Clinical methods to quantify trunk mobility in an elite male surfing population

Furness, James; Climstein, Mike; Sheppard, Jeremy M.; Abbott, Allan; Hing, Wayne

Published in:
Physical Therapy in Sport

DOI:
10.1016/j.ptsp.2015.09.003

TRUNK MOBILITY IN THE SAGITTAL AND HORIZONTAL PLANES: CLINICAL METHODS TO QUANTIFY MOVEMENT IN AN ELITE MALE SURFING POPULATION

ABSTRACT

Background: High numbers of acute shoulder and chronic lumbar injuries have been identified in a surfing population. A simple screening tool could be used to determine whether thoracic spine dysfunction is a possible contributor to shoulder or lumbar injuries. Importantly, thoracic mobility in the sagittal and horizontal planes are key requirements in the sport of surfing; however to date the normal values of these movements have not yet been quantified in a surfing population.

Objectives: To develop a reliable method to quantify thoracic mobility in the sagittal plane; to assess the reliability of a thoracic rotation method, and quantify thoracic mobility in an elite surfing population.

Design: Clinical Measurement, reliability (repeated measures) and comparative study.
Methods: 27 subjects were used to determine the reliability of a new method to assess thoracic mobility in the sagittal plane and 30 subjects were used to confirm the reliability of an existing thoracic rotation method. A total of 15 elite surfers were used as part of a comparative analysis with age and gender matched controls. Results: Intra-rater reliability (within and between session) intraclass correlation coefficient (ICC) values ranged between 0.95 - 0.99 for both thoracic methods in the sagittal plane and between 0.95 – 0.98 for the rotation method. There was no significant difference in the amount of thoracic mobility in the sagittal plane between groups; however the elite surfing group had significantly ($p \leq 0.05$) greater rotation than the comparative group (mean rotation 63.57° versus 40.80° respectively). Symmetry was also confirmed between left and right thoracic rotation in the elite surfing group (63.06 versus 64.01).
Conclusion: This study has illustrated reliable methods to assess the thoracic spine in the sagittal and horizontal planes. It has also quantified ROM in a surfing cohort; identifying thoracic rotation as a key movement. This information may provide clinicians, coaches and athletic trainers with imperative information regarding the importance of maintaining adequate thoracic rotation and symmetry. From a screening perspective thoracic rotation should be assessed for performance purposes and to limit the potential for injury in the thoracic spine or in surrounding regions.

KEY WORDS: Thoracic, range of motion, extension, rotation, surfing

INTRODUCTION

It appears that the thoracic spine is a region which has been neglected when it comes to the consensus on gold standard clinical methods to measure range of motion (ROM) (Edmondston et al., 2012; Johnson & Grindstaff, 2010). One of the difficulties of determining ROM in the thoracic region is that multiple joints above and below contribute to thoracic spine ROM (Kuo, Tully, & Galea, 2009). The thoracic movements of interest have generally been in the sagittal and horizontal planes; especially when considering the coronal orientation of the thoracic facets joints which favour rotation.

Physiotherapists usually attempt to utilize musculoskeletal screening measures that are specific to the sport the athlete participates in; however methods used must be standardised and shown to be reliable and valid (Spurrier, 2015). Generally, the premise behind musculoskeletal screening is three fold. This involves identifying limitation or asymmetry, enhancing performance and identifying injury prone regions (Spurrier, 2015). It would be deemed appropriate that athletes whose sports have a significant amount of stress on the thoracic spine would require a clinical method to assess this region.

In the case of surfing the thoracic spine is a key region which is stressed; especially considering that reduced range of motion may result in stress on surrounding joints and potentially affect performance (Furness et al., 2014). The sport of surfing can be broken down into three key phases; paddling (45% of the time), sitting (50% of the time) and actual wave riding (5% of the time) (Farley, Harris, & kilding, 2012; Meir, Lowdon, & Davie, 1991). During paddling the thoracic spine must be held in a prolonged extended position to allow for adequate arm clearance (Everline, 2007). A reduction in thoracic extension during paddling could potentially result in greater pressure via extension occurring at the lumbar spine or cervical spine (Furness et al., 2014). It could also result in greater shoulder abduction and extension to clear the water, thus causing shoulder impingement. During actual wave riding, thoracic rotation is a critical movement to assist in producing torque during turning manoeuvres (see Figure 1)(Everline, 2007). The surfer rotates towards the wave during the bottom turn and away from the wave during the top turn. During these movements the thoracic spine also flexes during the bottom turn and extends during the top turn; a combination of ROM and strength is needed with this movement. It could be suggested that for high-performing surfers, limitations in thoracic extension and rotation would result in the athlete ‘turning out of their lower back’, something that is generally identified as poor-scoring technique, and injurious.

When designing a surf specific musculoskeletal screen it is imperative to look at injury prone regions and specific joints which are under stress during the activity. Furness et al. (2014) revealed the two key areas with the highest frequency of chronic injury were the shoulder and lumbar spine. With regards to acute injuries the shoulder has been shown to have the highest frequency of injuries (Furness et al., 2015). The thoracic spine serves as a link between these two locations and could be a contributing factor to injuries sustained in both the lumbar spine and shoulder. Poor thoracic mobility has been associated with increased cervical pain and lumbar pain (O'Gorman & Jull, 1987) and shoulder pathology (Lewis & Valentine, 2010). Treatment directed at the thoracic spine has been associated with improvements in a range of musculoskeletal conditions including cervical and shoulder pathologies (Iveson, McLaughlin, Todd, & Gerber, 2010). An inability to attribute these findings to improvements in thoracic ROM may be due to the lack of feasible and reliable clinical methods to quantify thoracic ROM (Iveson et al., 2010).

It could be proposed that the poor thoracic mobility or excessive kyphosis during paddling could cause the scapulae to be protracted and downwardly rotated leading to potential compression of the subacromial tissues (subacromial bursa and rotator cuff tendons). This could also result in compensatory cervical extension or lumbar extension while paddling. It could be speculated that reduced thoracic rotation could result in greater stresses placed on the lumbar spine and hips. Simple screening measures to assess the thoracic spine could potentially rule in or out this region as a possible contributor.

A thorough systematic literature review (accessing Pubmed, EMBASE, CINAHL, and SPORT-Discuss). was conducted to identify clinical tests which could be used in assessing thoracic extension and rotation. When reviewing literature around thoracic extension large variations existed in the ROM expressed, the actual test position, clinical devices used and the starting position. Due to the large discrepancies it was deemed appropriate to design a new sports specific method to determine thoracic mobility in the sagittal plane. The literature around thoracic rotation revealed less variation with ROM expressed, starting positions and devices used (Furness, 2015). The lumbar locked position was determined an appropriate method to quantify thoracic rotation as it is easily applied clinically and requires minimal equipment. Therefore the purpose of this study was to establish a reliable method to quantify thoracic movement in the sagittal plane; to assess the reliability of the lumbar locked method (thoracic rotation) and quantify thoracic mobility in an elite surfing population.

Figure 1: An example of thoracic rotation during a top turn manoeuvre adapted from ASP (2014)

METHODS

Subjects

Reliability testing was completed on 27 individuals for the thoracic methods in the sagittal plane and 30 subjects for the rotation method; a sample size of 15-20 is often used in reliability studies with continuous data (Lexell & Downham, 2005). Participants were asked to complete a subjective questionnaire reporting age and injury history. This was done to gather background and demographical information about participants. The study was approved by the Bond University Ethics committee (RO1610) and informed consent was gained from all participants. Subjects were eligible for the study if they were between the ages of 18 – 75 and able to adopt the starting position (four point kneeling with hips and knees in maximal flexion).

Exclusion criteria included any acute or chronic spinal pathology (in the past 3 months) that may be aggravated or worsened through repeated testing of thoracic extension, flexion and rotation. Based on these aforementioned criteria, no participants were excluded. Participants were between the ages of 20 and 57 years with the mean age being 30.83 ± 10.96 years. A total of 27 subjects (12 males and 15 females) were utilised to determine the reliability of the thoracic methods in the sagittal plane with the average age being 31.69 ± 11.52 years (range 20 to 57). A total of 30 subjects (16 females and 14 males) with a mean age of 30.84 ± 10.96 years (range 20 to 57) were used for determining reliability of the thoracic rotation method.

Comparative analysis was completed on 15 elite surfers, all of which were males with a mean age of 26.47 ± 4.59 years (range 18 to 34 years). Five of the male surfers were competing on the World Championship tour (WCT) which involves the top 32 ranked surfers in the world. The remaining surfers were competing on the World Qualifying Series (WQS) ranked in the top 100 surfers in the world.

Raters

The evaluators were two Physiotherapists, one with seven years of clinical experience in the assessment and treatment of orthopaedic conditions and the other a new graduate Physiotherapist. The new graduate performed all measurements and the other physiotherapist recorded; this was done to ensure blinding occurred throughout all measurements. Data collection began in January 2014 and concluded in February 2014.

Equipment

Inclinometer

A standard gravity dependent inclinometer (Universal Inclinometer, model UI01, Performance Attainment Associates, Minnesota, United States) was used for all range of motion measurements. For thoracic rotation a horizontal reference point was used to ensure an accurate zero starting point, this was also established through the use of a bubble level.

HALO

The HALO (model HG1, HALO Medical Devices, Australia) is a new device on the market and is promoted as a digital way of recording joint range of motion. This device works through the use of magnets and accelerometers and is said to provide measures in the sagittal, coronal and transverse planes. The same HALO device was used for all joint range of motion measures in this study. To our knowledge, there is currently no available research investigating the reliability and validity of this device in measuring range of motion.

Tape Measure

A standard medical tape measure was used with a centimetre scale on one side and an inch scale on the other; this was used for the assessment of thoracic mobility in the sagittal plane only.

Design

The two evaluators participated in a one hour formal training session prior to data collection. The training session was undertaken by a physiotherapist with post graduate qualifications in musculoskeletal physiotherapy. Participants were provided with verbal instruction and performed the required movement three times as a warm up under the guidance of the assessors; this was done in order to minimise the risk of a learning effect. This procedure was standardised for all testing and we believe offered no mobilisation effect. Prior to all testing both T1, T1/2 and T12 were marked on each subject. As previously used by Lewis and Valentine (2010) T1 was identified by asking the subject to maximally flex their cervical spine; the most protruding spinous process was identified as C7 and T1 was directly inferior to this. If C6 and C7 was difficult to distinguish the subject was asked to flex and extend their cervical spine while continuing to palpate C7; if the spinous process was not felt to disappear in extension C7 was confirmed. In order to identify T12 the superior aspect of the subject's iliac crest was palpated and both thumbs were directed medially to meet at the spine. The intervertebral level palpated was determined as L4/5; this method was adapted from previous research (Kellis, Adamou, Tzilios, & Emmanouilidou, 2008). Once the L4/5 level was determined the evaluator counted superiorly to T12 and this level was marked.

Thoracic mobility in the sagittal plane:

The participant was positioned in sitting on an adjustable medical bed with their knees flexed at 90 degrees and both feet positioned on the floor. Hands were clasped together and were placed on the back of the neck to minimize cervical movement; both elbows remained horizontal and facing forwards. The participant then flexed the entire spine dropping both elbows directly downward. The verbal instruction given involved asking the participant to bend their entire spine by dropping their elbows in a downward direction as far as possible. As hip movement could potentially increase the amount of flexion both elbows were closely monitored to ensure they did not move in a forwards direction. Once a maximally flexed position was attained, this was considered the starting position and a tape measure was placed from T1 to T12 to record the starting position.

The participant then extended their entire spine by pointing both arms upwards as far as possible with the tape measure placed on the same landmarks and the distance recorded (A and B in Figure 2). The verbal instruction given involved asking the participant to extend their entire spine by pointing their elbows in an upward direction as far as possible. The final measure was subtracted from the initial measure and represented the total range of thoracic mobility in the sagittal plane. The criteria for "failure" of the required movements involved the participant being unable to maintain a maximally flexed or extended position to allow for measurement or additional movement in the coronal or horizontal planes. If this occurred the participant was corrected and the movement was repeated.

The same procedure was utilized with a HALO device, which was placed at T1/2 and 'zeroed' at the starting position (C in Figure 2). The participant then maximally extended their spine by pointing their elbows upwards with the amount of thoracic mobility recorded on the inclinometer or HALO (D in Figure 2). T1/2 was chosen as the landmark for this assessment method as it has previously been used for measuring thoracic mobility in the sagittal plane (Lee et al., 2003; O'Gorman & Jull, 1987). It needs to be noted that the HALO method does not distinguish between lumbar or thoracic movement and is considered to assess thoracolumbar mobility in the sagittal plane. A second HALO device could have been placed on T12/L1 and movement here subtracted from the total range, however this was considered time consuming for the clinician and a global method was chosen as an alternative technique.

The tape measure method was adapted from the distraction method used in the lumbar spine (Tousignant, Poulin, Marchand, Viau, & Place, 2005) where a line is drawn connecting both posterior iliac spines and a mark on the lumbar spine 15cm superior to this. The subject in standing then extends backwards with the distance between the two markers recorded. It was deemed appropriate to use a sitting position as this has been shown to bias the thoracic spine in the sagittal plane (Mellin, Kiiski, & Weckstrom, 1991). The justification for measuring extension from a maximally flexed position was that this method is not influenced by neutral kyphosis and difficulties with determining a standardised starting position are negated. The tape measure method also allows for associated lumbar movement to occur, however the thoracic spine is isolated as only the change in distance from T1 to T12 is measured. An alternative method using a HALO device was also applied in this study; however this movement assesses thoracolumbar mobility as there is no attempt to remove lumbar movement.

Figure 2: Thoracic mobility in the sagittal plane. A) represents the starting position for the tape measure method; B) end position for tape meaure; C) starting position for HALO metohod and D) end position for HALO method.

<u>Thoracic rotation method:</u>

The method chosen to measure thoracic rotation is known as the lumbar locked position (Johnson, Kim, Yu, Saliba, & Grindstaff, 2012). Here the participant is required to assume a four point kneeling position with both knees and hips in maximal flexion. The participant then places both elbows on the ground in contact with both knees; the elbows should be flexed at 90 degrees. The participant then places their hand on their neck and rotates the thoracic spine towards this side. The examiner must ensure that the arm that is not in contact with the ground maintains the same starting position (shoulder flexed to 90 degrees and hand on neck) throughout the rotation movement. An inclinometer is placed on T1/2 and the measurement is recorded at end range of rotation; both left and right rotation is measured (see Figure 3). The verbal instruction involved asking the participant to rotate their trunk while keeping one elbow fixed on the floor. The criteria for "failure" of the required movements involved the participant being unable maintain full flexion of the hips and knees or maintain the contralateral elbow on the ground or the angle of the ipsilateral elbow was not the same as the starting position. If this occurred the participant was corrected and the movement was repeated.

Each participant presented for two sessions on the same day for testing. The evaluators obtained two active ROM measurements with the inclinometer for each session. The two sessions were separated by a time period of 3 hours and subjects were instructed to avoid any stretching or exercise during this time period.

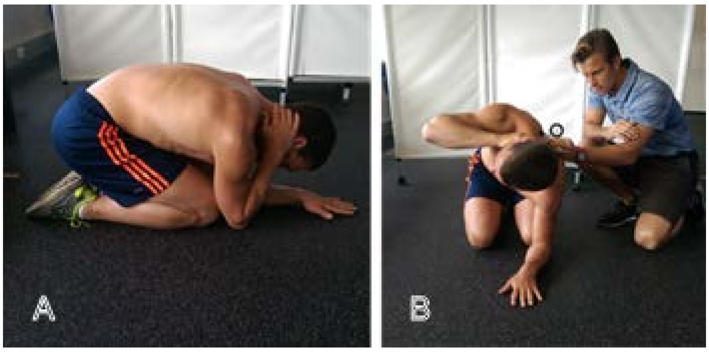

Figure 3: Thoracic rotation methods. A) Represents the starting position for the lumbar locked method using an inclinomteter; B) Right thoracic rotation with the lumbar locked method.

Data Analysis

Data analysis was performed with SPSS version 20.0. Descriptive statistics including means, standard deviations and ranges were calculated for each measure and for each session. The initial purpose of this study was to determine the reliability of two clinical methods to determine thoracic ROM. The intraclass-correlation coefficient (ICC) was used to reflect the reliability of the measures (Lexell & Downham, 2005). Fleiss (1986) recommended that ICC values >0.75 represent "excellent reliability" and values between 0.4-0.7 represent "fair to good reliability". A two way mixed model was used to determine reliability between measure one and measure two within the same session ($ICC_{3,1}$). The inter-session reliability was determined between the average of two measures from each session ($ICC_{3,2}$). This model was used because this investigator was the only tester of interest.

ICC values may be high despite poor trial to trial consistency if the inter-subject variability is too high (Lexell & Downham, 2005). To negate this issue the standard error of measurement (SEM) was used as this is not affected by inter-subject variability. The SEM was calculated using the formula SEM = √WMS (Hopkins, 2000; Lexell & Downham, 2005), where WMS is the mean square error term from the analysis of variance. The smallest real difference (SRD_{95}) was also calculated to determine the magnitude of change that would exceed the threshold of measurement error at the 95% confidence level. The formula used was SRD = 1.96 x SEM x √2 (Safrit & Wood, 1989). To calculate the level of agreement between sessions a one-sample t test was used which determines if any systematic bias was present. To calculate the 95% levels of agreement the formula mean diff – 1.96 x SD was applied. Data was then presented graphically through the use of Bland Altman plots.

The second purpose of this study was to quantify thoracic mobility in elite surfers. An independent *t*-test and the non-parametric Mann Whitney U test were used for comparative analysis between the elite surfing group and the age and gender matched controls.

RESULTS

Thoracic mobility in the sagittal plane

The within and between session intra-rater reliability analysis with ICC values, SEM and SRD are displayed in Table 1. ICC values ranged between 0.96 - 0.99 and were all within excellent reliability ranges (> 0.75) according to recommendations of Fleiss (1986).

Table 1: Within and between session intra-rater reliability analysis for thoracic mobility methods in the sagittal plane

	ICC average	95% CI of ICC	SEM†	SRD†
Tape measure (within session)	0.96	0.91 – 0.98	0.44	1.22
Tape measure (Between session)	0.95	0.88 – 0.98	0.49	1.36
HALO (within session)	0.99	0.97 – 0.99	2.92	8.08
HALO (between session)	0.98	0.95 0.99	3.86	9.21

†Tape measure values are in centimetres; and HALO measures are in degrees.

In order to determine agreement between session one and session two, Bland Altman plots were conducted for both the tape measure (Figure 4) method and the HALO method (Figure 5). Firstly, for the tape measure method the differences between session one and session two were analysed using a one sample *t*-test; assuming the mean difference would be zero (null hypothesis). A mean difference of 0.05cm was calculated which was insignificant ($p = 0.70$, $t = 0.39$) confirming the null hypothesis. This was also the case for the HALO method with a mean difference of 1.42 degrees ($p = 0.19$).

Figure 4 presents a Bland Altman plot of the tape measure method for between session reliability. The middle horizontal line presents the mean difference between session one and session two (0.05) and the lines above and below are the 95% confidence limits; these were calculated off the formula mean diff – 1.96 x SD. A regression analysis revealed no significant ($p = 0.43$) bias in the distribution of data points either side of the mean difference between session one and two.

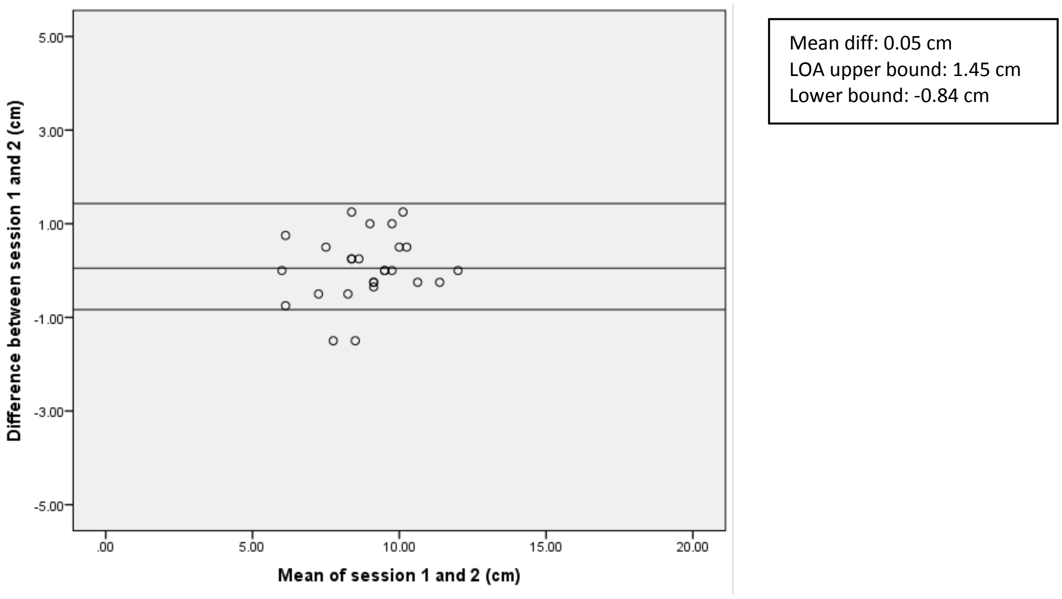

Figure 4: Bland-Altman plot for between session intra-rater reliability for the tape measure method

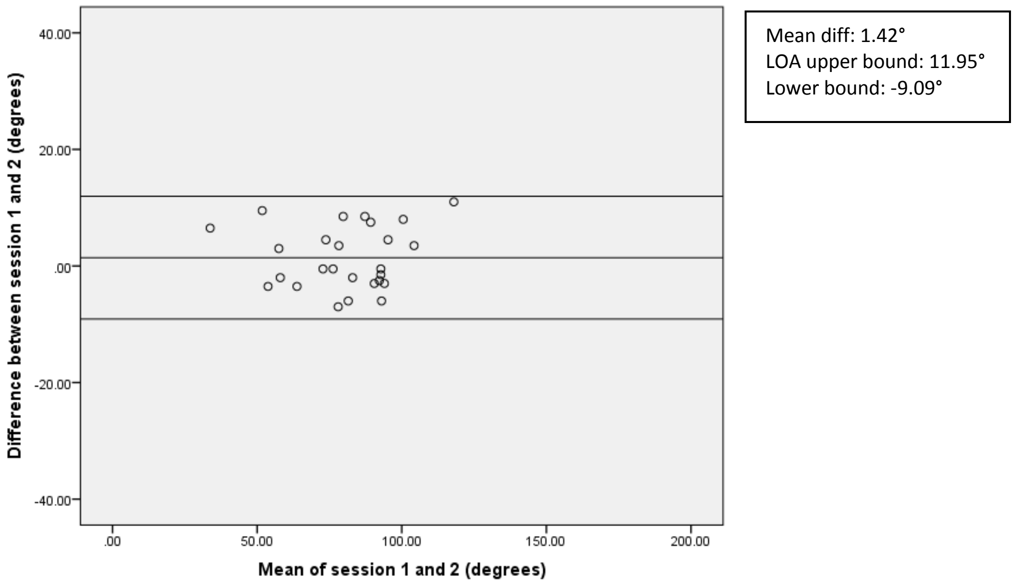

Figure 5: Bland Altman plot for between session intra-rater reliability for the HALO method

Thoracic mobility in the sagittal plane in elite surfers versus age and gender matched controls

An independent *t*-test revealed a significant difference (p = 0.01, t = 2.76) between the ages of the control group from the reliability study and the elite surfing group. Due to this difference those greater than 34.1 years old were removed from both groups. It was also determined to remove all females from both groups to allow for gender and aged matched groups providing a total of 15 elite surfers and 11 age and gender matched controls. An independent *t*-test was then performed and revealed no significant differences (p = 0.50) between the ages of both groups (controls 25.54 ± 3.86 vs. 26.47 ± 4.59 years). This was also applied to the thoracic rotation data to ensure age and gender matched groups (controls 25.67 ± 3.70 vs. 26.47 ± 4.59 years). .

A Shapiro-Wilks test (p >0.05) (Shapiro & Wilk, 1965) and a visual inspection of their histograms, normal Q-Q plots and box plots showed that the extension values were approximately normally distributed for both the surfing and control groups; with skewness of 0.39 (SE = 0.66) and kurtosis of 0.07 (SE = 1.28) for controls and a skewness of 0.78 (SE = 0.58) and a kurtosis of -0.57 (SE = 1.12) (Barnes, 1998; Cramer, 2012). Once the groups were aged and gender matched and the data was determined to be normally distributed; an independent *t*-test showed no differences in extension between the groups (Table 2).

Table 2: Comparison of thoracic mobility in the sagittal plane (centimetres and degrees) between elite surfers and age and gender matched controls

	Surfer (n = 15)	Controls (n = 11)	Significant Difference (p ≤ 0.05)
Tape measure method	9.86 (SD = 1.25)	9.20 (SD = 1.44)	t = 1.24 (p = 0.23)
HALO method	81.33 (SD = 16.43)	78.09 (SD = 15.24)	t = -0.51 (p = 0.61)

Thoracic Rotation:

Below Table 3 presents the within and between session intra-rater reliability analysis with ICC values, SEM and SRD calculated. ICC values ranged between 0.96 - 0.98 and were all within excellent reliability ranges (> 0.75). Between session ICC values were consistently lower and SEM and SRD values were consistently higher compared to within session values.

Table 3: Within and between session intra-rater reliability analysis for thoracic rotation methods

	ICC average	95% CI of ICC	SEM	SRD
Left thoracic rotation: Inclinometer (within session)	0.98	0.96 – 0.99	1.91	5.29
Left thoracic rotation: Inclinometer (between session)	0.95	0.89 – 0.98	3.04	8.43
Right thoracic rotation: Inclinometer (within session)	0.98	0.95 – 0.99	3.38	9.36
Right thoracic rotation: Inclinometer (between session)	0.97	0.93 – 0.98	2.94	8.16
Total ROM: Inclinometer (within session)	0.98	0.97 – 0.99	3.72	10.33
Total ROM: Inclinometer (between session)	0.96	0.91 – 0.98	5.37	14.89

Absolute agreement between session one and two was also determined; with the differences between session one and session two for total ROM analysed using a one sample *t*-test. Total ROM and between session values were chosen as this would most likely be used in the clinical setting. A mean difference of 0.53° was calculated which was insignificant ($p = 0.71$, $t = 0.38$) confirming that no fixed bias was present.

Figure 6 presents a Bland Altman plot for session one and two. The middle horizontal line presents the mean difference between session one and session two (0.53) and the lines above and below are the 95% confidence limits; these were calculated off the formula mean diff ± 1.96 x SD^{DIFF}. A linear regression analysis revealed no significant ($p = 0.892$) bias in the distribution of data points either side of the mean difference between session one and two.

Mean diff: 0.53°
LOA upper bound: 19.64°
Lower bound: -14.57°

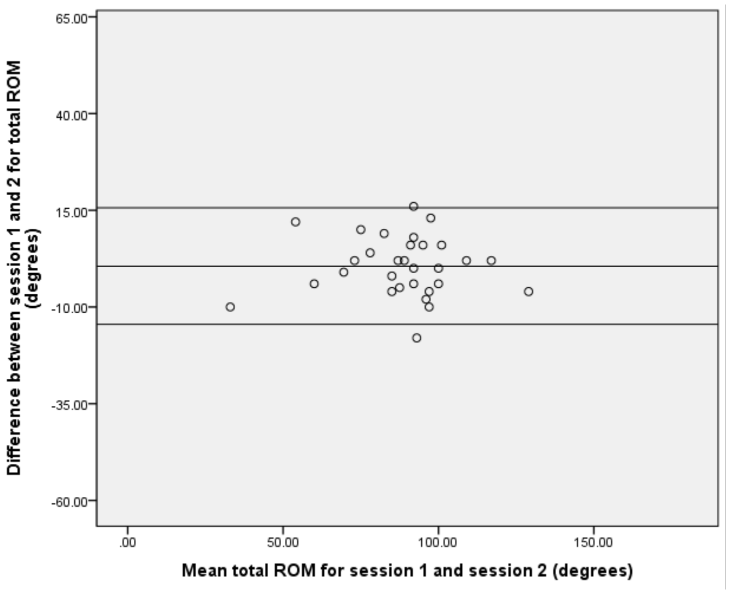

Figure 6: Bland Altman plot for between session intra-rater reliability for the thoracic rotation (total ROM)

<u>Thoracic rotation in elite surfers versus age and gender matched controls</u>

The thoracic ROM for the control group data was not normally distributed; this was determined through a Shapiro-Wilks test ($p = 0.032$). The Mann Whitney U test was the non-parametric test selected to determine if significant differences existed between groups; measures from session one were averaged and used for both groups (Table 4). Symmetry between left and right rotation was also determined for the elite surfing group through paired t-tests with no significance found ($p = 0.73$, $t = 0.36$) between either movement.

Table 4: Comparison of thoracic rotation ROM (degrees) between elite surfers and age and gender matched controls

	Surfer (n = 15)	Controls (n = 12)	Significant Difference ($p \leq 0.05$)*
Thoracic left rotation	64.01 (SD = 8.89)	40.33 (SD = 11.90)	U = 3.00 ($p < 0.001$ two tailed)*
Thoracic right rotation	63.06 (SD = 10.58)	41.50 (SD = 10.77)	U = 13.50 ($p < 0.001$ two tailed)*
Total Thoracic rotation	127.13 (SD = 16.21)	81.33 (SD = 21.10)	U = 4.00 ($p < 0.001$ two tailed)*

DISCUSSION

The initial findings from this study provide useful information for clinicians wanting to assess or screen the thoracic spine in the sagittal or horizontal planes. As previously mentioned quantifying thoracic extension provides several challenges for the clinician and hence the large disparities in ROM expressed in the research to date (Crawford & Jull, 1993; Edmondston et al., 2012; Kellis et al., 2008; Kuo et al., 2009). Position, devices used and the significant disparities in ROM expressed greatly differ between studies. This lack of consensus was a primary reason for exploring a new clinically applicable method that could be applied in a surfing cohort. This study applied a tape measure method, which uses a distraction technique and quantifies thoracic mobility in the sagittal plane (extension from a maximally flexed position). Neutral kyphosis does not influence the starting position as with previous inclinometry studies (Crawford & Jull, 1993; Edmondston et al., 2012; O'Gorman & Jull, 1987). The primary reason for eliminating the impact neutral kyphosis has on the range of extension was our observations of lower neutral kyphosis values (27.7° SD 8.7) in an elite surfing cohort compared to previous age and gender matched published data (Lewis & Valentine, 2010; O'Gorman & Jull, 1987). Kyphosis was determined through the inclinometer methods previously described by (Lee et al., 2003; Lewis & Valentine, 2010). The hypothesised reason for this decreased neutral kyphosis may be due to the activity requirements of surfing with approximately 50% of a surfing session spent in the prone position paddling (Farley et al., 2012). In order to have adequate arm clearance thoracolumbar extension needs to occur. This constant active extension may provide active and passive adaptations at the thoracic spine reducing the neutral thoracic kyphosis. A minimal neutral kyphosis may under-reflect the amount of thoracic extension. Therefore, to negate this issue extension commenced from a maximally flexed position. This movement is influenced by the amount of thoracic flexion achieved at the starting position and presents a value that reflects thoracic mobility in the sagittal plane or total thoracic ROM (flexion plus extension).

When reviewing both methods for thoracic mobility in the sagittal plane, within and between session reliability values are all within the excellent ranges (ICC > 0.70) according to Fleiss (1986). Systematic bias was also ruled out through one sample *t*-tests; this was considered an important statistical procedure as high correlations do not necessarily equate to agreement between measurements. This can occur due to large variations in sample data.

It needs to be noted that there were no statistical differences between the surfers and the control group for both thoracic and thoracolumbar mobility in the sagittal planes. Rationale for this may be attributed to the possibility that excessive thoracic or thoracolumbar mobility in the sagittal plane is not required in a surfing cohort, but reduced neutral kyphosis is more apparent. Another possibility may be attributed to the testing position; even though the sitting position may provide bias to the thoracic spine it may not replicate the demands of surfing.

Although no statistical difference was noted; both movements were greater in the surfing group suggesting clinical rationale for maintaining thoracic mobility in the sagittal plane. It could also be argued that a limitation in thoracic mobility in the sagittal plane (dysfunction) may prevent adequate rotation of the thoracic spine. Therefore maintaining mobility in both the sagittal and horizontal planes is essential in an elite surfing cohort.

The secondary aim of this study was to review the reliability of a thoracic rotation method and compare this data to a surfing cohort. Through visual observation it is clear thoracic rotation is imperative during surfing manoeuvres; however quantifying the amount of thoracic rotation in this cohort was not established previously. This study revealed excellent within and between session ICC values (0.95 – 0.98) and revealed no fixed bias between sessions ($p = 0.71$, $t = 0.38$). It most importantly presented the range of thoracic rotation in an elite surfing cohort which was significantly greater than the comparative group (see Table 3). When comparing the comparative group mean rotation values to previous research by Johnson et al. (2012) using the identical inclinometer method the results are very similar (40.80° vs. 44.76°; average age 31 vs. 24 years respectively). It also needs to be pointed out that the elite surfing cohort mean (63.57°) appears significantly greater to the results of Johnson et al. (2012).

Of interest there was no significant difference between left and right rotation in the elite surfing group ($p = 0.73$). A surfer is often required to rotate in both directions during a surfing session and therefore one would assume that the activity requirements promote this symmetry. This information may be useful for clinicians dealing with surfers; where by identified asymmetry or inadequate ROM provide direction for treatment and conditioning exercises.

The strengths of this study need to be noted and are evident in the methodology. An attempt was made to blind the rater by having a recorder present; the rater was competent in the assessment procedures and had received adequate training and a standardised warm-up was given in an attempt reduce any learning effects (systematic bias). The limitations of this study include the lack of randomisation of thoracic extension and rotation movements; this reduces the chances of potential learning effects. Inter-rater reliability was not assessed and therefore these results need to be viewed with caution when measuring between clinicians. Although this study had an adequate sample size for the reliability component; the sample size for the comparative and elite surfing group provide limitations when generalising results. The data for the control group for thoracic rotation was not normally disturbed and highlights the need for a larger group size for comparative analysis. Another limitation of this study is the absence of a female surfing cohort, future research should look to include this cohort.

CONCLUSION

This study has introduced a new clinically applicable method to assess thoracic mobility in the sagittal plane and has revealed excellent intra-rater reliability values for the lumbar locked method for thoracic rotation. To our knowledge this is the first research study to quantify thoracic mobility in an elite surfing cohort; of note this study found surfers to possess significantly more thoracic rotation than age and gender matched individuals. This information may provide clinicians, coaches and athletic trainers with imperative information regarding the importance of maintaining adequate thoracic rotation and symmetry. From a screening perspective thoracic rotation should be assessed for performance purposes and to limit the potential for injury in this or surrounding regions.

REFERENCES

ASP. (2014). Association of Surfing Professionals - Photos - ASP. from http://www.aspworldtour.com/

Barnes, J. (1998). Fundamental Statistics for Social Research: Step-by-step Calculations and Computer Techniques Using SPSS for Windows. By D. Cramer. Routledge, London, 1997. pp. 456. £60.00 (hb), £18.99 (pb). *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 39*(7), 1055-1055. doi: 10.1017/S0021963098233142

Cramer, D. (2012). *Fundamental Statistics for Social Research: Step-by-Step Calculations and Computer Techniques Using SPSS for Windows*. Hoboken: Taylor and Francis.

Crawford, H. J., & Jull, G. A. (1993). The influence of thoracic posture and movement on range of arm elevation. *Physiotherapy Theory & Practice, 9*(3), 143-148.

Edmondston, S., Ferguson, A., Ippersiel, P., Ronningen, L., Sodeland, S., & Barclay, L. (2012). Clinical and Radiological Investigation of Thoracic Spine Extension Motion During Bilateral Arm Elevation. *Journal of Orthopaedic & Sports Physical Therapy, 42*(10), 861-869. doi: 10.2519/jospt.2012.4164

Everline, C. (2007). Shortboard performance surfing: A qualitative assessment of maneuvers and a sample periodized strength and conditioning program in and out of the water. *STRENGTH AND CONDITIONING JOURNAL, 29*(3), 32-40.

Farley, O., Harris, N. K., & kilding, A. E. (2012). Physiological demands of competitive surfing. *Journal of Strength and Conditioning Research, 26*(7), 1887-1896.

Fleiss, J. L. (1986). *The design and analysis of clinical experiments*. New York: Wiley.

Furness, J. (2015). *Thoracic mobility; extension and rotation: A systematic review of clinical assessment methods*. Faculty of Health Sciences, Bond University.

Furness, J., Hing, W., Abbott, A., Walsh, J., Sheppard, J. M., & Climstein, M. (2014). Retrospective analysis of chronic injuries in recreational and competitive surfers: injury location, type, and mechanism. *International Journal of Aquatic Research and Education, 8*(3), 277-287. doi: 10.1123/ijare.2013-0032

Furness, J., Hing, W., Walsh, J., Abbott, A., Sheppard, J. M., & Climstein, M. (2015). Acute injuries in recreational and competitive surfers: incidence, severity, location, type, and mechanism. *The American Journal of Sports Medicine, 43*(5), 1246-1254. doi: 10.1177/0363546514567062

Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1-15. doi: 10.2165/00007256-200030010-00001

Iveson, B. D., McLaughlin, S. L., Todd, R. H., & Gerber, J. P. (2010). Reliability and exploration of the side-lying thoraco-lumbar rotation measurement (STRM). *North American Journal of Sports Physical Therapy, 5*(4), 201-207. http://www.najspt.org/

Johnson, K. D., & Grindstaff, T. L. (2010). Thoracic rotation measurement techniques: clinical commentary. *North American Journal of Sports Physical Therapy, 5*(4), 252-256.

Johnson, K. D., Kim, K.-M., Yu, B.-K., Saliba, S. A., & Grindstaff, T. L. (2012). Reliability of Thoracic Spine Rotation Rangeof-Motion Measurements in Healthy Adults. *Journal of Athletic Training, 47*(1), 52. http://www.nata.org/journal-of-athletic-training

Kellis, E., Adamou, G., Tzilios, G., & Emmanouilidou, M. (2008). Reliability of spinal range of motion in healthy boys using a skin-surface device. *Journal of Manipulative & Physiological Therapeutics, 31*(8), 570-576.

Kuo, Y., Tully, E. A., & Galea, M. P. (2009). Video based measurement of sagittal range of spinal motion in young and older adults. *Manual Therapy, 14*(6), 618-622. doi: 10.1016/j.math.2008.12.006

Lee, C. N., Robbins, D. P., Roberts, H. J., Feda, J. T., Bryan, J. M., Masullo, L., & Flynn, T. W. (2003). Reliability and validity of single inclinometer measurements for thoracic spine range of motion. *Physiotherapy Canada, 55*(2), 73-78.

Lewis, J. S., & Valentine, R. E. (2010). Clinical measurement of the thoracic kyphosis. A study of the intra-rater reliability in subjects with and without shoulder pain. *BMC musculoskeletal disorders, 11*(1), 39-39. doi: 10.1186/1471-2474-11-39

Lexell, J. E., & Downham, D. Y. (2005). How to assess the reliability of measurements in rehabilitation. *American Journal of Physical Medicine & Rehabilitation, 84*(9), 719-723. doi: 10.1097/01.phm.0000176452.17771.20

Meir, R. A., Lowdon, B. J., & Davie, A. J. (1991). Heart rates and estimated energy expenditure during recreational surfing. *Australian Journal of Science and Medicine in Sport, 23*(3), 70-74.

Mellin, G., Kiiski, R., & Weckstrom, A. (1991). Effects of subject position on measurements of flexion, extension, and lateral flexion of the spine. *Spine (Phila Pa 1976), 16*(9), 1108-1110.

O'Gorman, H., & Jull, G. (1987). Thoracic kyphosis and mobility: the effect of age. *Physiotherapy Practice, 3*, 154-162. http://informahealthcare.com/ptp

Safrit, M., & Wood, T. (1989). *Measurement concepts in physical education and exercise science*. Champaign, Illinois: Human Kinetics.

Shapiro, S. S., & Wilk, M. B. (1965). An Analysis of Variance Test for Normality (Complete Samples). *Biometrika, 52*(3/4), 591. doi: 10.2307/2333709

Spurrier, D. (2015). Pre-season screening and injury prevention. from http://www.ausport.gov.au/sportscoachmag/safety/pre-season_screening_and_injury_prevention

Tousignant, M., Poulin, L., Marchand, S., Viau, A., & Place, C. (2005). The Modified - Modified Schober Test for range of motion assessment of lumbar flexion in patients with low back pain: A study of criterion validity, intra- and inter-rater reliability and minimum metrically detectable change. *Disability and Rehabilitation, 27*(10), 553-553. doi: 10.1080/09638280400018411