Assessment of shoulder active range of motion in prone versus supine

A reliability and concurrent validity study

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ABSTRACT

Background: As swimming and surfing are prone dominant sports, it would be more sport specific to assess in this position. Objectives: To determine the reliability of the inclinometer and HALO© in supine and prone and the concurrent validity of the HALO©. Concurrent validity is based on the comparison of the HALO© and inclinometer. To determine if active range of motion (AROM) differences exists between prone and supine when assessing shoulder internal (IR) and external rotation (ER). Design: Clinical Measurement, reliability and validity. Methods: Thirty shoulders (mean age = 26.8 years) without shoulder pathology were evaluated. Measurements were taken in supine and prone with both an inclinometer and HALO© device. Results: Active ER ROM in prone was significantly higher than in supine when using both devices. Intra-rater reliability (within and between session) intraclass correlation coefficient (ICC) values ranged between 0.82-0.99 for both devices in supine and prone. An ICC test revealed a significant ($p < 0.01$) correlation for both devices in IR and ER movements ($ICC_{3,1} = 0.87$ and $ICC_{3,1} = 0.72$) respectively. Conclusion: This study has shown prone assessment to be a reliable and appropriate method for prone dominant athletes (swimmers and surfers). In this study greater ER ROM was achieved in prone compared to supine. This finding highlights the importance of standardising the test position for initial and follow up assessments. Furthermore the HALO© and inclinometer have been shown to be reliable tools that show good concurrent validity.

KEY WORDS: Shoulder, prone, reliability, range of motion, inclinometer

INTRODUCTION

Physiotherapists routinely evaluate joint range of motion (ROM) as part of a musculoskeletal assessment (Riemann, Witt and Davies, 2011). These measurements are critical in providing baseline measures, diagnosis of disorders and evaluation of treatment through quantifying degree of change (APTA, 2003; Muir, Corea and Beaupre, 2010). They are also routinely used in screening assessments for athletes to detect asymmetry, abnormality and potentially prevent future injury (Riemann, Witt and Davies, 2011).

It is worthwhile to consider whether assessment of a joint can be carried out in a position that is relevant and specific for the athlete. Researchers are currently undertaking musculoskeletal screening of the shoulder in both recreational and competitive surfers. Meir, Lowdon and Davie (1991) performed a time motion analysis of one hour of recreational surfing and found that 50% of the time is spent paddling in the prone position , therefore exploration of a prone shoulder AROM assessment was justified.

Shoulder injuries in a surfing population have been reported in previous literature (Meir, Zhou, Gilleard and Coutts, 2012; Nathanson, Haynes and Galanis, 2002; Taylor et al, 2004) however at present there are no studies which have evaluated joint ROM in this cohort. The current paucity of research which physically assesses shoulder active ROM in a surfing population and the need to perform this in a prone position was the premise for this study. Prior to undertaking physical assessment of the shoulder in a surfing population, a reliable procedure in the prone position needed to be established.

Altered internal (IR) and external rotation (ER) has been associated with the aetiology of shoulder disorders (Lin and Yang, 2006) . Both of these movements are critical when in the prone position during surfing and therefore were the movements which needed to be assessed. These movements can be objectively measured through a number of instruments including a ruler, tape measure, goniometer and inclinometer (Clarkson, 2005). Inclinometry appears superior to other devices as it can be calibrated on the basis of the universal constant of gravity. This enables the starting position to be consistently identified and repeated (Lea and Gerhardt, 1995).

The movement of shoulder IR and ER can be performed actively or passively; however active range of motion (AROM) is considered more reliable as this does not rely on the capability of the clinician to determine an end feel (Muir, Corea and Beaupre, 2010).

An electronic search was undertaken to investigate methodology for assessment of active shoulder ROM for the movements of IR and ER in the prone and supine position. The following databases MEDLINE, CINAHL and EMBASE were searched using the primary search terms (shoulder, range of motion and all synonyms for reliability). Only two research papers were identified which assessed shoulder range of motion in prone (Kolber and Hanney, 2012; Kolber, Saltzman, Beekhuizen and Cheng, 2009). Both papers assessed shoulder IR in the prone position, however ER was not assessed in the prone position. To our knowledge, there is no available research investigating shoulder ER in prone. The reliability of this movement for use in clinical assessment is yet to be established. Additionally no research existed which compared prone to supine for shoulder IR and ER. Research does however exist with shoulder IR or ER assessment in either prone or supine; however when comparing individual papers differences in methodology, device and sample population provide too many challenges to compare prone with supine results.

The absence of data for shoulder ER in prone developed the hypothesis that differences in ROM would be present when compared to supine. This has been previously demonstrated in the hip joint where significant differences existed when comparing mean ER values in sitting versus prone (36° SD 7° versus 45° SD 10°) (Simoneau, Hoenig, Lepley and Papanek, 1998).

Recently a new commercial device known as a HALO© digital goniometer is available for clinicians to assess ROM. The HALO© uses a magnetic system for movements in the horizontal plane and accelerometers in the sagittal plane. Two lasers are situated on either side of the HALO©; this allows specific landmarks to be intersected and ensure correct and repeatable positioning. This device also has a vertical zero mode which ensures a consistent starting position similar to an inclinometer. To our knowledge no published literature exists which has investigated the reliability or validity of this device.

Therefore three key aims were identified; to determine within session and between session intra-rater reliability of the Inclinometer and HALO©. This would be limited to the movement of shoulder IR and ER in both the supine and prone position. The second aim was to determine whether a ROM difference exists for IR and ER in prone versus supine. The third aim was to determine the concurrent validity of the HALO© device.

METHODS

Subjects

Testing was completed on both the dominant and the non – dominant arm; 30 shoulders in total (15 subjects) were tested and the data analysed accordingly to determine within and between session intra-rater reliability. A sample size of 15-20 is often used in reliability studies, however 30 or greater is required to form practically useful 95% smallest real differences (SRD) (Lexell and Downham, 2005). A total of 40 shoulders (20 subjects) were assessed to determine differences in prone versus supine. Demographic and background information was obtained on all participants; this included age, arm dominance and injury history. Subjects were eligible for the study if they were between the ages of 18 – 75 and able to adopt the starting position (90 degrees of shoulder abduction). The study was approved by the Bond University Ethics committee (RO1610) and informed consent was gained from all participants.

Exclusion criteria included any acute or chronic shoulder pathology that may be aggravated or worsened through repeated testing of IR and ER. Based upon these aforementioned criteria, no participants were excluded. Participants were between the ages of 22 and 48 years with the mean age being 26.8 (SD± 6.5) years.

Raters

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

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. To ensure the gravity dependent inclinometer was set to an accurate zero starting point, a vertical reference was established through the use of a bubble level. This reference point was then used throughout all testing.

HALO©

The HALO© (model HG1, HALO© Medical Devices, Australia) device was used for all joint range of motion measures in this study. This device has a "vertical zero mode", where vertical is zero degrees. Therefore even if the shoulder is starting in a slightly internally rotated position this movement is accounted for. To our knowledge, there is currently no available research investigating the reliability and validity of this device in measuring joint range of motion.

Insert figure 1 about here (caption: Figure 1: HALO© device)

Insert figure 2 about here (caption: Figure 2: Set up for active IR and ER in prone and supine; A) IR in supine with the HALO device; B) ER in supine with the inclinometer; C) ER in prone with the HALO device; D) IR in prone with the inclinometer)

Goniometer

A standard 12 inch, double armed 360 degree goniometer (JAMAR, E-Z Read) was used to establish a standardised patient set up. The goniometer was used to ensure each movement was started from 90 degrees of abduction.

Design

The two evaluators participated in a one hour formal training session with a musculoskeletal specialist to ensure correct measuring procedures were followed; this was done prior to data collection. Subjects were provided with verbal instruction and performed the required movement three times as a warm-up under the guidance of the assessors. This was completed to minimise the risk of a learning effect. This procedure was standardised for all testing and we believe offered no mobilisation effect.

Active shoulder IR and ER rotation was assessed. Measurements were taken in prone with both devices (inclinometer and HALO©) and then repeated in supine. IR and ER movements in prone and supine followed established protocols from Clarkson (2005). With all subjects, one assessor and one recorder were present. The assessor positioned the subject and instructed the movement to be performed. The recorder then read and recorded the joint range of motion ensuring blinding of the assessor. Throughout all testing, the HALO© was used in the “vertical zero mode”. The gravity dependent inclinometer was re-calibrated between each change in position. Details of the test positions, manual stabilisation and device placement are found in Appendix 1.

Each participant presented on two sessions on the same day for testing. The evaluators obtained two AROM measurements of shoulder IR and ER in both supine and prone with both the inclinometer and the HALO© device for each session. The two sessions were separated by a time period of three hours and subjects were instructed to avoid any stretching or exercise during this time period.

Data Analysis

Data analysis was performed with statistical package for the social sciences (version 20.0). Descriptive statistics including means, standard deviations and ranges were calculated for each measure and for each session. The intraclass correlation coefficient (ICC) is currently the preferred retest correlation coefficient and was the method used to determine reliability (Lexell and 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 were used to determine reliability between measure one and measure two within the same session ($ICC_{3,1}$). The between-session reliability was determined between the average of two measures from each session ($ICC_{3,2}$). This model was used because only the chief 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 and 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 = $\sqrt{WMS}$ (Hopkins, 2000; Lexell and 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 $\sqrt{2}$ (Safrit and Wood, 1989). Paired t tests were used to determine whether significant differences exist between both shoulder IR and ER in prone versus supine. Intraclass correlation coefficient (ICC) was used to determine the correlation for both devices in IR and ER movements. Linear regression was performed for both devices in IR and ER movements to calculate R squared strength of relationship.

RESULTS

A total of 30 shoulders were assessed (15 subjects, 8 males, 7 females) to determine the reliability of both devices in prone and supine. The overall mean age was 26.8 years (SD 6.5; range 22 to 48). Below table 1 presents the within session reliability analysis with ICC values, SEM and SRD calculated. ICC values ranged between 0.93-0.99 and were all within excellent reliability ranges (> 0.75) according to recommendations of (Fleiss, 1986). The SEM and SRD values for the inclinometer in the prone position revealed lower values compared to the HALO© in prone.

Below table 2 presents the between session reliability analysis with ICC, SEM and SRD values calculated. Lower ICC values (0.82-0.96) are represented compared to table two however they all are still with the excellent range. The SEM and SRD values are lower for the inclinometer in both positions compared to the HALO©.

Insert table 1 about here (caption: Table 1: Within session reliability analysis)

Insert table 2 about here (caption: Table 2: Between session reliability analysis)

Prone was the position of interest and the inclinometer was considered the valid tool to assess shoulder ROM; therefore Bland Altman plots were implemented for this position and tool. These plots graphically present between session intra-rater values for ER and IR. The differences between measurements from the two test occasions are plotted against the mean of the two test occasions for each shoulder measured; the 95% confidence intervals are also included. Both figure 3 and 4 reveal an unbiased agreement between session one and two for both ER and IR in the prone position.

Insert figure 3 about here (caption: Figure 3: Bland-Altman plot for between-session reliability for prone ER with the inclinometer)

Insert figure 4 about here (caption: Figure 4: Bland-Altman plot for between-session reliability for prone IR with the inclinometer)

<u>Prone versus supine</u>

A total of 40 shoulders (20 subjects, 12 males and 8 females) were assessed to determine if differences exist between prone and supine. The mean age was 26.4 years (SD 5.8, range 22 to 48). Table 3 presents the mean of measure one and two for session one in both prone and supine positions. ER in prone was significantly ($t = 3.0$, $p = 0.005$) higher than in supine (89.7° SD 7.2° versus 85.4° SD 6.4°) when using an inclinometer. This was also the case for the HALO© device where ER in prone was significantly ($t = 2.4$, $p = 0.02$) higher than in supine (89.2° ± 8.6° vs 85.1° ± 10.0°). IR with the inclinometer and HALO© device did not reveal significant differences despite a change in position.

To determine the level of agreement all data obtained for ER in prone were compared against ER in supine; the differences between individual data sets were analysed using a One-Sample T –Test. The results revealed a mean difference of 3.1 degrees between the two test positions which was statistically significant ($p = 0.01$); this indicates the lack of agreement between the two test positions for ER. This is assuming that the null hypothesis would result in a mean difference of zero. The same procedure was conducted for IR with a mean difference of -0.33 degrees which was statistically insignificant ($p = 0.82$) indicating agreement between the two test positions for IR. A regression analysis revealed no significant ($p = 0.20$) bias in the distribution of data points either side of the mean difference for IR.

Insert table 3 about here (caption: Table 3: A comparison of mean scores for prone versus supine from session 1)

Concurrent validity of HALO© device

Concurrent validity was based on the comparison of the HALO and inclinometer. All ICC values for within session and between sessions were within excellent ranges (> 0.75) in prone and supine. A correlational analysis was therefore performed regardless of position. This analysis took the combined average from both sessions and both positions and compared the values from the inclinometer against the HALO©. Intraclass correlation coefficient (ICC) revealed a significant ($p < 0.01$) correlation for both devices in IR and ER movements ($ICC_{3,1} = 0.87$ and $ICC_{3,1} = 0.72$ respectively). The squared correlation coefficient (r^2) for ER was 0.35 and IR 0.59 indicating a stronger relationship for IR for the two devices (figure 1 and 2).

Insert figure 5 about here (caption: Figure 5: Scatterplot presenting the linear relationship between the HALO© and Inclinometer for Internal Rotation in prone and supine)

Insert figure 6 about here (caption: Figure 6: Figure 6: Scatterplot presenting the linear relationship between the HALO© and Inclinometer for External Rotation in prone and supine)

DISCUSSION

While several clinical measurements are available to measure shoulder ROM, goniometry and inclinometers remain the most widely used (Roy and Esculier, 2011). Previous research has assessed active shoulder IR and ER using an inclinometer (Green, Buchbinder, Forbes and Bellamy, 1998; Hoving et al, 2002; Kolber and Hanney, 2012; Kolber, Saltzman, Beekhuizen and Cheng, 2009). Two of these papers used a prone position however this was performed for IR only (Kolber and Hanney, 2012; Kolber, Saltzman, Beekhuizen and Cheng, 2009). To our knowledge no paper has compared IR and ER in prone and supine. It would seem more logical to assess prone dominant athletes such as surfers in the prone position as this is specific to the sport.

The initial aim was to determine the reliability of both the HALO© and inclinometer. The current study revealed excellent within session (ICC 0.93 – 0.99) and between session reliability (ICC 0.82 and 0.96). Previous research (Green, Buchbinder, Forbes and Bellamy, 1998; Hoving et al, 2002; Kolber and Hanney, 2012; Kolber, Saltzman, Beekhuizen and Cheng, 2009) assessing reliability of inclinometry for shoulder active range of motion has reported varied results with ICC values ranging from 0.32 – 0.99. This current study's findings exceed previous research by both

Green, Buchbinder, Forbes and Bellamy (1998) (ICC 0.75 – 0.82) and Hoving et al (2002) (ICC 0.32- 0.43) and are comparable to results by (Kolber, Saltzman, Beekhuizen and Cheng, 2009) (0.96 – 0.99).

A thorough literature search revealed no published research investigating the reliability and/or validity of the HALO© device. The current results indicated excellent within session (ICC = 0.97 – 0.99) and between session reliability (ICC = 0.84 – 0.96). As this is a portable device (~$259.00 US currency), this new information offers clinicians an alternative assessment tool in measuring active shoulder internal and external rotation in prone or supine. It must also be noted that higher SEM and SRD values were associated with the HALO© when compared with the inclinometer (Table 2 and 3). This was predominantly seen in supine when considering IR (inclinometer SRD = 7.5, HALO© SRD = 16.1). This may be attributed to difficulty in maintaining the HALO© against the lateral forearm whilst also palpating for any humeral head movement with the free hand. When performing this measurement with the inclinometer, the device is easier to hold in one hand and maintain its position on the distal forearm. This is seen through higher ICC values and lower SEM and SRD values for the movement and position.

The secondary aim of this study was to determine whether discrepancies exist in shoulder ER and IR ROM in a prone versus supine position. Results revealed a significant difference in ER in prone versus supine when using either device. IR showed no significant differences between prone and supine. These findings show a distinct trend for the assessment of shoulder ER regardless of device.

The hypothesised reasons for the greater ER in prone compared to supine in this current study may be attributed to the reduced scapula stabilisation in the prone position as previous research has illustrated reduction in shoulder ROM the more the scapula is stabilised (Ellenbecker, Roetert, Piorkowski and Schulz, 1996; Lunden, Muffenbier, Giveans and Cieminski, 2010). Secondly it could be speculated that an increased muscular effort in prone may occur as the participant attempts to overcome this anti-gravity position. When in supine, the scapula is stabilised through direct pressure from the bed. In prone, it may be speculated that greater co-contraction of the peri-scapula muscles (rhomboids, mid/lower traps) occurs in conjunction with the external rotators (teres minor, infraspinatus). This may lead to greater muscular recruitment and therefore greater range of motion.

Another possible reason for the differences in prone and supine may be associated with the towel position. The position of the towel ensures the subjects arm is placed horizontal to the acromion. In prone it was placed parallel along the humerus to ensure the proximal aspect of the humerus did not translate forwards; instead was in direct contact with the towel. This consideration was also applied for supine as the towel was also positioned parallel to the humerus to ensure the proximal aspect of the humerus did not translate posteriorly. Therefore it is possible that the towel position causes some retraction of the scapula in the prone position and protraction in the supine position, hence the possible differences for ER in prone compared to supine.

The premise for this study was to design a sport specific screening method for the shoulder. These results have indicated the need to assess ER in a consistent position. Bearing this in mind these results would indicate a surfer should be assessed in a prone position. Additionally a clinician may choose to utilize the prone position to assess/ screen functional stability and structural restriction around the shoulder; especially considering that ER is assisted by gravity in the supine position. One could assume that a ROM greater than the normative values attained from uninjured surfers could clear the joint for functional stability and of any structural restriction. A reduction of ER in the prone position could indicate further testing around the shoulder is needed. It is imperative that normative values are attained from uninjured surfers to determine the appropriate ROM to clear the shoulder. It also needs to be noted that other prone dominant sports such as swimming could utilise this prone position to assess shoulder ER.

Results for IR ROM (46.6°) are similar to previous published research which has specifically looked at prone IR (Kolber, Saltzman, Beekhuizen and Cheng, 2009) 43° and 55° respectively. Unfortunately, both studies did not assess ER in prone therefore comparisons for this movement cannot be made.

The third aim was to determine the validity of the HALO© device. Inclinometers are widely used and accepted in clinical practice and therefore were the benchmark to determine the construct validity for the HALO© device. Figure 5 and 6 represent the linear relationship between the two devices. A significant correlation was identified through ICC test (IR = 0.87, ER = 0.72) assuring the HALO© and inclinometer are measuring the same movement.

There are several limitations that exist in this current study. Firstly, it was difficult truly blinding the tester when using the HALO© device. This was due to the large digital display and having to wait 2-3 seconds for the device to settle. As inter-rater reliability was not assessed, this needs to be recognised when applying these results to clinical practice especially when more than one clinician is treating the same patient. Finally, a standardised approach should be adopted to ensure reproducible effort by the patient between sessions, however this is extremely difficult to control.

CONCLUSION

This research has identified that greater ER is achieved in prone compared to supine regardless of device. Bearing this in mind, clinicians need to be aware of this when performing initial and follow up assessments and determining change. These findings also stress the need for established norms in the prone position and in a surfing or swimming population where ROM may exceed non-prone dominant athletes. Prone assessment was also a reliable position to assess shoulder range of motion. It would seem more logical to adopt this sport specific position when working with prone dominant athletes (surfing or swimming). Finally, as a significant correlation exists between the HALO© and inclinometer; this supports the use of either device in clinical practice as a reliable and valid tool.

REFERENCES

APTA 2003 American Physical Therapy Association (APTA) 2003 Guide to physical therapist pracitice 2nd Alexandria, VA, American Physical Therapy Association.

Clarkson HM 2005 Joint motion and function assessment: a research-based practical guide, London, Lippincott Williams & Wilkins.

Ellenbecker TS, Roetert EP, Piorkowski PA, Schulz DA 1996 Glenohumeral joint internal and external rotation range of motion in elite junior tennis players. The Journal of Orthopaedic and Sports Physical Therapy 24: 336-341.

Fleiss JL 1986 The design and analysis of clinical experiments, New York, Wiley.

Green S, Buchbinder R, Forbes A, Bellamy N 1998 A standardized protocol for measurement of range of movement of the shoulder using the Plurimeter-V inclinometer and assessment of its intrarater and interrater reliability. Arthritis Care and Research 11: 43-52.

Hopkins W 2000 Measures of reliability in sports medicine and science. Sports Medicine 30: 1-15.

Hoving JL, Ryan P, Stockman A, Buchbinder R, Green S, Forbes A, Bellamy N, Brand C, Buchanan R, Hall S, Patrick M 2002 How reliably do rheumatologists measure shoulder movement? Annals of the Rheumatic Diseases 61: 612-616.

Kolber MJ, Hanney WJ 2012 The reliability and concurrent validity of shoulder mobility measurements using a digital inclinometer and goniometer: a technical report. International Journal of Sports Physical Therapy 7: 306-313.

Kolber MJ, Saltzman SB, Beekhuizen KS, Cheng MS 2009 Reliability and minimal detectable change of inclinometric shoulder mobility measurements. Physiotherapy Theory and Practice 25: 572-581.

Lea RD, Gerhardt JJ 1995 Current concepts review: Range of motion measurements. The Journal of Bone and Joint Surgery America 77: 784-798.

Lexell JE, Downham DY 2005 How to assess the reliability of measurements in rehabilitation. American Journal of Physical Medicine & Rehabilitation 84: 719-723.

Lin J-j, Yang J-L 2006 Reliability and validity of shoulder tightness measurement in patients with stiff shoulders. Manual Therapy 11: 146-152.

Lunden JB, Muffenbier M, Giveans MR, Cieminski CJ 2010 Reliability of shoulder internal rotation passive range of motion measurements in the supine versus sidelying position. The Journal of Orthopaedic and Sports Physical Therapy 40: 589.

Meir RA, Lowdon BJ, Davie AJ 1991 Heart rates and estimated energy expenditure during recreational surfing. Australian Journal of Science and Medicine in Sport 23: 70-74.

Meir RA, Zhou S, Gilleard WL, Coutts RA 2012 An investigation of surf injury prevalence in Australian surfers: A self-reported retrospective analysis. New Zealand Journal of Sports Medicine 39 52-58.

Muir SW, Corea CL, Beaupre L 2010 Evaluating change in clinical status: reliability and measures of agreement for the assessment of glenohumeral range of motion. North American Journal of Sports Physical Therapy 5: 98-110.

Nathanson A, Haynes P, Galanis D 2002 Surfing injuries. The American Journal of Emergency Medicine 20: 155-160.

Riemann BL, Witt J, Davies GJ 2011 Glenohumeral joint rotation range of motion in competitive swimmers. Journal of Sports Sciences 29: 1191-1199.

Roy J-S, Esculier J-F 2011 Psychometric evidence for clinical outcome measures assessing shoulder disorders. Physical Therapy Reviews 16: 331-346.

Safrit M, Wood T 1989 Measurement concepts in physical education and exercise science, Champaign, Illinois, Human Kinetics.

Simoneau GG, Hoenig KJ, Lepley JE, Papanek PE 1998 Influence of hip position and gender on active hip internal and external rotation. The Journal of Orthopaedic and Sports Physical Therapy 28: 158-164.

Taylor DM, Bennett D, Carter M, Garewal D, Finch CF 2004 Acute injury and chronic disability resulting from surfboard riding. Journal of Science and Medicine in Sport 7: 429-437.

Appendix 1: Details of Testing Positions and Device Placement.

Prone Testing: Start Position

Participants were positioned on in a prone position with the arm being assessed over the edge of the plinth. The arm was then taken into 90 degrees of abduction, the forearm flexed to 90 degrees and the wrist placed in neutral pronation/supination (Clarkson 2005). The angle of abduction was confirmed through goniometric measurement. A rolled towel was placed under the upper arm so that the humerus was visually level with the acromion process. This ensured a neutral horizontal positioning of the arm.

Device	Movement	Procedure
HALO©	Internal Rotation	The HALO© was placed on the mid-point of the lateral forearm. The mid-point was determined as half way between the ulnar styloid and the olecranon. Subjects were instructed to actively rotate the arm as far as possible. The device remained in this position until end of range where a reading was taken. The examiners free hand was lightly placed over the lateral epicondyle to limit any horizontal extension of the shoulder or extension of the elbow.
	External Rotation	The HALO© was placed on the mid-point of the lateral forearm. Subjects were instructed to externally rotate the arm. From this prone position, examiners were able to visually see any thoracic extension or scapula retraction and correct this with verbal cueing.
Inclinometer	Internal Rotation	Subjects were instructed to internally rotate the arm. As per the HALO©, light pressure was placed over the lateral epicondyle ensuring pure rotation. At the end of range, the inclinometer was placed on the anterior forearm adjacent to the radial styloid and the measurement taken
	External Rotation	Subjects were instructed to externally rotate the arm. The inclinometer was placed as per internal rotation and the measurement recorded. Examiners visually monitored for any thoracic extension or scapula retraction.

Supine Testing: Start Position Participants were positioned in a supine position with the olecranon at the edge of the plinth. All other aspects of the starting position were the same as the prone set up.		
HALO©	Internal Rotation	The HALO© was placed on the mid-point of the lateral forearm. The examiners other hand palpated the anterior humeral head and coracoid process. Active rotation was performed and subjects instructed to stop when scapula movement was felt.
	External Rotation	The HALO© was placed on the mid-point of the lateral forearm. Subjects were instructed to externally rotate and the HALO© remained on the forearm until end of range where the measurement was taken.
Inclinometer	Internal Rotation	The inclinometer was placed on the anterior forearm adjacent to the radial styloid. The movement was palpated as mentioned in HALO© internal rotation
	External Rotation	Subjects were instructed to externally rotate the arm. At the end of range, the inclinometer was placed on the anterior forearm adjacent to the radial styloid and the measurement taken.