexion (Figure 7b). Although no reliability data are available for this technique, a similar technique using an inclinometer reported typical error of 2.2-2.8°.[5]

BENT KNEE FALLOUT TEST

Purpose: Bent knee fallout test measures hip abduction ROM. Reduced ROM during the bent knee fallout test has been found in athletes with groin pain[20] and may be useful as a monitoring tool to gauge loading on the adductor musculature.[25] Hip abduction is also important for efficient squat mechanics.[32]

Equipment: Tape measure.

Start position: The athlete is positioned in either an upright seated or supine lying position, with the feet together and the knees flexed to 90° (Figure 8a shows the test performed in a seated position). Whether an athlete is tested in a seated or supine position depends on whether the coach is interested in hip abduction capacity with the hip in a flexed or extended alignment, respectively. For example, squatting requires the hip to flex and concurrently abduct.[32] Therefore, the seated bent knee fallout test may be more relevant to determine abduction capacity for this pattern.

Movement: The athlete is instructed to allow their knees to fallout to the side and, as they do so, bring the soles of the feet together (Figure 8b). Athletes are encouraged to 'pull the knees as close to the floor as possible'. Knee angle must be maintained throughout and coaches should monitor pelvic alignment by ensuring the athlete keeps their lower back in contact against the wall.

Measurement technique: In clinic, measurement to the nearest 0.5 cm is taken for the distance of the fibula head to the surface of the plinth.[18] However, many coaches may lack the skill set to palpate the fibula head. As a result, the authors recommend measuring the distance between the tibial tuberosity, a more prominent and identifiable landmark, and the ground (Figure 8b). To improve accuracy, mark the apex of the tibial tuberosity for both limbs in the start position (Figure 5c). Following the active hip abduction movement, the coach should measure both sides to the nearest 0.5 cm. Intra-rater typical error for fibula head-plinth distance has been reported to be 1 cm.[18]

ACTIVE HIP ROTATION TEST (INTERNAL AND EXTERNAL)

Purpose: Reduced hip rotation ROM may be a risk factor for lower-extremity injuries.[35]

Start position: The athlete is positioned on the edge of a plinth, with the knees flexed at 90° and the lower legs freely hanging off the table. For this test, athletes may perform the test in either a seated of supine position, depending on whether hip rotation is of interest in a hip flexed or extended position, respectively.[6] For both internal and external rotation, the non-test leg is placed over the

Figure 8a. Start position

Figure 8b. End range for hip abduction

call out

lateral edge of the plinth by abducting the hip (Figure 9a).

Movement: The athlete is instructed to maximally rotate the foot away from (hip internal rotation) or towards (hip external rotation) the midline of their body, while maintaining a 90° flexed position at the knee (Figure 9b and 9c, respectively). Coaches must ensure that no compensatory motion occurs at the hip or knee of the test leg.

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall) and a horizontal line is made 10 cm above the inferior tip of the lateral malleolus.[18] For both internal and external rotation, the smartphone is placed directly above the marked line (Figure 9b and 9c).[16] Typical error of hip internal and external rotation measurements in both seated and supine positions using a smartphone are approximately 3°.[6]

ACTIVE KNEE EXTENSION TEST

Purpose: The active knee extension test is used to measure biarticular hamstrings length. Reduced hamstring extensibility negatively impacts the hip hinge pattern during lifting tasks[4] and is a possible risk factor for lower-extremity injuries in athletic populations.[41]

Start position: The athlete lies supine on the ground, with both legs extended and flat on the ground and the arms by the athlete's side. The test limb is then flexed at the hip and knee to 90° and foot positioned in a neutral alignment (Figure 10a).

Movement: The athlete is cued to maximally extend the knee, while maintaining hip alignment. The athlete must keep the majority of the non-test limb against the ground in order to prevent spinal contribution. The coach must also ensure that the athlete maintains a neutral hip alignment in the frontal and transverse plane throughout the movement, with the foot and ankle remaining in a neutral position (Figure 10b).

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall). At the point of maximal knee extension, the smartphone is placed on the anterior border of the tibia below the tibial tuberosity (Figure 10b). Typical error has been reported to be 3.3° for the active knee extension test using a smartphone device.[11]

MODIFIED WEIGHT-BEARING LUNGE TEST

Purpose: The modified weight-bearing lunge test measures ankle dorsiflexion ROM. As this test is performed with a bent knee, values represent extensibility of the uniarticular plantar flexors (eg, soleus) and ankle joint mobility. Limited ankle dorsiflexion ROM is a risk factor for a number of lower-extremity injuries.[27] For example, reduced ankle dorsiflexion ROM has been shown to increase the risk of developing patellar tendinopathy in volleyball players.[17] Reduced ankle dorsiflexion ROM may limit squat depth[16] and, therefore, is likely to be of interest to the S&C coach.

Start position: The athlete starts in a half-

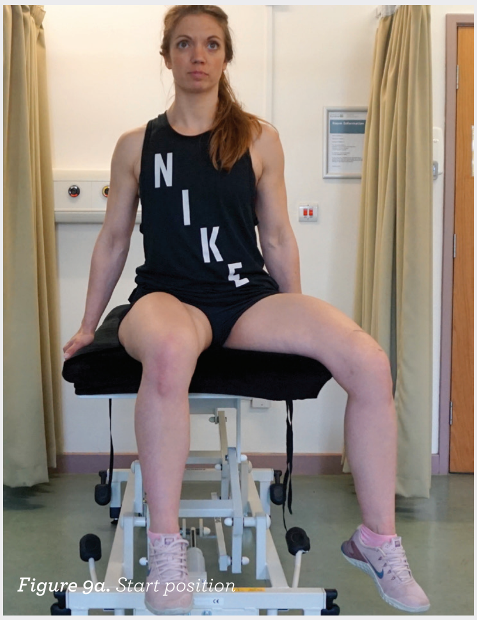


Figure 9a. Start position

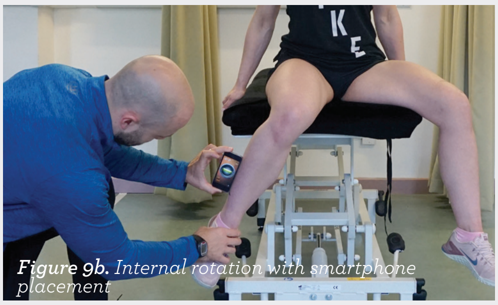


Figure 9b. Internal rotation with smartphone placement

Figure 9c. External rotation with smartphone placement

call out

kneeling position, with the pelvis facing forwards and the trunk relatively upright (some forward lean is allowed). The test foot is positioned half a foot length ahead of the knee of the non-test leg, with the knee aligned directly over the foot on the test limb. Many athletes may require additional support for balance and, therefore, placing the hands against a relatively stable object (ie, a wall) is permitted (Figure 11a).

Movement: The athlete is instructed to reach the knee forward as far as possible, while keeping the knee over the foot, the heel down against the ground and the pelvis facing forward (Figure 11b). The coach should be positioned on the inside of the athlete to ensure the heel remains in full contact with the ground. Although the use of an elastic band under the heel has been suggested as a method to monitor heel rise during the weight-bearing lunge test,[29] the authors suggest this technique is avoided. In the authors' experience of using this method, scores for the weight-bearing lunge test are grossly exaggerated, possibly due to joint segments distal to the ankle contributing to the forward rotation of the tibia. This occurs as considerable unloading of the heel is allowed before a loss in tension results in the elastic band coming out from under the foot. Instead, coaches are suggested to visually monitor heel rise, a technique shown to have excellent reliability during a variation of this test.[13] Lastly, coaches should also monitor the shape of the medial longitudinal arch during the test. A collapse of the medial longitudinal arch represents pronation of the foot that may result in dorsiflexion occurring through the midtarsal joints,[2,34] potentially inflating scores.

Measurement technique: Prior to testing, the smartphone is zeroed against a vertical reference (eg, a wall). At the point of maximal ankle dorsiflexion just prior to heel-lift, the smartphone should be placed on the anterior border of the tibia below the tibial tuberosity (Figure 11b). Intra-rater reliability for measuring ankle dorsiflexion ROM during the weight-bearing lunge test with a smartphone has a typical error of 1°.[37]

Calculating typical error for ROM tests

Although coaches can depend on values of absolute reliability from the literature, it is important to note that the skill level of the tester, the population tested and subtle changes in the testing procedures may influence these values and as such, lead to a misinterpretation of findings. It is therefore recommended that coaches produce their

'S&C coaches who follow the procedures outlined herein are adequately equipped to measure athletes' ROM for any given structure'


Figure 10a. *Start position*


Figure 11a. *Start position*

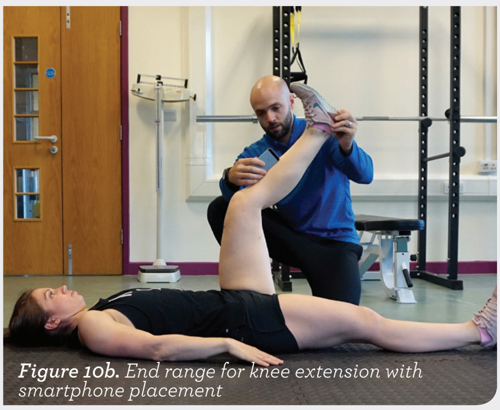


Figure 10b. *End range for knee extension with smartphone placement*


Figure 11b. *End range ankle dorsiflexion with smartphone placement*

Table 1. Modified weight-bearing lunge test data for 10 athletes from two separate testing days and the between-session absolute difference

	TEST DAY 1 (°)	TEST DAY 2 (°)	TEST-RETEST DIFFERENCE (°)
Athlete 1	35.5	34.1	-1.4
Athlete 2	41.3	41.4	0.1
Athlete 3	43.2	42.8	-0.4
Athlete 4	25.3	25.9	0.6
Athlete 5	37.3	36.5	-0.8
Athlete 6	40.4	39.7	-0.7
Athlete 7	26.4	26.9	0.5
Athlete 8	33.3	33.7	0.4
Athlete 9	36.9	37.3	0.4
Athlete 10	44.6	45.6	1.0
Mean	**36.4**	**36.4**	**0.0**
Standard deviation	**6.6**	**6.5**	**0.8**

own values of typical error for each test. A brief example is provided to demonstrate how typical error can be calculated from data for the modified weight-bearing lunge test using the procedures previously described. Ten athletes were tested five days apart, with the mean of three measurements used to represent each athlete's ankle dorsiflexion ROM for that day. Table 1 presents the scores for each athlete for both test day 1 and test day 2, along with test-retest difference. The standard deviation of the test-retest difference is used to calculate typical error with the following equation:

Typical error = Standard deviation of the test-retest difference / ffl2

Typical error = 0.8° / ffl2

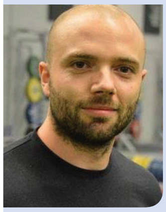
Typical error = 0.6°

Therefore, typical error for the modified weight-bearing lunge test in this example is 0.6°. Using the procedures outlined here, coaches can calculate typical error for all tests shown. To further develop an understanding for determining reliability and establishing real change, it is recommended coaches see Spence and Cushion.[31]

Conclusion

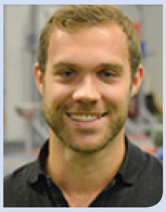
As mobility underpins many athletic activities, an athlete's capacity for this quality should be of interest to the S&C coach when assessing athletes for the initial gap analysis and for monitoring athletes to identify the success of the training programme. The skill set required to produce objective data of ROM scores for various anatomical regions has relied on experience in the use of specialised equipment, excellent anatomical knowledge and palpatory skills that not all S&C coaches may possess. However, this article has highlighted a number of assessments that may be used to measure ROM for key movements, with no specialised equipment and minimal palpatory skills. As a result, S&C coaches who follow the procedures outlined herein are adequately equipped to measure athletes' ROM for any given structure, which might be necessary to identify movement deficits or changes elicited by mobility programmes. Additionally, coaches who quantify measures of error (ie, typical error) will be better equipped to appreciate changes in mobility that are not due to random variation associated with their testing procedures.

AUTHORS' BIOGRAPHIES



LOUIS HOWE, MSC, ASCC

Louis has been coaching athletes of all levels for over ten years. He is currently a lecturer at the University of Cumbria for the Sport Rehabilitation undergraduate programme. Academically, he is currently completing his PhD, investigating restrictions in ankle dorsiflexion range of motion and its effect on landing mechanics



DR MARK WALDRON

Mark is a senior lecturer in sport and exercise sciences, Swansea University, College of Engineering.

References

1. Aguinaldo AL, Buttermore J, and Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *Journal of Applied Biomechanics* 23: 42-51. 2007.
2. Blackwood CB, Yuen TJ, Sangeorzan BJ, and Ledoux WR. The midtarsal joint locking mechanism. *Foot and Ankle International* 26: 1074-1080. 2005.
3. Bucke J, Spencer S, Fawcett L, Sonvico L, Rushton A, and Heneghan NR. Validity of the digital inclinometer and iphone when measuring thoracic spine rotation. *Journal of Athletic Training* 52: 820-825. 2017.
4. Carregaro RL, and Coury HJCG. Does reduced hamstring flexibility affect trunk and pelvic movement strategies during manual handling?. *International Journal of Industrial Ergonomics* 39: 115-120. 2009.
5. Cejudo A, de Baranda PS, Ayala F, and Santonja F. Test-retest reliability of seven common clinical tests for assessing lower extremity muscle flexibility in futsal and handball players. *Physical Therapy in Sport* 16: 107-113. 2015.
6. Charlton PC, Mentiplay BF, Pua YH, and Clark RA. Reliability and concurrent validity of a Smartphone, bubble inclinometer and motion analysis system for measurement of hip joint range of motion. *Journal of Science and Medicine in Sport* 18: 262-267. 2015.
7. Crosbie J, Kilbreath SL, and Dylke E. The kinematics of the scapulae and spine during a lifting task. *Journal of Biomechanics* 43: 1302–1309. 2010.
8. Dill KE, Begalle RL, Frank BS, Zinder SM, and Padua DA. Altered knee and ankle kinematics during squatting in those with limited weight-bearing-lunge ankle-dorsiflexion range of motion. *Journal of Athletic Training* 49: 723-732. 2014.
9. Doinn TÓ, Whyte E, O'Connor S, Downey M, and McCaffrey N. Reliability of smartphone goniometric measurements of the modified Thomas test using biofeedback stabilisation—a preliminary report. *Mesentery and Peritoneum* 2: 136. 2018.
10. Gabbe BJ, Finch CF, Bennell KL, and Wajswelner H. Risk factors for hamstring injuries in community level Australian football. *British Journal of Sports Medicine* 39: 106-110. 2005.
11. Hansberger BL, Loutsch R, Hancock C, Bonser R, Zeigel A, and Baker RT. Evaluating the relationship between clinical assessments of apparent hamstring tightness: a correlational analysis. *International Journal of Sports Physical Therapy* 14: 253–263. 2019.
12. Howe LP, and Blagrove RC. Shoulder function during overhead lifting tasks: Implications for screening athletes. *Strength and Conditioning Journal* 37: 84-96. 2015.
13. Howe LP, Bampouras TM, North J, and Waldron M. Ankle dorsiflexion range of motion is associated with kinematic but not kinetic variables related to bilateral drop-landing performance at various drop heights. *Human Movement Science* 64: 320-328. 2019.
14. Johnson KD, Kim KM, Yu BK, Saliba SA, and Grindstaff TL. Reliability of thoracic spine rotation range-of-motion measurements in healthy adults. *Journal of Athletic Training* 47: 52-60. 2012.
15. Kebaetse MS, McClure P, and Pratt NA. Thoracic position effect of shoulder range of motion, strength and three-dimensional scapular kinematics. *Archives of Physical Medicine and Rehabilitation* 80: 945–950. 1999.
16. Kim SH, Kwon OY, Park KN, Jeon IC, and Weon JH. Lower extremity strength and the range of motion in relation to squat depth. *Journal of Human Kinetics* 45: 59-69. 2015.
17. Malliaras P, Cook JL, and Kent P. Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. *Journal of Science and Medicine in Sport* 9: 304-309. 2006.
18. Malliaras P, Hogan A, Nawrocki A, Crossley K, and Schache A. Hip flexibility and strength measures: reliability and association with athletic groin pain. *British Journal of Sports Medicine* 43: 739-744. 2009.
19. Moreside JM, and McGill SM. Quantifying normal 3D hip ROM in healthy young adult males with clinical and laboratory tools: hip mobility restrictions appear to be plane-specific. *Clinical Biomechanics* 26: 824-829. 2011.
20. Mosler AB, Weir A, Hölmich P, and Crossley KM. Which factors differentiate athletes with hip/groin pain from those without? A systematic review with meta-analysis. *British Journal of Sports Medicine* 49: 810-810. 2015.
21. Novacheck TF. The biomechanics of running. *Gait and Posture* 7: 77-95. 1998.
22. Norlander S, Gustavsson BA, Lindell J, and Nordgren B. Reduced mobility in the cervico-thoracic motion segment--a risk factor for musculoskeletal neck-shoulder pain: a two-year prospective follow-up study. *Scandinavian Journal of Rehabilitation Medicine* 29: 167-174. 1997.
23. Ofcom. (n.d.). UK: smartphone ownership by age from 2012-2018. In Statista - The Statistics Portal. Retrieved June 18, 2019, from https://www.statista.com/statistics/271851/smartphone-owners-in-the-united-kingdom-uk-by-age/.
24. Ozaras N, Gulec MG, Celik HKA, Demir SE, and Guler M. Effect of body shape on tragus-to-wall distance in the normal population. *Clinical Rheumatology* 33: 1169-1171. 2014.
25. Paul DJ, Nassis GP, Whiteley R, Marques JB, Kenneally D, and Chalabi H. Acute responses of soccer match play on hip strength and flexibility measures: potential measure of injury risk. *Journal of Sports Sciences* 32: 1318-1323. 2014.
26. Peeler J, and Anderson JE. Reliability of the Thomas test for assessing range of motion about the hip. *Physical Therapy in Sport* 8: 14-21. 2007.
27. Pope R, Herbert R, and Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in army recruits. *Australian Journal of Physiotherapy* 44: 165–172. 1998.
28. Pourahmadi MR, Taghipour M, Jannati E, Mohseni-Bandpei MA, Takamjani IE, and Rajabzadeh F. Reliability and validity of an iPhone® application for the measurement of lumbar spine flexion and extension range of motion. *PeerJ* 4: e2355. 2016.
29. Škarabot J, Beardsley C, and Štirn I. Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes. *International Journal of Sports Physical Therapy* 10: 203-212. 2015.
30. Shipe NK, Billek-Sawhney B, Canter TA, Meals DJ, Nestler JM, and Stumpff JL. The intra-and inter-rater reliability of the tragus wall distance (TWD) measurement in non-pathological participants ages 18–34. *Physiotherapy Theory and Practice* 29: 328-334. 2013.
31. Spence A, and Cushion E. Determining reliability: a data collection guide for S&C practitioners. *Professional Strength and Conditioning Journal* 36: 27-33. 2015.
32. Swinton PA, Lloyd R, Keogh JW, Agouris I, and Stewart AD. A biomechanical comparison of the traditional squat, powerlifting squat, and box squat. *The Journal of Strength and Conditioning Research* 26: 1805-1816. 2012.
33. Taylor JB, Ford KR, Nguyen AD, and Shultz SJ. (2016). Biomechanical comparison of single-and double-leg jump landings in the sagittal and frontal plane. *Orthopaedic Journal of Sports Medicine* 4: 2325967116655158. 2016.
34. Tiberio D, Bohannon RW, and Zito MA. Effect of subtalar joint position on the measurement of maximum ankle dorsiflexion. *Clinical Biomechanics* 4: 189-191. 1989.
35. Verrall GM, Slavotinek JP, Barnes PG, Esterman A, Oakeshott RD, and Spriggins AJ. Hip joint range of motion restriction precedes athletic chronic groin injury. *Journal of Science and Medicine in Sport* 10: 463-466. 2007.
36. Vigotsky AD, Lehman GJ, Beardsley C, Contreras B, Chung B, and Feser EH. The modified Thomas test is not a valid measure of hip extension unless pelvic tilt is controlled. *PeerJ* 4: e2325. 2016
37. Vohralik SL, Bowen AR, Burns J, Hiller CE, and Nightingale EJ. Reliability and validity of a smartphone app to measure joint range. *American Journal of Physical Medicine and Rehabilitation* 94: 325-330. 2015.
38. Walker H, Gabbe B, Wajswelner H, Blanch P, and Bennell K. Shoulder pain in swimmers: a 12-month prospective cohort study of incidence and risk factors. *Physical Therapy in Sport* 13: 243-249. 2012.
39. Werner BC, Holzgrefe RE, Griffin JW, Lyons ML, Cosgrove CT, Hart JM, and Brockmeier SF. Validation of an innovative method of shoulder range-of-motion measurement using a smartphone clinometer application. *Journal of Shoulder and Elbow Surgery* 23: 275-282. 2014.
40. Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, Evans TJ, and Andrews JR. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. *The American Journal of Sports Medicine* 43: 2379-2385. 2015.
41. Witvrouw E, Danneels L, Asselman P, D'Have T, and Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players: a prospective study. *The American Journal of Sports Medicine* 31: 41-46. 2003.