Journal of Athletic Training 2021;56(12):1355–1361
doi: 10.4085/564-20

www.natajournals.org

A Novel Method of Assessing Trunk Lateral-Flexion Range of Movement in First-Class Cricket Players

Andrew Nealon, PhD*; Jill Cook, PhD†; Sean Docking, PhD†

*Aspire Physiotherapy Centre, Holgate, New South Wales, Australia; †La Trobe University, Melbourne, Victoria, Australia

Context: Lateral-flexion range of movement (LF ROM) is used to assess and monitor recovery of side strain injury in athletes.

Objective: To establish a reliable and pragmatic measure of LF ROM and investigate the stability of the measure over time in athletes.

Design: (1) Cross-sectional reliability study and (2) cohort longitudinal study.

Setting: Elite cricket teams in Australia and England.

Patients or Other Participants: Ten healthy first-class cricket players recruited from Australia and England domestic and international competitions.

Main Outcome Measures: (1) The intrarater and interrater reliability of 2 methods of measuring LF ROM toward and away from the bowling arm was assessed (distance to the floor or distance to the fibular head). Three experienced physiotherapists obtained the measures. Intraclass correlations [2,1] were calculated for absolute agreement for all 3 testers. (2) Lateral-flexion ROM was measured monthly during the preseason and competitive season. A 1-way repeated-measures analysis of variance was performed to identify differences within the preseason, within the competitive season, and between competitive seasons.

Results: Both methods had good intratest and intertest reliability (intraclass correlations > 0.84). As LF ROM measurement to the floor was easier for clinicians, it was used for the longitudinal study. Lateral-flexion ROM did not alter throughout the preseason and competitive season or between seasons (P values $> .05$).

Conclusions: This new method of measuring LF ROM demonstrated good intrarater and interrater reliability and stability over time and can be used as an outcome measure in side strain injury.

Key Words: side strain injury, reliability, athletes

Key Points

- Trunk side strain occurs in throwing athletes and can be persistent and recurrent.
- Trunk lateral flexion is a clinical outcome measure used to assess the response to treatment and readiness to return to play after injury.
- Trunk lateral flexion can be measured simply and reliably with this standardized clinical test.

Side strain injury is common in throwing and bowling athletes, with internal or external oblique, intercostal, or rib muscle strains accounting for 92% of these injuries. A review of 23 Major League Baseball disability lists indicated the occurrence of 393 side strain injuries, accounting for 5% of all injuries over a 20-year period.[1] Side strain injury also affects cricket fast bowlers and had the second highest incidence and third highest prevalence of all injury types in Australian first-class cricket players over 18 years of age in 2013–2014 (Figure 1).[2]

Daily life seldom requires extremes of lateral-flexion range of motion (LF ROM).[3] However, throwing and bowling are repetitive, strenuous, and asymmetric tasks. In a 3-dimensional kinematic study of professional first-class bowlers, the bowling action induced 30% more trunk LF ROM during the front-foot phase of the delivery stride than standing.[4] For baseball pitchers, the proposed moment of injury is the late cocking or early acceleration stage of throwing.[5] Authors[6] of a kinematic study showed that the most demanding moment for the trunk during pitching was near the instant of front-foot contact. This was the moment when maximum trunk rotation and high trunk axial acceleration were produced, implying high torque.

Diagnosis of side strain injury is clinical, based on the mechanism of injury and localized tenderness over the lateral trunk near or over the rib cage, but clinical practices of assessing this injury vary.[7] Lateral-flexion ROM may be the simplest and most widely used measure for quantifying the severity of side strain injury. However, no current consensus exists on a reliable and feasible method of obtaining this measurement in the clinical setting. Several methods of measuring LF ROM of the trunk and lumbar spine have been described in both clinical and sporting populations, with reliability varying from poor to excellent and little consensus on the most reliable method.[4,8–26] In 1 review,[26] the researchers even suggested no reliable way of measuring it existed. Further, some investigators used a single measurement method, whereas others averaged multiple measures. Some of these methods may be viable in the laboratory, but their utility is limited for the clinician, who requires convenient and quick methods in practice.[14]

It is essential that a reliable method of measuring LF ROM and measurement variations during and between seasons be established before its utility as a potential predictor of injury, clinical assessment test, and predictor of prognosis and recurrence can be determined. In this study,

Figure 1. Cricket fast bowling action demonstrating the jump, back-foot contact, and follow through (left to right). Left center image demonstrates a common delivery point where bowler side strain injury is likely to occur. Image courtesy of Cricket Australia.

we aimed to examine the reliability of LF ROM via 2 methods (measurement of the finger to the floor [FLR] and measurement of the finger to the fibular head [FIB]). The second aim was to examine the variations in LF ROM during the preseason and competitive season and between seasons.

METHODS

Ethics approval for this study was granted by 2 university human research ethics committees, and all participants supplied written informed consent.

Reliability

Participants. Ten first-class cricket players from the same English county team (6 fast bowlers, 1 spin bowler, and 3 specialist batsmen [mean age = 26.8 years, mean height = 182.7 cm]) attended 1 testing session. Five of the fast bowlers had previously sustained a side strain injury, including 1 who underwent rib resection 5 years earlier. Recruits were included if they were free of any injury that would affect training or participation in competitive matches at the time of testing. Participants had not bowled in a competitive match on the day of testing, as this might have affected the results. They were excluded if inactive in competitive cricket for any reason.

Figure 2. Starting and finishing positions for testing active trunk lateral-flexion range of motion.

Test Description. The barefoot participant stood with his side to a flat wall, feet hip-width apart, with the base of the fifth metatarsal and greater trochanter touching the wall. The arm adjacent to the wall was abducted overhead and the elbow comfortably flexed so that this arm was not pushing the participant away from the wall. The individual was instructed to "slowly run your fingers down the outside of your leg and reach as far as you can while continuing to look straight ahead." He maintained contact with the wall at both lower limb points and kept both feet and heels flat on the floor at all times. The participant was given specific instructions and tactile feedback to keep the lateral border of the foot in contact with the wall (Figure 2). The physiotherapist stood near the participant's feet to ensure compliance with this instruction. The individual laterally flexed at the trunk without trunk or hip flexion or extension. The measurement was obtained in both directions: toward and away from the bowling arm. Two methods of determining ROM were performed for comparison of reliability: FLR and FIB.

The measurements were conducted by 3 experienced first-class cricket team physiotherapists (13, 6, and 8 years of experience) using a retractable tape measure (Nurses Tape Measure; Medisave). Testing was completed in a single session to prevent potentially confounding of the data due to time-of-day variations and activity between testing sessions. Each physiotherapist tested each participant in a randomized order for both trials to demonstrate intrarater reliability. After every measurement, the physiotherapist ensured that the ROM mark on the participant's leg was completely removed using an alcohol wipe. Each measurement was taken for a separate movement, rather than having multiple testers measure the same movement. This introduces the variable of the actual difference

between movements in addition to the reliability of the measurement technique between and within testers.

Repeated Measurements in and Between Seasons

Participants. Participants were recruited from men's professional cricket teams in Australia and England. They were included if they were aged 18 years or older and selected as a fast bowler. A total of 24 teams were invited to take part (each team had approximately 5 fast bowlers), and data were provided by 72 participants in season and 49 participants between seasons. At the start of data collection, each person's age, standing height, bowling arm, and number of previous side strain injuries were recorded. Only data on injury-free bowlers were included.

Measurements. The physiotherapists for each team recorded the ROM of participants on each occasion. Lateral-flexion ROM measured from the floor was first obtained 3 months before the start of the preseason (month -3) and repeated at intervals not exceeding 1 month until the fourth month of the competitive season (month 4) in year 1. During years 2 and 3, the first measure was taken at the start of preseason (month -3) and repeated at intervals not exceeding 1 month until the first month of the competitive season (month 1). Measurements were taken before any bowling on that day. Measurement points were labeled according to their timing either before or after each bowler's competitive season.

Within-Preseason Variation. Changes in ROM within the preseason were assessed at 3 time points**.** The latest measures were taken in the month before the start of each bowler's respective competitive season. The prior measures were taken not more than 1 month apart.

Within-Competitive Season Variation. Changes in ROM within the competitive season were assessed at 5 time points**.** The first measure was taken in the month before the start of each bowler's respective competitive season. The subsequent measures were taken not more than 1 month after each preceding measure.

Between-Competitive Seasons Variation. Changes in ROM between competitive seasons were assessed at 3 time points**.** Each measure was taken in the first month of each bowler's respective competitive season over successive seasons.

Statistical Analyses

Reliability. Reliability was calculated on a single-measure basis (SPSS, version 27.0.1.0; IBM Corp) to match the clinical setting, in which ROM was only measured once. Intrarater and interrater reliability was determined using the intraclass correlation (ICC) with 95% CIs, SD, standard error of measurement (SEM), and minimum detectable change (MDC) in both directions. Reliability was reported as *poor* ($>$ 0.5), *moderate* (0.5–0.75), *good* (0.75–0.9), or *excellent* ($>$ 0.9) based on published criteria.[27] The SEM indicates the amount of variability in a test due to measurement error, whereas *MDC* is the smallest amount of change that represents real change beyond measurement error. Statistics were calculated for both FIB and FLR. Absolute agreement was chosen over consistency.

Intrarater and interrater reliability was calculated for all 3 testers using a 2-way random-effects model looking for absolute agreement based on a single (first) measure of each tester.

The SEM provides an absolute index of reliability, in the same units as the measurement, thereby quantifying the precision of the test scores. We determined the SEM from the square root of the mean square error value generated from a 1-way repeated-measures analysis of variance.[28] The MDC was calculated using the formula MDC = SEM $\times$ 1.96 $\times \sqrt{2}$.

Repeated Measurements in and Between Seasons. Range of motion was identified using FLR due to ease of measurement. A lower number represents a larger magnitude of motion. Ranges presented are minimum to maximum. Unless stated otherwise, all data were normally distributed for all time points (Shapiro-Wilk significance value $>$.05). Data were analyzed for seasonal variation using a 1-way repeated-measures analysis of variance. Given the asymmetric demands of the bowling action and potentially different effects of past side strain injury on the behavior of ROM in either direction, data for the directions toward and away from the bowling arm were considered independently. Cases with any missing time points were excluded. Unless specified otherwise, sphericity was assumed for all significance values because the Mauchly test values were $>$.05. Differences in ROM between time points were mapped on a scatterplot to highlight individual variations in LF ROM, with 95% confidence bands based on the SEM for interrater reliability using the FLR.

RESULTS

Reliability

Intrarater Reliability. Intrarater reliability for all raters was good to excellent when LF ROM FLR and FIB were measured both toward and away from the bowling arm (Table 1). The FLR ICCs were marginally higher than the FIB ICCs for all 3 raters. The MDC for the FLR was lower for all 3 raters when measuring LF ROM away from the bowling arm. Much greater MDC variation was present among raters for measures toward than away from the bowling arm.

Interrater Reliability. Interrater reliability demonstrated similar ICCs for the FLR and the FIB, both toward (FLR = 0.91, FIB = 0.84) and away from (FLR = 0.96, FIB = 0.94) the bowling arm. The MDCs for away from the bowling arm were almost identical for the FLR and FIB (FLR away = 28 mm, FIB away = 27 mm, FLR toward = 41 mm, FIB toward = 48 mm).

Repeated Measurements In and Between Seasons

Data were collected over 3 years from the start of the England County cricket season in 2011 and the Australia State cricket season in 2011–2012. A total of 1736 ROM measurements were taken of 238 first-class cricket fast bowlers by physiotherapists for all 24 first-class teams and each national team from Australia and England. Data received from national teams were distributed to the sets for each bowler's domestic first-class team. Data for bowlers who changed teams between seasons were transferred to the team dataset in which the bowler began the data-collection period.

Table 1. Intrarater Reliability for Measurement to Floor and Fibula

	Measurement to							
	Floor				Fibula			
		mm				mm		
Tester	ICC (95% CI)	SEM	MDC	Mean ± SD	ICC (95% CI)	SEM	MDC	Mean ± SD
Away from bowling arm								
1	0.96 (0.80–0.99)	10	28	491 ± 50	0.95 (0.79–0.99)	10	28	−4 ± 44
2	0.97 (0.87–0.99)	10	28	489 ± 50	0.94 (0.78–0.98)	10	29	−3 ± 38
3	0.95 (0.82–0.99)	11	31	480 ± 53	0.90 (0.66–0.97)	12	34	−1 ± 38
Toward bowling arm								
1	0.98 (0.91–0.99)	7	21	482 ± 48	0.96 (0.84–0.99)	8	23	−1 ± 43
2	0.94 (0.79–0.99)	13	36	479 ± 56	0.94 (0.80–0.98)	11	32	4 ± 50
3	0.89 (0.63–0.97)	16	44	475 ± 49	0.87 (0.58–0.97)	14	38	4 ± 35

Abbreviations: ICC, intraclass correlation; MDC, minimum detectable change; SEM, standard error of measurement.

Within-Preseason Variation. Complete ROM datasets were obtained from 56 bowlers (24% of cohort, mean age = 24.4 years [range = 18–36 years], mean standing height = 188.7 cm [range = 175–203 cm]) from 9 teams at 3 time points in a single preseason. There were 49 right-arm and 7 left-arm bowlers; data were analyzed as toward and away from the bowling arm to account for this. Twenty-seven bowlers had a history of side strain injury: 22 bowlers had 1 injury, 4 bowlers had 2 injuries, and 1 bowler had 3 injuries. No difference in ROM existed either toward or away from the bowling arm or among the 3 time points, with P values $>.05$ (Table 2). A total of 84% of measurements toward the bowling arm and 67% of measurements away from the bowling arm varied within the 95% CIs such that an individual's ROM varied due to the systematic error of the measurement (Supplement 1).

Within-Competitive Season Variation. Complete data were provided by 72 bowlers (30% of cohort, mean age = 25.1 years [range = 18–39 years], mean height = 187.2 cm [range = 173.6–204 cm]) from 13 teams at 5 time points in a single competitive season. There were 61 right-arm and 11 left-arm bowlers. Thirty-nine bowlers had a history of side strain injury: 30 bowlers had 1 injury, and 9 bowlers had 2 injuries.

No difference in ROM existed away from the bowling arm or among any of the 5 time points, with P values $> .05$ (Table 3). However, a difference in ROM occurred toward the bowling arm among the 5 time points. Post hoc pairwise comparisons revealed that the active trunk (AT) LF ROM toward the bowling arm was different between months 1 and 4 ($P < .01$). Yet the mean difference (15.8 mm) was smaller than the MDC for the ROM test. Therefore, the AT LF ROM both toward and away from the bowling arm did not vary more than the measurement error from the final month of preseason and within the competitive season. Seventy-six percent of measurements toward the bowling arm and 62% of measurements away from the bowling arm varied within the 95% CIs such that an individual's ROM varied due to the systematic error of the measurement (Supplement 2).

Between-Competitive Seasons Variation. There were 49 bowlers (21% of cohort, mean age = 25.4 years [range = 18–37 years], mean standing height = 188.5 cm [range = 176.0–204 cm]) from 14 teams with complete datasets for 3 time points being the first measure in 3 consecutive competitive seasons. A total of 42 were right-arm and 7 were left-arm bowlers. A history of side strain injury was present in 31 bowlers: 25 bowlers had 1 injury, 4 bowlers had 2 injuries, 1 bowler had 3 injuries, and 1 bowler had 4 injuries.

No difference in ROM existed, either toward or away from the bowling arm, among the 3 time points, with P values $> .05$ (Table 4). Sixty-six percent of measurements toward the bowling arm and 51% of measurements away from the bowling arm varied within the 95% CIs such that an individual's ROM varied due to the systematic error of the measurement (Supplement 3). Therefore, LF ROM within the first month of the competitive season did not vary.

DISCUSSION

In this study, we describe a new simple and reliable method of measuring AT LF ROM. The reliability of previous methods has varied from poor to excellent, with some of those methods requiring expensive and cumbersome equipment.[1] Further, LF ROM in professional cricket players was shown to be consistent during the preseason and competitive season and between seasons. Establishing the reliability and natural variation of LF ROM is a critical step in understanding its role in the clinical assessment,

Table 2. Lateral-Flexion Range of Motion of 56 Cricket Players Both Away From and Toward the Bowling Arm at Monthly Intervals During the Preseason (n = 56)

	Lateral-Flexion Motion Away From and Toward the Bowling Arm, Monthly Interval					
	Away From			Toward		
Measure, mm	−3	−2	−1	−3	−2	−1
Mean ± SD	495 ± 49	489 ± 56	492 ± 50	490 ± 51	485 ± 55	485 ± 54
Range[a]	620–415	620–370	620–372	610–391	610–390	640–380

[a] Range demonstrated significant values, but no changes were observed.

Table 3. Lateral-Flexion Range of Motion of 72 Cricket Players Both Away From and Toward the Bowling Arm at Monthly Intervals From Preseason End (Month −1) to \ Competitive Season End (Month 4)

Movement With Respect to Bowling Arm, mm	Month				
	−1	1	2	3	4
Away from					
Mean ± SD	495 ± 57	466 ± 61	472 ± 77	471 ± 65	476 ± 64
Range	600–335	575–320	600–320	604–330	620–330
Toward[a]					
Mean ± SD	467 ± 53	457 ± 61	466 ± 60	466 ± 57	472 ± 60
Range	570–330	560–327	560–310	585–330	605–330

[a] Post hoc analysis revealed a range-of-motion difference toward the bowling arm between months 1 and 4.

screening, and prognosis of side strain injuries among cricket and throwing athletes.

Reliability

Lateral-flexion ROM measured with this novel method has been demonstrated to have good to excellent intrarater and interrater reliability. The MDC was smallest for the method to the floor for most measures. Reliability statistics were similar for the direction toward the bowling arm and away. Toward the bowling arm indices of interrater reliability were comparable with those for intrarater reliability. Greater variability existed for the direction away from the bowling arm.

The levels of reliability identified in this study are consistent with those of Ng et al (2001),[17] who used a custom-built pelvic-restraint device. We suggest that our method was similarly reliable with the distinct advantages of simplicity, minimal equipment, and time, as a single measure can be completed within 30 seconds. This is important in the clinical and sporting settings when assessing a patient in pain and screening many players.

Side listing of the pelvis and lumbar spine is a common coupling movement with LF of the trunk and lumbar spine. A tendency to deviate in the sagittal and horizontal planes has previously been reported to reduce the reliability of the LF ROM measurement compared with sagittal movements.[29] Standing in close proximity to and facing a wall did not improve reliability.[29] The lack of complete pelvic fixation limiting free motion of the pelvis in terms of sagittal rotation was also noted to contribute to the poor reproducibility of computerized measuring equipment.[9] The participant's desire as well as the instructions to reach to maximize ROM may also encourage hip and spine flexion. The novel method we described overcomes the concern about side listing by insisting that the participant's lateral foot and greater trochanter maintain contact with the wall, thus providing a physical block. The instruction for the participant to maintain a straight-ahead gaze was also considered helpful, which has been observed earlier.[29] This necessitates that the participant avoid cervical and, consequently, trunk and hip flexion, optimizing the purity of the LF movement.

Several strengths of the measurement method to the floor exist. First, the measurement is an objective measure of distance that does not require palpation of any bony landmarks. This distance is a direct measure to the floor with no skin movement under a measurement tool. The measure is noninvasive, and the only equipment required in a wall and tape measure. The good to excellent reliability of the test is based on a single measure, making it quick to implement in the clinical context. Another major strength of the measurement method is its simplicity. Two of the 3 testers in this study had no previous experience using the test; they received only a written and pictorial description and a single demonstration before performing the measurements. The method has now been shown to have good to excellent reliability, and its SEM and MDC have been determined and can be factored into research and clinical decisions. These are essential steps for implementation of the test in prospective research and clinical practice.

Variation Between Measurements

Range of motion did not vary during measurements 1 month apart within the preseason, within the competitive season, or among 3 competitive seasons. Side strain occurs frequently in the initial months of the season.[30] This suggests that the increased demands of transition from training to competition may be a contributing factor.

For the clinician who is managing athletes at risk of sustaining side strain injuries, our work has certain implications. The lack of variation in ROM within the preseason and competitive season and between seasons indicates that a baseline measure taken in the 3 months before the start of the competitive season is consistent not only during the season but also during subsequent seasons.

This study was methodologically robust, with a prospective study design and large dataset. Good to excellent levels of intrarater and interrater reliability existed, the measure-

Table 4. Lateral-Flexion Range of Movement of 49 Cricket Players Both Away From and Toward the Bowling Arm in the First Month of 3 Successive Competitive Seasons

	Movement With Respect to Bowling Arm, Season					
	Away From			Toward		
Measure, mm	1	2	3	1	2	3
Mean ± SD	495 ± 49	488 ± 61	483 ± 48	476 ± 59	485 ± 53	478 ± 47
Range[a]	620–415	632–345	580–375	580–340	630–365	580–380

[a] Range showed significant values, but no changes were observed.

ments were consistent with how tests are used clinically, and the participants were representative of a clinical population. The findings provide a pragmatic and simple measurement tool that clinicians can use both clinically and in a sporting context.

A limitation of this study was that the AT LF ROM test has not yet been shown to be reliable in injured players, unlike the active knee-extension and passive knee-extension tests for hamstrings injury.[31] Also, missing data reduced the size of the cohorts for each analysis. However, for this study, we were dependent on the contributions of many physiotherapists working within the time constraints of the first-class cricket season, and measures taken more than 1 calendar month apart or on injured players were excluded.

In summary, with this research, we provide clinicians with a reliable and simple way to evaluate LF ROM in a time-efficient manner. The results may improve clinicians' measurement techniques and reproducibility of LF assessment, which enables its use as a screening tool and an outcome measure after injury. Authors of future studies could investigate the progression of LF ROM during recovery from side strain injury and determine if it is a criterion measure for return to sport.

CONCLUSIONS

We demonstrated good to excellent intrarater and interrater reliability of a novel method of measuring LF ROM that is simple and quick to use in the clinical setting. This measurement did not vary during or between preseasons or competitive seasons in a large cohort of uninjured first-class cricket fast bowlers. These findings provide a basis for future prospective researchers to investigate LF ROM as a predictor of injury, clinical assessment test, and predictor of recovery time and recurrence after side strain injury.

REFERENCES

1. Conte SA, Thompson MM, Marks MA, Dines JS. Abdominal muscle strains in professional baseball 1991–2010. *Am J Sports Med*. 2012;40(3):650–656. doi:10.1177/0363546511433030
2. Orchard J, Kontouris A, Sims K, Orchard J, Beakley D, Brukner P. Cricket Australia 2014 Injury Report. *Sport Health*. 2014;32(4):14–18.
3. Mellin G. Physical therapy for chronic low back pain: correlations between spinal mobility and treatment outcome. *Scand J Rehabil Med*. 1985;17(4):163–166.
4. Ranson CA, Burnett AF, King M, Patel N, O'Sullivan PB. The relationship between bowling action classification and three-dimensional lower trunk motion in fast bowlers in cricket. *J Sports Sci*. 2008;26(3):267–276. doi:10.1080/02640410701501671
5. Steven KJ, Crain JM, Akizuki KH, Beaulieu CF. Imaging and ultrasound-guided steroid injection of internal oblique muscle strains in baseball pitchers. *Am J Sports Med*. 2010;38(3):581–585. doi:10.1177/0363546509350105
6. Fleisig GS, Hsu WK, Fortenbaugh D, Cordover A, Press JM. Trunk axial rotation in baseball pitching and batting. *Sports Biomech*. 2013;12(4):324–333. doi:10.1080/14763141.2013.838693
7. Nealon AR, Kountouris A, Cook JL. Side strain in sport: a narrative review of pathomechanics, diagnosis, imaging and management for the clinician. *J Sci Med Sport*. 2017;20(3):261–266. doi:10.1016/j.jsams.2016.08.016
8. American Medical Association. *Guides to the Evaluation of Permanent Impairment*. 3rd ed. AMA Press; 1990.
9. Dillard J, Trafimow J, Andersson G, Cronin K. Motion of the lumbar spine reliability of two measurement techniques. *Spine (Phila Pa 1976)*. 1991;16(3):321–324. doi:10.1097/00007632-199103000-00011
10. Batti'e MC, Bigos SJ, Sheehy A, Wortley MD. Spinal flexibility and individual factors that influence it. *Phys Ther*. 1987;67(5):653–658. doi:10.1093/ptj/67.5.653
11. Klein AB, Snyder-Mackler L, Roy SH, DeLuca CJ. Comparison of spinal mobility and isometric trunk extensor forces with electromyographic spectral analysis in identifying low back pain. *Phys Ther*. 1991;71(6):445–454. doi:10.1093/ptj/71.6.445
12. Dopf CA, Mandel SS, Geiger DF, Mayer PJ. Analysis of spine motion variability using a computerized goniometer compared to physical examination a prospective clinical study. *Spine (Phila Pa 1976)*. 1994;19(5):586–595. doi:10.1097/00007632-199403000-00015
13. Mellin G. Measurement of thoracolumbar posture and mobility with a Myrin inclinometer. *Spine (Phila Pa 1976)*. 1986;11(7):759–762. doi:10.1097/00007632-198609000-0001
14. Mellin GP. Accuracy of measuring lateral flexion of the spine with a tape. *Clin Biomech (Bristol, Avon)*. 1986;1(2):85–89. doi:10.1016/0268-0033(86)90081-1
15. Moll JM, Liyanage SP, Wright V. An objective clinical method to measure lateral spinal flexion. *Rheumatol Phys Med*. 1972;11(5):225–239. doi:10.1093/rheumatology/11.5.225
16. Merritt JL, McLean TJ, Erickson RP, Offord KP. Measurement of trunk flexibility in normal subjects: reproducibility of three clinical methods. *Mayo Clin Proc*. 1986;61(3):192–197. doi:10.1016/s0025-6196(12)61848-5
17. Ng JK, Kippers V, Richardson CA, Parnianpour M. Range of motion and lordosis of the lumbar spine: reliability of measurement and normative values. *Spine (Phila Pa 1976)*. 2001;26(1):53–60. doi:10.1097/00007632-200101010-00011
18. Reynolds PM. Measurement of spinal mobility: a comparison of three methods. *Rheumatol Rehabil*. 1975;14(3):180–185. doi:10.1093/rheumatology/14.3.180
19. Newton M, Waddell G. Reliability and validity of clinical measurement of the lumbar spine in patients with chronic low back pain. *Physiotherapy*. 1991;77(12):796–800. doi:10.1016/S0031-9406(10)61906-2
20. Nitschke JE, Nattrass CL, Disler PB, Chou MJ, Ooi KT. Reliability of the American Medical Association guides' model for measuring spinal range of motion. Its implication for whole-person impairment rating. *Spine (Phila Pa 1976)*. 1999;24(3):262–268. doi:10.1097/00007632-199902010-00013
21. Dimnet J, Fischer LP, Gonon G, Carret JP. Radiographic studies of lateral flexion in the lumbar spine. *J Biomech*. 1978;11(3):143–150. doi:10.1016/0021-9290(78)90006-4
22. Frost M, Stuckey S, Smalley LA, Dorman G. Reliability of measuring trunk motions in centimeters. *Phys Ther*. 1982;62(10):1431–1437. doi:10.1093/ptj/62.10.1431
23. Gottlieb H, Strite LC, Koller R, et al. Comprehensive rehabilitation of patients having chronic low back pain. *Arch Phys Med Rehabil*. 1977;58(3):101–108.
24. Mellin G, Härkäpää K, Hurri H. Asymmetry of lumbar lateral flexion and treatment outcome in chronic low-back pain patients. *J Spinal Disord*. 1995;8(1):15–19.
25. Michel A, Kohlmann T, Raspe H. The association between clinical findings on physical examination and self-reported severity in back pain. Results of a population-based study. *Spine (Phila Pa 1976)*. 1997;22(3):296–303; discussion 303–304. doi:10.1097/00007632-199702010-00013
26. Lankhorst GJ, van de Stadt RJ, Vogelaar TW, van der Korst JK, Prevo AJ. Objectivity and repeatability of measurements in low back pain. *Scand J Rehabil Med*. 1982;14(1):21–26.

27. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155–163. doi:10.1016/j.jcm.2016.02.012
28. Bland JM, Altman DG. Measurement error. *BMJ*. 1996;313(7059):744. doi:10.1136/bmj.313.7059.744
29. Mellin G, Kiiski R, Weckström A. Effects of subject position on measurements of flexion, extension, and lateral flexion of the spine. *Spine (Phila Pa 1976)*. 1991;16(9):1108–1110. doi:10.1097/00007632-199109000-00016
30. Humphries D, Orchard J, Kontouris A. Abdominal wall injuries at the elite level in Australian male professional cricketers. *J Postgrad Med Educ Res*. 2015;49(4):155–158. doi:10.5005/jp-journals-10028-1167
31. Reurink G, Goudswaard GJ, Oomen HG, et al. Reliability of the active and passive knee extension test in acute hamstring injuries. *Am J Sports Med*. 2013;41(8):1757–1761. doi:10.1177/0363546513490650

Address correspondence to Jill Cook, PhD, La Trobe University, Melbourne, Victoria 3086, Australia. Address email to J.Cook@latrobe.edu.au.