MSc Research Project

Programme: MSc Sports Physiotherapy

Title: A cross-sectional study comparing overhead activities of senior tennis players with and without shoulder pain

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Lastly, I would like to thank my family, my husband Gerrit and my boys, Ben and Leo, for their patience and support while I had to complete the task at hand.

I value your love, patience and understanding.
A cross-sectional study comparing overhead activities of senior tennis players with and without shoulder pain

Abstract

Study design
Cross-sectional design

Background
Repetitive overhead activity during tennis is a causative factor of shoulder pain. Age and playing years will influence shoulder movement and possibly result in shoulder injuries for throwers and hitting athletes. Literature assessing the shoulder movements of senior overhead athletes with shoulder pain exist, but correlation with serve kinematics is lacking.

Objectives
This study compares the effect of shoulder overhead activities on senior tennis player - with and without shoulder pain. The differences between movement patterns by means of inertial measurement and shoulder clinical assessments were assessed and correlated with the effect of age and playing history.

Methods
Twenty-two advanced level senior tennis players were divided into 2 groups: Older Asymptomatic group (OA), (n=12; males : females = 6 : 6; aged 56.6 ±8.3 years; 24.8 ±16.5 playing experience years), and Older Symptomatic group (OS), (n=10; males : females = 7 : 3; aged 53.7 ±13.6 years; 38.7 ±16.8 playing experience years). A Clinical assessment (using an inclinometer) of glenohumeral internal rotation (GIR), glenohumeral external rotation, total range of motion (TROM) and scapula upward rotation were recorded. A dynamometer determined muscle strength and ratios for shoulder Internal Rotators, External Rotators (ER), Middle and Lower Trapezius. Kinematics measures were collected during flat tennis serve by an inertial measurement system.
Results

By comparing between-groups humeral acceleration (Hum_a), OS-Hum_a was significantly increased by 42% (p<0.001). Both OA and OS-groups presented with reduced TROM and GIR. OS-TROM and OS-GIR were significant inverse correlated (p<0.05, p<0.01) with OS-Hum_a. OS-Scapular Angular velocity (Scap_ω) and OS-Hum_ω were elevated.

Conclusion

Age and Pain may have caused the OS-group to modify their technique due to a reduced OS-TROM and OS-GIR and an increased OS-Hum_a, Hum_ω and Scap_ω, causing stress on the shoulder joint and musculature. It is important to promote shoulder mobility by including sleeper and cross-body posterior shoulder stretches.

Key words: tennis, overhead injury, kinematics
1 Introduction

Overhead shoulder injuries are prevalent in tennis and account for 25-47% of all upper limb injuries and represent 7-16% of all tennis injuries (Kibler & Safran, 2000). Most shoulder injuries develop over time due to repetitive strain (Ellenbecker, et al., 2009).

During serving and overhead hitting, huge repetitive strain develops within the shoulder causing injury (Kibler, et al., 2013). The shoulder, which is a small and unstable joint, presents a crucial link within the force transference of the kinetic chain resulting in shoulder pathology, (Kibler, 1995).

Although gender differences do not influence shoulder injuries (Kibler, et al., 1996), the numbers of playing years and progressive age affect the shoulder structure and range of motion (ROM), (Kibler, et al., 1996, Moor, et al., 2014). Injury risk factors increase when the volume of tennis play-time exceeds 6 hours per week (Hjelm, et al., 2012), together with improper mechanics, joint stiffness, soft tissue inflexibility, muscle weakness or imbalance, and repetitive strain may be factors related to injury (Hjelm, et al., 2012, Kibler & Sciascia, 2016, Linther, et al., 2008).

In recent years, inertial motion assessment has become a popular method to record kinematics on the sports field and occupational assessments (Rawashdeh, et al., 2016, Schall, et al., 2016a). By attaching wearable inertial measurement units (IMUs) to the upper limb and trunk, shoulder kinematic variables can be recorded over a lengthy period. By comparing the reliability of IMU and the gold standard laboratory three-dimensional motion capture system, an acceptable estimated difference of 7.2°-12.1° for the upper arm was demonstrated while the average angular displacement variants were less than 4.5° (Schall, et al., 2016b).

To our knowledge, no studies have been conducted to compare the inertial shoulder kinematics during tennis together with clinical assessments of senior tennis players with and without shoulder pain.

A plethora of studies, involving mostly younger elite players, identify shoulder adaptation, specifically influencing Scapular Upward Rotation (UR), Glenohumeral Internal Rotation (GIR) and
Glenohumeral External Rotation (GER) ROM together with the strength of glenohumeral Internal Rotator (IR), External Rotator (ER), Middle Trapezius (MT) and Lower Trapezius (LT) strength and strength ratio (ER/IR), exist, (Chandler. 2009, Cools, et al., 2010, Cools, et al., 2014, Hjelm, et al., 2012, Kibler & Safran 2000, Saccol, et al., 2010). However, fewer investigations focussed on comparative studies involving the senior tennis populations.

This study aimed to determine the effects of repeated overhead movements of the glenohumeral and scapula-thoracic region of the separate groups of senior tennis players. By analysing differences in the kinematics of the shoulder in terms of angular velocity and linear acceleration, the study hypothesises that differences in kinematics will be found between the groups and these differences correlate with the results of the clinical assessment.

These findings will provide new insights into the causes of shoulder pathologies and the aging process of tennis players. Furthermore, these results will provide guidelines for coaches, physiotherapists and the tennis population, who desire to stay active and to promote activity and longevity.

**Objectives and Questions investigated during the current study**

1. What were the differences between the clinical assessment for the non-dominant and dominant shoulder, and between the two groups?

2. Were there any differences in the kinematics of the shoulder between senior players (with or without shoulder pain) that were exposed to frequent overhead activity?

3. Did any of the outcomes from the playing history and clinical assessment correlate with players’ shoulder kinematics?
2 Methods

A cross-sectional study compared two separate groups of tennis players, divided for age, years of tennis experience and shoulder pain symptoms. The study included quantitative methodologies (clinical assessment including scapular UR, ROM, strength as well as flat serve kinematic measurements).

2.1 Participants

Twenty-two advanced level senior players from Bath and Weybridge clubs were recruited by means of a general information leaflet and club information emails. Interested participants were invited to participate after completing a pre-selection questionnaire (Appendix 1) that was scrutinised for inclusion and exclusion criteria set-out below.

On the assessment day, each player completed the Short Form Disability of the arm, shoulder and hand (QUICKDASH) outcome measurement (Hudak, et al., 1996, Kennedy, et al., 2011), participant information form, consent form and health questionnaire (Appendices 2, 3 and 4).

The criteria for inclusion were: ages included were between 35 to 75 years for both groups; all athletes were either good club, county or elite level; players had a minimum experience of five years and a training/match load higher than six hours per week; the symptomatic-group may have received injection therapy and must have been able to perform a flat serve; both sexes were included; and the player’s serving side was regarded as dominant and was either left or right.

Exclusions criteria included shoulder surgery, diabetes, frozen shoulder, cervical pain.

Participants were assigned to two groups:

Older Asymptomatic (OA) (n=12; 6 males and 6 females; aged 56.6 ±8.3 years; 24.8 ±16.5 playing experience years), and

Older Symptomatic (OS) (n=10; 7 males, 3 females; aged 53.7 ±13.6 years; 38.7 ±16.8 playing experience years).
2.2 Ethical & Legal statement

Ethical approval was obtained from the University of Bath Ethics Committee REACH (Research Ethics Approval Committee for Health). Participants had to provide informed written consent. All rights, safety, dignity or participants were upheld. Participants were warned that physical activity and testing may cause musculoskeletal aching and guidelines about how to manage it, was provided. Anonymous data was stored on security-protected computers. Participants were free to withdraw at any point during the study.

2.3 Assessment

Participants’ assessment included clinical assessment (Table 1) and IMU shoulder kinematic assessment (humerus and scapula), (Roldam-Jimenez, et al., 2016) during tennis serving (Table 2).

2.3.1 Clinical Assessment

A clinical assessment consisting of Body Biometrics, UR, GIR, GER and ER, IR, MT, LT strength measurements and compared to the non-dominant side (Table 1).
<table>
<thead>
<tr>
<th>Test</th>
<th>Structure/s tested</th>
<th>Method</th>
<th>Reference</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body Biometrics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Clinical Tests</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scapular upward rotation #</td>
<td>Measuring of scapular upward rotation of scapula at 0° &amp; 60° &amp; 90° Shoulder abduction, with Inclinometer</td>
<td>Measurements with inclinometer on spina of scapula. Measurements are taken of the shoulder in 30° frontal plane at 0°, 60° &amp; 90° shoulder abduction with Bubble goniometer strapped to upper arm, use 2 bubble levels, attached to inclinometer and attach ruler to inclinometer to level the scapula spine. Repeat measurement 3 times &amp; determine mean bilaterally</td>
<td>Cools, et al., 2010, 2014. Johnson, et al., 2001. Scibek &amp; Garcia 2012</td>
<td>Intra-rater reliability ICC (3,1) (0.89-0.96) validity (0.74-0.92).</td>
</tr>
<tr>
<td>Glenohumeral Internal and External rotation #</td>
<td>Measuring the passive GIR &amp; GER</td>
<td>Supine, Shoulder at 90° Abd, elbow 90° flexion, small towel under humerus – Inclinometer placed 5 cm distal from olecranon on the shaft of Ulna - measure GIR, GER, passively. The rater stabilises GHJ to avoid any scapular/trunk movement. Measure 3 times &amp; determine average bilaterally</td>
<td>Cools, et al., 2014, Kibler, et al., 2016.</td>
<td>Intra-rater reliability ICC (0.70-0.93) validity (0.74-0.81).</td>
</tr>
<tr>
<td><strong>Strength &amp; Ratio ##</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder Internal Rotators and Shoulder External Rotators</td>
<td>Measure shoulder internal and external strength</td>
<td>Supine with arm at 90° shoulder abduction 3 repetitions perform 5 sec ‘make’ test rest period of 10sec in-between tests. Calculate the mean. Determine the ratio. Compare to the non-dominant side</td>
<td>Cools, et al., 2014, Donatelli, et al., 2000.</td>
<td>Intra-rater reliability ICC (3.1) (0.97) validity (0.74-0.92).</td>
</tr>
<tr>
<td>Middle Trapezius and Lower Trapezius</td>
<td>Measure Middle and Lower Trapezius strength</td>
<td>Prone: Middle Fibres: Shoulder at 90°Abduction and external rotation. Lower Fibres: Shoulder at 145° abduction with external rotation. Investigator provides support to adduct scapula while supporting arm – all support is released and downwards pressure is applied at the level of the wrist. Investigator provide fixation downwards on the opposite scapula to avoid trunk rotation. Perform 5 sec ‘make’ test 3 repetitions with 10sec rest period in-between. Calculate the mean. Compare to the non-dominant side.</td>
<td>Cools, et al., 2010, Donatelli, et al., 2000, Kolber, et al., 2017.</td>
<td>Intra-rater reliability ICC (3.1) (0.89-0.96) validity (0.74-0.91).</td>
</tr>
</tbody>
</table>

# Range of motion and Scapular upward rotation measurements are performed with Baseline Digital Inclinometer & Baseline Bubble Inclinometer (Pro 360, Baseline® Fabrication Enterprises, White Plains, NY)
## Muscle strength measurements were performed with handheld digital dynamometer (MicroFET2®, Hoggan Health Industries, Draper, Utah, USA) with Software.
2.3.2 Inertial Shoulder Kinematics

Evaluation of the shoulder kinematics were assessed during tennis serving, by using wearable IMUs (MTw, Xsens Technology B.V., NL). This assessment was designed to respect the ecological validity of the study, since measurements were performed while playing on court (Roldam-Jimenez & Cuesta-Vargas, 2016). See Table 2.

**Table 2. Inertial Monitoring for Shoulder Kinematics**

<table>
<thead>
<tr>
<th>Test</th>
<th>Structure(s) tested</th>
<th>Method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tennis serve</td>
<td>Measure humerus and scapula linear acceleration and angular velocity</td>
<td>5-10 min of warm up followed by a sequence of flat serves with 1 min rest after every 3 serving sets.</td>
<td>Martin, et al., 2014</td>
</tr>
</tbody>
</table>

The IMU incorporating 3D accelerometers, gyroscope, and magnetometer were used to measure 3D accelerations and angular velocities of the trunk and shoulder anatomical segments of the players. Each player was equipped with 3 IMUs placed on the dominant arm on the insertion of deltoid, slightly posterior lateral on the humerus, the middle third of the upper spine of the scapula and the xiphoid sternum. That placement was described in the protocol established by Cutti, et al., (2008) and Roldam-Jimenez & Cuesta-Vargas, (2016), (Figures 1, 2 and 3). Before being positioned on players, the IMUs were calibrated while positioned in a calibration frame to align the orientation output with an earth-fixed coordinate system. The sampling frequency was set at 100HZ. The 3D accelerations and angular velocities were relative to an anatomically-related coordinated system integral to the IMUs positioned on the body segment.
Figures 1-3: Placement of the IMU’s & Axis indicators (Roldam-Jimenez & Cuesta-Vargas, 2016).

Figure 1.

Figure 2.
Figure 3.

2.3.3 Tennis Serve Simulation

The players perform a 5 to 10 minute warm-up and familiarize themselves with the testing environment and court landmarks. The players perform consecutive ‘flat’ serves by using their own racket. A 1-minute rest period was allowed between three sets of serves. The serve was performed for right-handed players by serving from the right service court and serving towards the ‘T’ of the deuce serve box. Minimal clothing was worn to limit any movement of the markers that can cause errors. Good fixation of the IMUs was ensured. The test was completed when the player completed at least three successful serves as demonstrated in Figure 4.
Figure 4. Flat serve performed while motion tracking data is being recorded
2.3.4 Statistics & Data Analysis

SPSS statistical software (SPSS) was used to calculate the statistics. All data was presented as mean ± SD and significance was accepted at p<0.05.

Anthropometric group differences for age, body mass, height and playing history, were determined using an Independent t-test.

Paired sample t-test compared the mean values of the dominant and non-dominant sides of individual groups for UR, ROM and muscles strength.

The dominant and non-dominant TROM were calculated by adding GER & GIR for each side, respectively. The between-sides TROM differences were calculated by a Paired t-test within the same group and an independent t-test between the groups.

Muscle strength values were expressed as normalised values. This was calculated by the strength measurement (N) divided by the body mass (kg) of each player. All further strength calculations were performed by using the normalised values.

Muscle strength ratios were determined by dividing the ER by the IR.

During the flat serve, kinematics was calculated by identifying the five phases of the serve: wind-up, cocking, acceleration, deceleration and follow-through. During the acceleration phase, maximal linear accelerations and maximum angular velocities were calculated as the root mean square of the sum of the square of the three different components. The average value obtained from the three successful serves were calculated.

Independent t-test compared the clinical tests and inertial kinematics during serving, for the OA-Group and OS-Groups.

Bivariate Pearson Correlation Coefficient was used to determine the relationship between the outcome of the clinical assessment and the kinematic variables.
3 RESULTS

3.1 Pre-selection Questionnaire Results

The OA-group and OS-group completed a pre-selection questionnaire, determining their tennis habits (Table 3). Both groups played tennis on average of 6.5 ±1.3 hours per week. The flat serve was preferred for 50% of both groups. Two dominant left-handed participants were included in the OS-group while only one was included in the OA-group.

Table 3. Tennis Habits: OS-and OA-Group

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>Females</th>
<th>Males</th>
<th>Hours of play per week (h)</th>
<th>Preferred Serve</th>
<th>Level of Play</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flat</td>
<td>Kick</td>
</tr>
<tr>
<td>OA n=12</td>
<td>6</td>
<td>6</td>
<td>6.5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>OS n=10</td>
<td>3</td>
<td>7</td>
<td>6.5</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

3.2 Injury record of the OS-Group

The OS-group injury record identified the following:

The average VAS pain score was determined at 3.7/10. Five participants reported nocturnal pain. The average QUICKDASH outcome measurement was determined at 19.55/100. Four players consulted a consultant orthopaedic surgeon and received magnetic resonance imaging and six players consulted a sports physiotherapist. All OS-participants were diagnosed with dominant-sided rotator cuff tendinopathy while the non-dominant side was asymptomatic.

3.3 Anthropometric data

3.3.1.1 Differences between the OS and OA-groups

Non-significant differences between-groups (Table 4).

The OS-Years of play was non-significant increased by 13.9 ±7.1 (p<0.07).
Table 4. Anthropometric Data

<table>
<thead>
<tr>
<th>Groups</th>
<th>OA (n=12)</th>
<th>OS (n=10)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Mass (kg)</td>
<td>75.4 (±12.1)</td>
<td>79.0 (±14.9)</td>
<td>3.6 (±5.9)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.9 (±6.6)</td>
<td>176.6 (±7.1)</td>
<td>2.6 (±2.9)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>56.6 (±8.3)</td>
<td>53.7 (±13.6)**</td>
<td>2.9 (±4.9)</td>
</tr>
<tr>
<td>Years of play</td>
<td>24.8 (±16.5)</td>
<td>38.7 (±16.8)**</td>
<td>13.9 (±7.1)</td>
</tr>
</tbody>
</table>

Mean value and SD standard deviation in brackets

**p<0.01 Significant correlation OS-Group Age and Years of Play

3.3.1.2 Significant Correlations

OS-group

OS-Age correlated with OS-Years of Play (p<0.01, r=0.914).

3.4 Clinical Assessments

3.4.1 Scapular Upward Rotation (UR)

3.4.1.1 Dominant and Non-dominant differences for OS and OA-groups (Table 5)

Non-significant

Table 5. Differences for Scapular Upward Rotation for the dominant & non-dominant shoulders between the OS & OA-Groups.

<table>
<thead>
<tr>
<th>Shoulder Abduction</th>
<th>0°</th>
<th>60°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ND</td>
<td>D</td>
<td>ND</td>
</tr>
<tr>
<td>OS</td>
<td>2.3° (±2.1)</td>
<td>2.4° (±2.1)</td>
<td>1.1° (±0.7)</td>
</tr>
<tr>
<td>OA</td>
<td>1.8° (±1.1)</td>
<td>1.7° (±1.1)</td>
<td>0.8° (±0.6)</td>
</tr>
</tbody>
</table>

ND: Non-Dominant   D: Dominant   OA: Asymptomatic Group   OS: Symptomatic Group

Mean value and SD standard deviation in brackets

3.4.1.2 Significant Correlations

OS-group

Dominant UR at 60° inversely correlated with dominant GIR (p<0.05, r=-0.665).
3.4.2 Glenohumeral Range of Motion

3.4.2.1 Differences between dominant and non-dominant shoulder (Table 6 and 7)

Non-significant

OS-Group

GER

Dominant GER was increased $6.4^\circ \pm 2.96$ (p=0.061) (Figure 5).

GIR

Dominant GIR was reduced $4.8^\circ \pm 3.54$.

OA-group

GER

Dominant GER was increased $14.2^\circ \pm 13.58$.

GIR

Dominant GIR was reduced $8.0^\circ \pm 4.03$.

Figure 5. Inclinometer measurement for Glenohumeral External Rotation ROM
3.4.2.2 Differences between OS and OA-groups (Table 6).

Non-significant

Dominant GER

Dominant OS-GER was reduced, 11.4°±6.30.

Dominant GIR

Dominant OS-GIR was reduced, 0.3°±7.51.

Non-dominant GER

Non-dominant OS-GER was reduced 3.6°±5.52.

Non-dominant GIR

Non-dominant OS-GIR was reduced 3.4°±6.77.
Table 6. Range of motion and Total range of motion for the Dominant and Non-Dominant sides in both groups

<table>
<thead>
<tr>
<th></th>
<th>OA-GROUP (n=12)</th>
<th>OS-GROUP (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ND</td>
<td>D</td>
</tr>
<tr>
<td>GER</td>
<td>89.2° (±21.89)</td>
<td>103.4° (±15.12)</td>
</tr>
<tr>
<td>GIR</td>
<td>90.1° (±17.32)</td>
<td>82.2° (±15.73)</td>
</tr>
<tr>
<td>TROM</td>
<td>179.3° (±24.64)</td>
<td>185.5° (±18.53)</td>
</tr>
</tbody>
</table>

Mean value and SD standard deviation in brackets
ND: Non-Dominant D: Dominant
GER: Glenohumeral External Rotation
GIR: Glenohumeral Internal Rotation
TROM: Total Range of Motion (GER + GIR)
*p<0.05 Significant correlation OS-Group Dominant GER and GIR
**p<0.01 Significant correlation OS-Group Dominant shoulder TROM, GIR and GER

3.4.2.3 Significant Correlations

OS-Group
Dominant OS-GER correlated with OS-GIR (p<0.05, r=0.695).

OA-Group
Non-significant

3.4.3 Total Range of Motion (TROM) (Table 6 and 7)

3.4.3.1 Differences between the dominant and non-dominant TROM
Non-significant

TROM OS-Group
Dominant-TROM reduced by 1.5°.

TROM OA-Group
Dominant-TROM reduced by 6.2°.

3.4.3.2 Differences between OS and OA-Groups
Non-significant
TROM Dominant shoulder differences

Dominant OS-TROM reduced by 11.7° ±10.93.

TROM Non-dominant shoulder differences

Non-dominant OS-TROM reduced by 7.0° ±4.73.

3.4.3.3 Significant Correlations

OS-TROM

Dominant OS-TROM correlated with dominant GIR and GER (p<0.01; r=0.939, r=0.900), respectively.

OA-TROM

Dominant OA-TROM correlated with dominant GIR and GER (p<0.05; r=0.621, r=0.579), respectively.

Table 7. Comparing the ROM for both groups and dominant and non-dominant sides.

<table>
<thead>
<tr>
<th></th>
<th>OA-Group</th>
<th>OS-Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>GER D vs ND</td>
<td>D increased 13.7%</td>
<td>D increased 6.9%</td>
</tr>
<tr>
<td>GIR D vs ND</td>
<td>D reduced 8.8%</td>
<td>D reduced 5.5%</td>
</tr>
<tr>
<td>GIR D OA vs OS</td>
<td>D reduced 11.1%</td>
<td></td>
</tr>
<tr>
<td>GIR D OA vs OS</td>
<td></td>
<td>D Reduced 0.4%</td>
</tr>
<tr>
<td>TROM D vs ND</td>
<td>D Increased 3.3% in relation to ND</td>
<td>D increased 0.9% in relation to ND</td>
</tr>
<tr>
<td>TROM D compared OS vs OA</td>
<td></td>
<td>D Reduced 6.3% in relation to D OA</td>
</tr>
<tr>
<td>TROM ND compared OS and OA</td>
<td>3.9% reduced in relation to OA ND-side</td>
<td></td>
</tr>
</tbody>
</table>

ND: Non-Dominant  D: Dominant
OS: Older Symptomatic Group  OA: Older Asymptomatic group
GER: Glenohumeral External Rotation  GIR: Glenohumeral Internal Rotation

3.4.4 Muscle Strength

Muscle strength of the IR, ER, MT and LT were compared, and the values were expressed as Absolute strength (N) and Normalised Values (N/kg) by dividing the values by body mass (Table 8).

3.4.4.1 Dominant and non-dominant differences

Non-significant
OS Group ER

OS-ER dominant stronger by 3.4%.

OA Group ER

OA-ER dominant stronger by 3.9%.

OS Group IR

OS-IR dominant stronger by 3.7%.

OA Group IR

OA-IR dominant stronger by 3.6%.

3.4.4.2 OS and OA-group differences

Non-significant

OS and OA ER

OA-ER dominant stronger by 8.6 %.

OS and OA IR

OA-IR dominant stronger by 9.4%.

Table 8. Muscle Strength - Normalised & Absolute Values

<table>
<thead>
<tr>
<th></th>
<th>OA-GROUP</th>
<th>OS-GROUP</th>
<th>OA-GROUP</th>
<th>OS-GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>ND</td>
<td>D</td>
<td>ND</td>
</tr>
<tr>
<td>ER</td>
<td>1.28**</td>
<td>1.23</td>
<td>1.17**</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>(±0.37)</td>
<td>(±0.41)</td>
<td>(±0.53)</td>
<td>(±0.50)</td>
</tr>
<tr>
<td>IR</td>
<td>1.49**</td>
<td>1.44</td>
<td>1.35**</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>(±0.37)</td>
<td>(±0.39)</td>
<td>(±0.64)</td>
<td>(±0.60)</td>
</tr>
<tr>
<td>MT</td>
<td>0.70</td>
<td>0.63</td>
<td>0.69**</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>(±0.18)</td>
<td>(±0.23)</td>
<td>(±0.31)</td>
<td>(±0.27)</td>
</tr>
<tr>
<td>LT</td>
<td>0.68</td>
<td>0.63</td>
<td>0.73**</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>(±0.18)</td>
<td>(±0.154)</td>
<td>(±0.29)</td>
<td>(±0.27)</td>
</tr>
</tbody>
</table>

Mean value and SD standard deviation in brackets
ND: Non-Dominant  D: Dominant
ER: External rotation strength, IR: Internal Rotation, MT: Middle Trapezius, LT: Lower Trapezius
**p<0.01 Significant correlation OS-Group dominant ER and IR
OS-Group dominant IR, dominant MT and LT
OA-Group dominant ER and IR
3.4.4.3 Significant Correlations

OS-Group

Dominant ER inversely correlated with Years of Play (p<0.05, r=-0.704). Dominant ER correlated with IR (p<0.01, r=0.846). Dominant IR correlated with dominant MT and LT (r=0.831 p<0.01; r=0.845 p<0.01), respectively.

OA-Group

Dominant ER correlated with dominant IR (p<0.01, r=0.826) and dominant GER (p<0.05, r=0.618).

3.4.5 Balance Strength Ratio ER/IR

Static balance ratio of ER/IR was determined by using normalised values (Table 9).

3.4.5.1 Dominant and non-dominant differences

Non-significant

3.4.5.2 OS and OA-group differences

Non-significant

OA-ER/IR reduced by 0.7%.

Table 9. Static ER/IR Muscle Balance Ratio (Normalised values)

<table>
<thead>
<tr>
<th>ER/IR</th>
<th>OA-GROUP</th>
<th>OS-GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>ND</td>
</tr>
<tr>
<td>Normalised % values</td>
<td>85.9%</td>
<td>85.4%</td>
</tr>
</tbody>
</table>

ND: Non-Dominant  D: Dominant

3.4.6 Inertial Shoulder kinematics (during the tennis serve)

Results of the maximal humeral and scapular linear acceleration and angular velocity are presented (Table 10). Figure 6 and 7 demonstrate the maximal humeral acceleration and scapular angular velocity during the flat serve of an OS-player.
Table 10. Maximal Segmental Linear Acceleration (m/s²) and Angular Velocity (Rad/s) during an average of flat serves

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>Humeral Linear Acceleration (m/s²)</th>
<th>Scapular Linear Acceleration (m/s²)</th>
<th>Humeral Angular Velocity (Rad/s)</th>
<th>Scapular Angular Velocity (Rad/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>103.10 (±5.94)**</td>
<td>35.60 (±12.49)</td>
<td>19.30 (±5.19)</td>
<td>12.26 (±2.87)</td>
</tr>
<tr>
<td>OA</td>
<td>59.99 (±17.24)</td>
<td>35.18 (±11.29)</td>
<td>16.67 (±4.41)</td>
<td>10.43 (±2.55)</td>
</tr>
</tbody>
</table>

Mean value and SD standard deviation in brackets
** (p<0.001) Significant difference elevated OS-Humeral Acceleration

Figure 6. IMU determined the Maximal Linear Humeral Acceleration for an OS-player during a Flat serve

Figure 7. IMU determined the Maximal Scapular Angular Velocity for an OS-player during the Flat serve
3.4.6.1 Differences between OS and OA-group (Table 10)

Maximal Linear Humeral Acceleration (Hum_a)
Significant elevated OS-Hum_a of 43.11m/s² ±5.73, (p<0.01) (Figure 8).

Maximal Linear Scapular Acceleration (Scap_a)
Non-significant elevated OS-Scap_a of 0.42m/s² ±5.21 (Figure 8).

Maximal Humeral Angular Velocity (Hum_ω)
Non-significant elevated OS-Hum_ω of 2.63 rad/s ±2.05 (Figure 9).

Maximal Scapular Angular Velocity (Scap_ω)
Non-significant elevated OS-Scap_ω of 1.82 rad/s ±1.07 (Figure 9).

**p<0.001 Maximal Linear Humeral Acceleration significant difference between groups

Figure 8. OS and OA-group differences of Maximal Linear Humeral (p<0.001) and Scapular Acceleration during the Flat serve
3.4.6.2 Significant Correlations

**OS-Group**

An inverse correlation between Hum_a and dominant GIR and TROM (p<0.01, r=-0.777; p<0.05, r=-0.660), respectively, existed. Hum_a correlated with Hum_ω (p<0.05, r=0.864). An inverse correlation between Scap_a and Age (p<0.05, r=-0.636), was found. Scap_ω correlated with Scap_a (p<0.01, r=0.865) and dominant UR at 60° (p<0.05, r=0.676), respectively. Inverse correlations between Scap_ω and dominant GIR and TROM (p<0.05, r=-0.668; r=-0.701), respectively, were found.

**OA-Group**

Scap_ω correlated with dominant ER (p<0.05, r=0.065).

4 Discussion

The aim of the study was to determine the differences of the clinical assessment of dominant and non-dominant shoulders of groups of older overhead players in attempt to understand what effect age, years of play and pain have on ROM and muscle strength. By analysing differences in the kinematics of the shoulder in terms of maximal angular velocity and linear acceleration, the study
hypothesises that differences in kinematics will be found between the groups and these differences will correlate with the results of the clinical assessment.

4.1 Anthropometrics

The groups of players had similar characteristics in terms of age, height and body mass. The OS-age significantly correlated with the OS-playing years, and inversely with OS-Scap_a, which was not present for the OA-group. Previously, it has been shown that age will reduce Scap_a and Hum_a in certain planes, in comparison to the young, (Roldan-Jimenez & Cuesta-Vargas, 2016). However, in the current study a minimal Scap_a difference (1.2%) was found between-groups, possibly due to group similarities. Age and number of years played would affect painful shoulder joints causing scapula dyskinesia and weakness, that may influence Scap_a, (Kibler, et al., 1996; Ludewig & Cook, 2000).

4.2 Scapular Upward Rotation

The groups had similar UR characteristics without any significant differences between-sides and between-groups. When comparing the dominant and non-dominant OA-UR at 60° and 90°, calculations showed that the dominant-side OA-UR increased by 20% and 7%, respectively. Conversely, an 18% reduction of dominant OS-UR at 60° was shown and dominant OS-UR at 60° inversely correlated with dominant OS-GIR (p<0.05).

Cools et al. (2010), determined that young overhead athletes present with performance adaptations, such as increased scapular UR during arm elevation, to prevent the acromion from impinging on the sub-acromial structures. That study compared the dominant and non-dominant UR of young healthy tennis shoulders and showed that the UR of the dominant shoulder were often increased. Comparable results were found in this study for the OA-group. Throwing athletes usually suffer shoulder impingement signs from 60° of abduction (Fleisig, et al., 1996). Age-related changes could
affect scapula-thoracic kinematics (Roldan-Jimenez & Cuesta-Vargan, 2016), causing a reduced UR during shoulder abduction, that change scapular orientation, decrease posterior tilt and increase thoracic kyphosis, (Endo, et al., 2004.). Shoulder kinematics could be altered if pathology is present (Ludewig & Reynolds 2009). Aging and shoulder degeneration influence shoulder movement (Moor, et al., 2014). Recently, it was shown that rotator cuff tendinopathy will delay the scapular muscle activation which will influence the scapular kinematics, especially UR at approximately 60°-120° abduction, (Leong, et al., 2017). The OS-dominant UR at 60° correlated with OS-Scap._ω. By group-comparison, the OS-Scap._ω was increased by 15.5%, indicating the importance of strengthening the scapular musculature to improve UR, (Meyer, et al., 2008).

Furthermore, the UR measurement-values were lower in comparison to previous studies involving younger players with higher UR- values (Cools, et al., 2010). However, during the current study, the UR-values were lower, possibly due to older age groups and reduced ROM.

4.3 Muscle strength

The two groups had similar muscle strength without any significant difference between sides or between groups, for normalised strength values. When comparing group-differences for the dominant and non-dominant ER, the dominant OA-ER was increased (8.6%), as well as the non-dominant OA-ER (8.1%), indicating the OA-ER was stronger than the OS-ER.

The glenohumeral-joint is highly dependent on functional stability provided by the dynamic musculature. During the serve acceleration phase, the function of the strong internal rotators must perform a concentric action to increase the humeral internal rotation torque, until ball contact is reached. During the deceleration phase, the weaker external rotators must decelerate the humerus by contracting eccentrically, demonstrating the intricate balance between these muscles groups during the stretch-shortening cycle, (Noffal, 2003).

During this study, static muscle ratios determined were similar between-sides and groups (Table 9). In the current study the dominant OA-ratio was 85.9%, while the OS-ratio was 86.6%. Although
other studies assessed eccentric/concentric ratios (Johansson et al., 2015), others have studied static ratios and found that these ratios ought to be 65-70% ER/IR, (Cools, et al., 2014).

According to Cools et al.(2015), muscle strength of the dominant ER and IR ought to be 10% stronger in comparison with the non-dominant side. The differences of ER and IR strength between the dominant and non-dominant sides of both groups were in the range of 3.5-3.8% - lower than the guidelines for both groups. As part of injury prevention, exercise programmes should include strengthening of the musculature, especially the posterior rotator cuff that include concentric and eccentric exercises that mimic the stretch-shortening throwing cycle, plyometrics and absolute strength training (Cools, et al., 2015; Ellenbecker & Roetert, 2004; Martin, et al., 2016).

The dominant OS-ER had a significant inverse correlation with OS-years of play. By comparing between-groups years of play, OS-years of play was slightly elevated by 13.9 ±7.1 (p<0.07), which may have influenced this group correlation value. However, this still indicate that the ER will reduce with increased play (and possibly age) and compare to findings by Marcondes, et al., (2013).

4.4 Range of Motion

Martin, et al. (2016) showed that GIR and TROM reduced but GER did not increase much after playing tennis for a long duration. In the current study, by comparing the dominant and non-dominant sides of the two groups, the GER increased slightly for both groups on the dominant sides and dominant OA-GER showed a higher increase.

Other authors showed that GIR is affected by increased exposure to serving (Kibler, et al., 1996, Kibler, et al., 2013), and argued that the reduction of GIR and TROM is due to the overuse of the posterior shoulder structures as the repeated eccentric action decelerates the humeral head, during the serve deceleration phase. Although it is believed that this is a physiological response due to serving, it is suggested that an accumulative effect cause harm when GIR and TROM is reduced, over a longer period, (Reinold, et al., 2008). Posterior capsule thickening, posterior cuff muscle tightness, anterior humeral head displacement resulting in instability, labrum tears, and adaptation that
include osseous retrotorsion of the humerus, are commonly associated with glenohumeral internal rotation deficit (GIRD), (Burkhart, et al. 2003; Reinold, 2008; Noonan, et al., 2015). GIRD may also vary depending on the population that is assessed, (Kibler, et al., 2012). It was concluded that any GIRD between 11-18° and TROM reduction of 5°, compared to the non-dominant shoulder, place the shoulder at risk of injury or indicate pathology, (Wilk, et al., 2011; Cools, et al.,2015). In the current study, GIR reduced less for both groups’ dominant sides while the OA-GIR reduced more than the OS-GIR. Therefore, an increased OA-GER and a small reduction of OS-GIR was present, when comparing the groups. When comparing TROM between-groups, a greater reduction was shown for the OS-TROM (Table 7).

Furthermore, the evident OS-GIRD and reduced OS-TROM may potentially have a negative effect on ball velocity and therefore performance (Cohen, et al., 1994), which implies that more stress was placed on the OS-glenohumeral-joint to perform to the same level as their OA-counterparts.

A study that compared children and adult ROM, suggested that age-related changes will increase glenohumeral stiffness resulting in further ROM (and TROM) restrictions, (Dayanidhi, et al.,2005). The dominant OS-GIRD and OS-TROM significantly correlated (p<0.01). The smaller OS-GIR and TROM values (Table 7), were less than the previously mentioned critical values by Wilk (2011), indicating that although the ROM was not critically reduced, the OS-GIRD and OS-TROM must have had a negative effect due to the OS-group’s pathology.

For Injury prevention, it is suggested that GIR and TROM be monitored and flexibility maintained, (Wilk, et al., 2011), by stretching the posterior shoulder structures, for instance performing sleeper and horizontal adduction stretches, (Cools et al 2015; Pellengrini, et al., 2016).

4.5 Inertial shoulder Kinematics

Studies have demonstrated that age and pathology will influence angular velocity. Roldan-Jimenez and Cuesta-Vargas, (2016), demonstrated that shoulder angular velocity increased for healthy younger groups when compared to the aged. Jolles, et al., (2011), showed that progress after
shoulder arthroplasties could be measured by assessing the increase in angular velocity, monitored over a year.

The OS-group with increased age and shoulder pathology, demonstrated increased Hum_\(\omega\) (13.6\%) and Scap_\(\omega\) (14.9\%). OS-Scap_a inversely correlated with OS-, while OS-Scap_a correlated with OS-Scap_\(\omega\). Elliott et al., 1995, determined that the average maximal internal rotation angular velocity at ball impact for young, elite male tennis players are 33.0 rad/s, during the serve. Internal rotation angular velocity is the main determinant that can improve racket head velocity (up to 54.2\%) and this can reach values up to 5580 degrees/s (\(\approx\) 97 rad/s), as calculated in later studies on elite overhead sports, (Wagner, et al., 2012). During the current study the angular velocity was much lower for both groups, possibly due to the level of players and their progressive age.

By performing the flat serve, the OS-Hum_a was significantly increased, when compared to OA-Hum_a, (42\%, \(p<0.001\)), but no significant difference was noted between-groups Scap_a.

Since OS-Hum_a correlated with OS-Hum_\(\omega\) (\(p<0.05\)), the OS-players who had a slightly higher OS-Hum_\(\omega\) reached a much higher OS-Hum_a. However, the reduced ROM when measuring OS-TROM and OS-GIR was inverse correlated to an elevated OS-Hum_a and OS-Scap_\(\omega\), when reaching peak angular velocity, during serving. Thus, the OS-Group, with a limited ROM, could potentially have been required to perform the serving task by increasing the Hum_\(\omega\) and Scap_\(\omega\), indicating a much higher required force and joint stress to complete the serve.

Although no correlation could be found for the OS-ER, a significant correlation between OA-Scap_\(\omega\) and dominant shoulder ER (\(p<0.05\)), was established. If the GIR and TROM was reduced, the player had to increase the ER muscle activity to increase the Hum_a. This could potentially cause an increase demand on the muscular structures and joint stress. The reduced OS-ROM increased stress on shoulder structures that may have caused the group to amend their technique resulting in an increased Hum_a, Hum_\(\omega\) and Scap_\(\omega\), during serving. A small study, assessed young female tennis players with shoulder pain. It found that they modified their technique by reducing GER and
abduction, during the cocking-end phase of the serve (Gillet, et al., 2018). This implies that technique modification can take place to produce the serve, which correlates with the OS-group. Even though the shoulder ROM has not been measured and calculated in this study, the current results compared with another study that assessed different volleyball spike techniques. During the modified spike, shoulder flexion and external rotation ROM were limited when performing the modified technique, which proved to be a safer alternative technique. This technique placed less stress on the joint and produced a higher rotational angular velocity, (Seminati, et al., 2015), which may also be relevant during this tennis serve. Pain caused by structural changes and reduced GIR flexibility will be improved by performing sleeper stretches and across-body horizontal adduction stretches, hold relax and contact relax methods to increase ROM, (Tucker & Slone, 2015).

4.6 Limitations and Further research

The limitations include a small sample size and the reduced OS- and OA-differences that existed. Due to the lower OS-QUICKDASH and VAS-pain scores, differences between the OS and OA groups were limited, however, it was crucial for the OS-participants to be able to perform a sequence of serves. The considerations discussed about the serve technique were based only on linear acceleration and angular velocity data. Recommendations for further research is to analyse the surplus ROM data that was captured during inertial tracking of serving, to determine the varied techniques executed at different joint levels.

5 Conclusion

A comparison was made between symptomatic shoulder pain and asymptomatic senior tennis players, by means of clinical and kinematic differences and correlations. OS-Hum_a demonstrated a significant increase when comparing it to OA-Hum_a. By comparing the dominant and non-dominant shoulder, non-significant differences for dominant OS-GIR and OS-TROM were established and had an inverse correlation with OS-Hum_a. By comparing between groups, the OS-TROM
reduced and OS-Hum_a increased. It is proposed that the symptomatic players may modify their serving technique by adapting kinematic adjustments due to a reduced available ROM, resulting in higher stress placed on the shoulder joint and muscular structures. This highlights the benefit of stretches for the posterior shoulder structures, to reduce injury risk.

Word count 4283
6 References


**Webpage**

7 Appendices
7.1 Appendix 1

Questionnaire Information

The Player screening tool to be published on a website. Tennis players that like to participate in the study will be able to access the form online. The data will be captured by the form will be emailed to the researchers and added into a spreadsheet.

The Questionnaire will be accessible at the address

http://www.meyerphysio.com/survey/shoulder-study/

Currently this address is blocked until Ethical approval has been received

### Shoulder Study Questionnaire

If you are a Tennis Player and would like to participate in our Shoulder Study, please fill in the Questionnaire below and we will contact you with further details.

The Questionnaire should take no longer than 10 minutes to complete.

### Personal Information

<table>
<thead>
<tr>
<th>Name and Surname</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

### Player Information

1. Gender
   - [ ] Male
   - [x] Female

2. Date of Birth

3. Age in Years

### Sporting History

4. Current Level of Competition
   - [ ] Club level
   - [ ] County level
   - [ ] Elite level
<table>
<thead>
<tr>
<th><strong>5. How many hours of tennis do you play per week?</strong> (Including on-court training and matches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Comments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>6. Years of Playing Tennis</strong></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>7. Which is your Dominant Hand?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Right</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>8. Type of Serve used most frequently</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
</tr>
<tr>
<td>Slice</td>
</tr>
<tr>
<td>Kick</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

**Shoulder**

<table>
<thead>
<tr>
<th><strong>9. Do you have any Shoulder Pain?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No (If No please proceed to Question 18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>10. Which side is the pain?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Right</td>
</tr>
<tr>
<td>Both</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>11. How much is your Pain Score on a Scale of 0 (no pain) to 10 (extreme pain)?</strong></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>12. When did the pain start</strong></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>13. Do you have Pain at Night?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>14. Can you Serve with your pain?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

**Injury Diagnosis**

<table>
<thead>
<tr>
<th><strong>15. Did you consult any of these professionals about your shoulder pain?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiotherapist</td>
</tr>
<tr>
<td>GP</td>
</tr>
<tr>
<td>Shoulder Consultant</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Question</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>16. If you have seen a clinician, what was their diagnosis?</td>
</tr>
<tr>
<td>17. Have you had any Imaging (X-Rays/ Ultra-sound/ MRI) scans taken of your shoulder?</td>
</tr>
<tr>
<td>Medical History</td>
</tr>
<tr>
<td>18. Do you suffer from Cervical Pain?</td>
</tr>
<tr>
<td>19. Do you suffer from Frozen Shoulder?</td>
</tr>
<tr>
<td>20. Do you suffer from Diabetes?</td>
</tr>
<tr>
<td>21. Have you had any Shoulder Surgery in the last 12 months?</td>
</tr>
<tr>
<td>22. Have you had any Shoulder Infiltrations?</td>
</tr>
</tbody>
</table>
7.2 Appendix 2

QUICKDASH OUTCOME MEASUREMENT

Short form of The Disabilities of the Arm, Shoulder and Hand Score (QuickDASH), (Kennedy, et al., 2011).

To be completed only by Tennis Players with Shoulder Pain.


(http://www.dash.iwh.on.ca/)

<table>
<thead>
<tr>
<th>Clinician’s name (or ref)</th>
<th>Patient’s name (or ref)</th>
</tr>
</thead>
</table>

**INSTRUCTIONS:** This questionnaire asks about your symptoms as well as your ability to perform certain activities. Please answer *every question*, based on your condition in the **last week**. If you did not have the opportunity to perform an activity in the past week, please make your **best estimate** on which response would be the most accurate. It doesn't matter which hand or arm you use to perform the activity; please answer based on you ability regardless of how you perform the task.

**Please rate your ability to do the following activities in the last week.**

<table>
<thead>
<tr>
<th>Activity</th>
<th>No difficulty</th>
<th>Mild difficulty</th>
<th>Moderate difficulty</th>
<th>Severe difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Open a tight or new jar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Do heavy household chores (eg wash walls, wash floors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Carry a shopping bag or briefcase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Wash your back</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Use a knife to cut food</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational activities in which you take some force or impact through your arm, shoulder or hand (eg golf, hammering, tennis, etc)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. During the past week, <strong>to what extent</strong> has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?</td>
<td>Not at all</td>
<td>Slightly</td>
<td>Moderately</td>
<td>Quite a bit</td>
<td>Extremely</td>
</tr>
<tr>
<td>7. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?</td>
<td>Not limited at all</td>
<td>Slightly limited</td>
<td>Moderately limited</td>
<td>Very limited</td>
<td>Unable</td>
</tr>
</tbody>
</table>

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Please rate the severity of the following symptoms in the last week

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Arm, shoulder or hand pain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Tingling (pins and needles) in your arm, shoulder or hand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand?</td>
<td>No difficulty</td>
<td>Mild difficulty</td>
<td>Moderate difficulty</td>
<td>Severe difficulty</td>
<td>So much difficulty I can't sleep</td>
</tr>
</tbody>
</table>

10. Select which best describes your physical ability in the past week. Did you have any difficulty.....

<table>
<thead>
<tr>
<th></th>
<th>No difficulty</th>
<th>Mild difficulty</th>
<th>Moderate difficulty</th>
<th>Severe difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Using your usual technique for playing your instrument or sport?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Playing your musical instrument or sport because of your arm, shoulder or hand pain?</td>
<td></td>
<td></td>
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<tr>
<td>3. Playing your musical instrument or sport as well as you would like?</td>
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<tr>
<td>4. Spending your usual amount of time practising or playing your instrument or sport?</td>
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</tr>
</tbody>
</table>

Thank you very much for completing all the questions in this questionnaire.

Applied Biomechanics Suite, 1.308
BA2 7AY, BATH (UK)
7.3 Appendix 3

Participant Information

7.3.1 Researchers

Suegnet Meyer (Chartered Physiotherapist, University of Bath MSc Student), Dr Elena Seminati (University of Bath Research Associate, Department of Biomechanics, Research Supervisor) and Dr Ezio Preatoni (Assistant Professor in Biomechanics & Motor Control, Second Supervisor).

7.3.2 Study Purpose

The study aims to determine the effects of repeated overhead movements of the glenohumeral and scapula-thoracic region of 3 different groups of tennis players. By analysing differences in the kinematics of the shoulder in terms of angular mobility and linear acceleration the study hypothesis is that differences in mobility and acceleration will be found between both groups and these differences correlate with the results of the clinical assessment.

These findings will provide new insights into the causes of shoulder pathologies and the aging process of the tennis players. Furthermore, the results will provide guidelines for coaches and physiotherapists and the tennis population, who may stay active longer - promoting activity and longevity.

7.3.3 Background

Many tennis players suffer shoulder injuries causing them to stop playing tennis. These injuries are most likely caused by a combination of frequent playing for many years. This cause repetitive strain and injuries of the shoulder joint. Many studies have been performed on young healthy tennis players without shoulder pain. No comparative studies have been performed to assess older players with and without shoulder pain to younger healthy players.

7.3.4 What does the study involve?

You will be asked to attend a session where clinical assessment and an on-court session will take place. Confidential data will be collected on how your shoulders move during day to day actions and while your serve.

7.3.5 Participant selection

You have been invited to this study to assess both your shoulders. You are selected based on the following criteria

- You are a tennis player
- You are between the age of 13-21 years or 35-75 years
- You play more than 6 hours per week tennis,
- You play high club/county/elite level tennis,
- You may suffer dominant sided shoulder pain or not.
7.3.6 Methods

Your shoulder condition is assessed via specific shoulder clinical tests (non-invasive) and measurements are taken to evaluate how the segments of your arm move. Muscle strength and range of motion is measured by using dedicated equipment, non-invasively. The shoulder movements and the way you serve is measured by placing small non-invasive inertial sensors on your trunk and upper arm. You will then be asked to serve 5 times while recordings are taken. You will be asked to attend 1 session with a duration of approximately 90 minutes.

7.3.7 Benefits of Involvement

Each participant will benefit from receiving customised study results of identifying shoulder injury risk components that should be addressed and/or communication to their coaching staff. Indirect benefits to the wider sports community will be provided by improving treatments and minimising the risk of future injury in players of all ages and abilities. The outcome will be applicable to tennis or other overhead sports for instance cricket and volleyball.

7.3.8 What risks are involved?

Taking in consideration the level of player you are, no real risks are involved. You may have slight aching muscles after the assessment. This will be no more than the normal feeling after a match/training. None of the assessment techniques are invasive or present any risk to you.

7.3.9 Freedom of consent

Your participation during this study is voluntary. You may ask question at any time before or during the study. You may decline consent or withdraw from the study without any penalty, at any time. Please advise the researchers of this decision, as soon as possible.

7.3.10 Ethical Approval

This study has been reviewed by and ethical clearance by the University of Bath - Research Ethics Approval Committee for Health (REACH).

7.3.11 Confidentiality, Data & Results

Confidentiality of personal data and study results will be upheld. All manuscripts, reports or publications will utilise study coding instead of individual names. All study information will be stored anonymously on password protected PCs when doing the study and at the University of Bath. Unnecessary personal information will be limited and if not required, be destroyed as soon as possible. Regulations will be maintained accordingly to the Data Protection Act. Anonymous data sets will be archived at the University of Bath Code of Practice – Research and be stored for a minimum of five years.
7.3.12 Enquiries

Potential participants can ask more questions about the study before they decide whether to participate by contacting any of the researchers or asking the researcher present when signing the consent form.

Contact: Mrs. Suegnet Meyer; tel: +44 (0) 773 6731022; email: suegnet@meyerphysio.com
7.4 Appendix 4

Informed Consent and Medical Health Questionnaire

I have been given information about the named study above. I have discussed any queries about participation with the research team (Dr Elena Seminati, Suegnet Meyer)

I understand that by consenting to participate in this study, I will be asked to:

- attend the clinical assessment and on-court testing session.
- have my body mass and height assessed
- have my shoulder movements recorded by a motion capture system
- perform simulated serves on-court that will be captured and analyzed
- have my shoulder strength measured during maximal static contractions
- have my shoulder range of motion measured
- have my shoulder clinically be assessed

I confirm that I:

- have read the participant information sheet;
- have had the opportunity to ask questions about the study and have received satisfactory answers to questions, and any additional details requested;
- understand that I may withdraw from the study without penalty at any time by advising the researchers of this decision;
- understand that this project has received ethics clearance through the Research Ethics Approval Committee for Health (REACH) of the University of Bath;
- understand who will have access to the data, how the data will be stored, and what will happen to the data at the end of the project;
- understand that if I have concerns or complaints about the way this research has been conducted I can contact the Research Ethics Approval Committee for Health (Secretary to REACH, Department Administrator, Department for Health, University of Bath, Claverton Down, Bath, BA2 7AY) in the first instance;
- agree to participate in the study;
- consent for the research team to use any photographs or videos of my person for written or oral presentations such as scientific journal articles, conference presentation and reports, ensuring my anonymity is preserved at all times.

Please tick the following statements and sign & date where indicated.

☐ I confirm that I have played for 5 or more years of high competitive level tennis.
☐ I confirm that I am between the age of 35-75 years.
☐ I confirm that I am currently able to perform a tennis serve sufficiently.

Informed Consent & Health History Questionnaire

I have been given information about the named study above. I have discussed any queries about participation with the research team (Dr Elena Seminati, Mrs Suegnet Meyer)

I understand that by consenting to participate in this study, I will be asked to:
• attend the clinical assessment and on-court testing session.
• have my body mass and height assessed
• have my shoulder movements recorded by a motion capture system
• perform simulated serves on-court that will be captured and analyzed
• have my shoulder strength measured during maximal static contractions
• have my shoulder range of motion measured
• have my shoulder clinically be assessed

I confirm that I:

• have read the participant information sheet;
• have had the opportunity to ask questions about the study and have received satisfactory answers to questions, and any additional details requested;
• understand that I may withdraw from the study without penalty at any time by advising the researchers of this decision;
• understand that this project has received ethics clearance through the Research Ethics Approval Committee for Health (REACH) of the University of Bath;
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<table>
<thead>
<tr>
<th>Participant’s name</th>
<th>Participant’s signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLEASE FILL USING CAPITAL LETTERS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Researcher’s name</th>
<th>Researcher’s signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLEASE FILL USING CAPITAL LETTERS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please tick the following statements and sign & date where indicated.

☐ I confirm that I have played for 6 or more years of high competitive level tennis.
☐ I confirm that I am between the age of 35-75 years.
☐ I confirm that I am currently able to perform a tennis serve sufficiently.
Health History Questionnaire

<table>
<thead>
<tr>
<th>Date of Birth</th>
<th>Sex</th>
<th>Weight</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>(dd/mm/yyyy)</td>
<td>(M/F)</td>
<td>[kg]</td>
<td>[m]</td>
</tr>
</tbody>
</table>

Please answer the following questions by circling the correct answer

- Have you suffered with chest pain in the last month? [Yes] [No]
- Have you ever experienced chest pain whilst exercising? [Yes] [No]
- Have you ever been made aware by a medical professional that you have a heart condition, epilepsy or blood pressure problems and that physical activity is contra-indicated? [Yes] [No]
- Are you taking any prescription medication for blood pressure, heart conditions, blood thinning (Warfarin) or Diabetes? [Yes] [No]
- Do you suffer from vertigo or loss of balance? [Yes] [No]
- Do you suffer from anxiety or drop attacks? [Yes] [No]
- Do you have any problems with hips, knees, ankles or spine that will be exacerbated by exercise? [Yes] [No]
- Do you have any problems with your elbows or wrists that will be exacerbated by exercise? [Yes] [No]
- Is there any reason why you are not allowed to do exercises? [Yes] [No]

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