Original Research

The Immediate Effects of Serving on Shoulder Rotational Range of Motion in Tennis Players

ABSTRACT

Objective: This study aimed to investigate the immediate effects of serving on shoulder rotational range of motion (ROM) in tennis players by comparing to groundstrokes.

Design: Same-subject, randomised, crossover study.

Setting: Indoor hard courts.

Participants: Eighteen male and 12 female professional and university level tennis players.

Main outcome measures: Passive glenohumeral internal and external rotation ROM measurements, using a digital inclinometer, were undertaken at baseline and immediately following serving and groundstroke tasks on both dominant and non-dominant shoulders. Total rotation was calculated as the sum of internal and external rotation.

Results: On the dominant and non-dominant shoulders there was no significant interaction effect between the factors of tennis task (serving and groundstrokes) and time (pre and post) (p = <0.05). Indicating that change in rotational ROM was not specific to tennis task. On the dominant shoulder there was a significant main effect of time (p = 0.007), with internal, external and total rotational ROM decreasing irrespective of tennis task.

Conclusion: Both tennis tasks resulted in immediate significant reductions in shoulder rotational ROM on the dominant shoulder but not the non-dominant shoulder of professional and university tennis players. There was no significant difference between serving and groundstroke tasks.

Clinical Trial Registration Number: researchregistry1956

Keywords: Tennis; Serve; Shoulder; Range of Motion

1. Introduction

Competitive tennis players undergo a constant programme of tournaments and events that take place throughout the year (Fernandez, Mendez-Villanueva & Pluim, 2006). Tennis stroke production involves the generation of serves and groundstrokes that are of high intensity and short duration, with matches lasting on average between 1 hour 30 minutes to 4 hours; depending on the level of tournament played and whether the player is female or male (Reid & Duffield, 2014). High training volume and competition exposure can make players susceptible to risk of injury (Myers, Sciascia, Kibler & Uhl, 2016).

There has been a wide variation in the overall reported incidence and prevalence of injuries in tennis, across recreational, collegiate and professional level players (Dines *et al*, 2015). A review conducted between 1966 – 2005, reported injuries as ranging from 0.04 to 3.0 per 1000 hours played, with injuries per player ranging from 0.05 to 2.9 per year (Pluim, Staal, Windler & Jayanthi, 2006). Upper limb injuries have been found to account for 20 – 49 percent (%) of injuries, with the shoulder and elbow being most frequently injured and reported as overuse in nature (Dines *et al,* 2015; Abrams, Renstrom & Safran, 2012).

Commonly reported injuries to the shoulder include subacromial pain syndrome, rotator cuff pathology and superior labrum anterior and posterior (SLAP) tears (Lintner, Noonan & Kibler, 2008). Epidemiological studies have associated the serve with these overuse injuries as a potential cause, which have been found to be common in all levels of competitive tennis, although there is no evidence to disprove groundstrokes (Dines *et* *al*, 2015; Abrams *et al*, 2012). This is because during service games there are more serves reported per game than any other type of stroke, accounting for 45 – 60% of strokes from 616 games analysed at the 2003 French Open and Wimbledon Championships respectively (Johnson & McHugh, 2006). During the repetitive overhead motion of the serve the shoulder is the focal point for force transfer and contributes to 20% of the total force generated during the stroke (Reid, Elliott & Alderson, 2007). The shoulder is also the most mobile joint in the body, with its anatomical design allowing for a wide range of motion, leading to a fragile equilibrium between stability and mobility when serving (Van der Hoeven & Kibler, 2006).

Overhead athletes are reported to experience anatomical changes of their shoulders over time, such as thixotrophy (increased passive stiffness) of the external rotators, thickening of the posterior glenohumeral joint capsule, as well as retroversion of the humeral head (Van der Hoeven & Kibler, 2006). These changes have not been confirmed in tennis players, but a decrease in dominant shoulder internal and total rotation, in comparison to the non-dominant shoulder, has been found in both junior and senior tennis players (Schmidt-Wiethoff, Rapp, Mauch, Schneider & Appell, 2004; Ellenbecker, Roetert, Bailie, Davies & Brown, 2002). This decrease in range has been found to correlate with increasing years of tennis practice and play, as well as a player's age (Moreno-Perez, Moreside, Barbado & Vera-Garcia, 2015; Kibler, Chandler, Livingston & Roetert, 1996). This adaptation is theorised to exist as a result of the follow through of the serve, requiring the dominant shoulder to decelerate through eccentric action of the external rotators, to slow internal rotation of the shoulder and therefore arm motion (Ellenbecker & Wilk, 2017; Kibler *et al*, 2013). This has not been confirmed by empirical research.

A normal variation occurring in the dominant shoulder of overhead athletes is an anatomical glenohumeral internal rotation deficit (aGIRD) (Manske, Wilk, Davies, Ellenbecker & Reinold, 2013). This is a difference in internal rotation between the dominant and non-dominant shoulders of less than or equal to 18 – 20 degrees, with a corresponding symmetry of total range of motion (TROM) (sum of internal and external rotation) of less than 5 degrees. However when this deficit becomes larger (loss in dominant shoulder internal rotation that is greater than 18 – 20 degrees, with a corresponding loss of TROM of greater than 5 degrees, when compared with the non-dominant shoulder), is termed a pathological GIRD (pGIRD) (Kibler, Sciascia & Thomas, 2012a). This has been identified as a risk factor for shoulder injuries in overhead athletes, due to causing a shift in the humeral head instant centre of rotation on the glenoid (Wilk *et al*, 2011). Most recently the concept of an external rotation deficiency (ERD) (loss in dominant shoulder external rotation that is greater than 5 degrees, when compared with the non-dominant shoulder), has also been highlighted as a risk factor in overhead athletes for shoulder injuries (Wilk *et al*, 2015).

Several studies have reported that short term changes to shoulder ROM are dependent on athletic exposure in the sporting environment (Martin, Kulpa, Ezanno, Delamarche & Bideau, 2016; Moore-Reed, Kibler, Myers & Smith, 2016; Kibler, Sciascia & Moore, 2012b). Martin *et al* (2016) investigated changes in dominant shoulder passive rotation during and immediately after competitive tennis play, in 8 professional adult males undertaking 3 hour matches. Measurements were undertaken with a goniometer, but rater reliability statistics to calculate standard error of measurement (SEM) and minimal detectable change (MDC) were not reported. There was a significant decrease in internal rotation from pre warm up to immediately after match play (20.8 degrees) (p = 0.005). The most significant decrease was following 90 minutes. There was also a significant decrease in TROM from pre warm up to immediately after match play (24.6 degrees) (p = 0.001). The most significant decrease was following 30 minutes. The serve was implicated for these changes however as it was not directly compared to groundstrokes during this study its claim cannot be supported.

In contrast, Moore-Reed *et al* (2016) investigated changes in dominant shoulder passive rotation after competitive tennis play in 79 professional adult females from 4 tournaments, undertaking a maximum of 3 set matches. Measurements were undertaken with a digital inclinometer and interday intra-rater reliability was established for internal rotation (intra-class correlation coefficient ($ICC_{2,1}$) = 0.80, SEM = 2.8 degrees, MDC = 4.0 degrees), external rotation ($ICC_{2,1}$ = 0.91, SEM = 4.7 degrees, MDC = 6.6 degrees) and total rotation ($ICC_{2,1}$ = 0.91, SEM = 4.7 degrees, MDC = 6.6 degrees). There was a significant decrease in internal rotation from baseline to immediately after match play (4 degrees) (p =0.002) and from baseline to 24 hours after (5 degrees) (p = 0.001). There was also a significant decrease in TROM from baseline to immediately after match play (4 degrees) (p = 0.04). The percentage of measurements greater than MDC (demonstrating with 95% certainty that changes in shoulder ROM were attributed to tennis play rather than measurement error), was 17 – 24% for internal rotation and 14% for total rotation. Similarly the serve was also implicated for these changes and was not directly compared to groundstrokes during this study, so its claim cannot be supported. Researchers from both studies did not establish the anatomical and physiological basis behind these short term changes to shoulder ROM, but hypothesised posterior muscular tightness from repetitive eccentric contractions, based upon the amount of change and length of time the changes took (Martin *et al*, 2016; Moore-Reed *et al*, 2016).

If findings from these studies are generalisable it might suggest potential shoulder injury risk for tennis players training or competing back to back over 24 hours, who develop a pGIRD or ERD and do not regain full ROM between training sessions or matches (Manske *et al*, 2013). Furthermore these ROM deficits may persist even longer, as measurements were only recorded in one of the studies up to 24 hours following tennis (Moore-Reed *et al*, 2016). This might suggest a need for resolution or improvement of rotational ROM prior to training and match play, to reduce the potential risk of shoulder injury. However we cannot infer from these studies, as only ROM measurements on the dominant shoulder were recorded and were not directly compared with the non-dominant shoulder to enable detection of a pGIRD or ERD. There is currently speculation that the serve in particular is responsible for these changes in shoulder rotational ROM in tennis players, but there is no evidence to support this. This study therefore aims to investigate the immediate effects of serving on shoulder passive rotational ROM in tennis players by comparing to groundstrokes, on both dominant and non-dominant shoulders.

2. Method

2.1 Design

An invitation email including a participant information sheet was circulated to competitive tennis players, by the performance director of an International High

Performance Centre (IHPC). A convenience sample of the first 30 who responded was selected. An experimental same-subject crossover design was used. Research assistant A allocated participants into either serving or groundstroke tasks in advance, through selecting concealed names at random. Each participant then undertook the allocated tasks and the order of participation in the tasks was reversed a minimum of one week later, to counterbalance order effects. Data was collected at least 48 hours after their last training session or match, to allow for sufficient recovery whilst not impeding preparations. The study was given ethical approval by the ethics committee of two universities in the South of England. All participants gave written informed consent prior to participation.

2.2 Participants

Tennis players were aged between 18 – 30 years (mean 20 years). Eighteen were male and 12 were female. Fifteen participants were recruited from an IHPC, 8 from a University Tennis Club first team and 7 from a second team (Table 2.1). Participants with previous shoulder stabilisation surgeries and spinal / upper / lower limb injuries and disabilities requiring medical attention 3 months prior to testing were excluded.

Hand Dominance	**Backhand Style**	**Years of Playing Experience**
26 right handed	25 double handed	Ranged between 7 – 24 years (mean 14 years)
4 left handed	5 single handed	

Table 2.1: Participant hand dominance, backhand style and years of playing experience.

2.3 Procedures

In preparation for the shoulder ROM measurements participants' olecranon and ulna styloid processes, and the midpoint between these landmarks, were marked by the researcher using a temporary marker, on arrival at the indoor hard courts. Each participant then undertook a 15 minute standardised general body warm up (Appendix A), led by research assistant A. This was to prepare participants for the tasks ahead and to reduce the risk of injury, exposing all to a similar stimulus.

Next, baseline measurements of glenohumeral internal and external rotation were taken by the researcher and research assistant B, who were blinded to the tasks. Participants lay supine on a plinth and a digital inclinometer (Wixey WR360) was attached to the midpoint of their dorsal forearm using velcro straps. A metal bar was fixed between the straps to attract and secure the magnet on the base of the inclinometer (Figure 2.1):

Figure 2.1: *The digital inclinometer attachment*

A wooden measuring framework was used to standardise the start position for all participants, keeping their shoulder and elbow aligned without blocking their full shoulder rotation ROM (Figure 2.2):

Figure 2.2: *The measuring framework*

The measuring framework was aligned to the inferior aspect of the head hole on the plinth and participants were positioned with their olecranon 10 cm from the edge of the framework, with their humerus level with their acromion process. Participants' knees were flexed to 90 degrees. Glenohumeral internal and external rotation were measured passively at 90 degrees of shoulder abduction and elbow flexion, on both the dominant and non-dominant shoulders. During internal rotation the researcher stabilised the scapular, by cupping the coracoid process with their thumb and spine of the scapular with their fingers of one hand. The participants' upper limb was then rotated passively with the researcher's other hand by gripping around the wrist, until their coracoid process was felt to rise into the researcher's thumb. This was to reduce scapulothoracic compensation and was found to have the highest intra-rater reliability, when comparing different glenohumeral internal rotation measuring techniques (Wilk *et al*, 2009). Each measurement was undertaken three times and the nearest whole numbers were recorded to determine the mean (Norkin & White, 2003). Total rotation was calculated as the sum of internal and external rotation. Research assistant B recorded the results to ensure the researcher performing the measurements was blinded to the results (Figure 2.3). Internal, external and total rotation were recorded on both the dominant and non-dominant shoulders, to differentiate an aGIRD from a pGIRD or ERD:

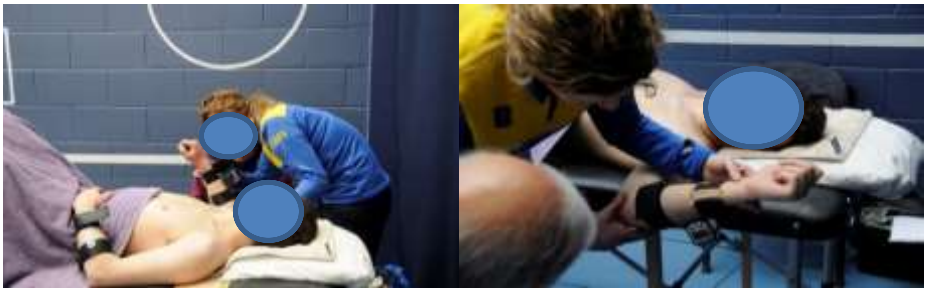

Figure 2.3: *The measuring process*

The order of measuring, in terms of shoulder (dominant or non-dominant) and direction of rotation of shoulder ROM (internal or external), was block ordered for each participant by the researcher in advance and the sequence reversed following the serving and groundstroke tasks, to counterbalance order effects.

<u>*Tennis Tasks*</u>:

The tennis tasks were designed by the researcher in conjunction with coaching staff, to replicate both a hard training session and match play:

<u>*Serving Task*</u>: Research assistant A was responsible for overseeing the task which involved serving 120 balls, based on 3 set match statistic averages from a study by Myers *et al* (2016) and the International Tennis Federation (ITF) Professional Circuit Live Scores Website analysed during July 2016. Type of serve and ball target direction

was chosen by the participant, with no longer than 25 seconds delay between serves. Sixty were served from the deuce side of the court and 60 from the ad side, through alternating sides after every 2 serves. It involved a combination of flat, kick and slice serves directed up the T, to the middle and out wide. The first 20 were the warm up and 2 minutes rest was given after the first 60, replicating the duration for the end of a set. Measurements of shoulder rotational ROM were undertaken immediately following 120 serves. The serving task was piloted in advance and was found to take between 15 – 25 minutes, with a rate of perceived exertion (RPE) of between 11 (fairly light) – 18 (very hard) based on the Borg scale (Chen, Fan & Moe, 2002).

Groundstroke Task: Research assistant A was also responsible for overseeing the groundstroke task, which involved hitting 120 groundstrokes against a partner of the same sex and similar age. The type of groundstroke and ball target direction was chosen by the participant, with no longer than 25 seconds delay if the ball went off court. The hitting partner hit sixty cross-court from the deuce side and 60 cross-court from the ad side, ensuring the participant was moved all over the court and having to return. It involved a combination of forehands and backhands directed up the middle and out wide. The first 20 were the warm up and 2 minutes rest was given after the first 60, replicating the duration for the end of a set. Measurements of shoulder rotational ROM were undertaken immediately following 120 groundstrokes. The groundstroke task was also piloted in advance and was found to take between 6 – 8 minutes, with a RPE of between 12 (fairly light) – 20 (very, very hard).

2.4 Analysis

Statistical analysis was conducted using the SPSS statistical package version 24. The critical alpha level of 0.05 was considered significant for all statistical analyses. Internal, external and total rotation were analysed on both the dominant and non-dominant shoulders, to differentiate an aGIRD from a pGIRD or ERD. The mean of three measurements for each ROM recorded was used. The Shapiro-Wilk test was initially undertaken to determine if ROM data was normally distributed. Non-normal data was transformed using log10. To determine if there was a statistically significant interaction effect between the factors of tennis task (serving and groundstrokes) and time (pre and post), a two-way repeated measures analysis of variance (ANOVA) was computed. This was undertaken on measurements recorded prior to and following serving and groundstroke tasks. To determine the interday intra-rater reliability when using the digital inclinometer, $ICC_{3,1}$ and their 95% confidence intervals (CI) were computed. Values between 0.75 – 0.9 and greater than 0.90, were indicative of good and excellent reliability respectively (Koo & Li, 2016). This was undertaken on measurements recorded prior to serving and groundstroke tasks, to calculate SEM and MDC. These were calculated by hand using the following equations ($SEM = SD \sqrt{(1-ICC)}$; $MDC = 1.96 \times \sqrt{2} \times SEM$).

3. Results

Shoulder rotational ROM measurements were recorded for both tennis tasks a minimum of 1 week to a maximum of 7 weeks apart. Two participants dropped out during the study as they sustained injuries away from the study. The results of 28 participants in total were analysed. The interday intra-rater reliability of measuring shoulder ROM was found to be excellent for internal and external rotation, on both dominant and non-dominant shoulders (Table 3.1). Changes in shoulder ROM following tennis tasks greater than MDC (3.0 and 3.6 degrees for internal rotation on the non-dominant and dominant shoulders respectively; 2.0 and 2.3 degrees for external rotation on the dominant and non-dominant shoulders respectively), could be attributed to tennis tasks rather than measurement error with 95% certainty (Table 3.1):

Dominant & Non-Dominant Glenohumeral Passive Rotational Range of Motion	**ICC**	**95% CI**		**SEM (Degrees)**	**MDC (Degrees)**
		Lower Bound	**Upper Bound**		
Internal Rotation Dominant	0.93	0.84	0.97	1.3	3.6
Internal Rotation Non-Dominant	0.94	0.88	0.97	1.1	3.0
External Rotation Dominant	0.96	0.92	0.98	0.7	2.0
External Rotation Non-Dominant	0.96	0.92	0.98	0.8	2.3
Total Rotation Dominant	0.95	0.89	0.98	1.4	4.0
Total Rotation Non-Dominant	0.95	0.89	0.98	1.4	3.9

Table 3.1: *Intraclass correlation coefficients (ICC), 95 percent (%) confidence intervals (CI), standard error of measurement (SEM) & minimal detectable change (MDC), based on means recorded prior to serving & groundstroke tasks.*

Mean passive internal, external and total rotation ROM measurements with standard deviations of the dominant and non-dominant shoulders, prior to and following serving and groundstroke tasks, are displayed in Table 3.2:

Glenohumeral Passive Rotational Range of Motion	**Serving Dominant (Degrees)**	**Serving Non-Dominant (Degrees)**	**Groundstroke Dominant (Degrees)**	**Groundstroke Non-Dominant (Degrees)**
Pre Internal Rotation	52.8 ± 9.0	60.0 ± 9.7	52.7 ± 8.9	59.5 ± 10.4
Post Internal Rotation	50.5 ± 9.6	60.4 ± 11.6	52.6 ± 9.6	59.6 ± 12.3
Pre External Rotation	77.1 ± 10.0	76.0 ± 10.7	76.9 ± 9.6	75.0 ± 11.7
Post External Rotation	75.4 ± 11.6	75.0 ± 10.9	74.3 ± 10.4	73.0 ± 11.7
Pre Total Rotation	129.9 ± 15.1	136.0 ± 14.1	129.6 ± 14.5	134.5 ± 14.6
Post Total Rotation	125.9 ± 16.0	135.4 ± 13.0	126.9 ± 16.0	132.6 ± 16.2

Table 3.2*: Mean passive glenohumeral internal, external & total rotation range of motion with standard deviations, prior to & following serving & groundstroke tasks, on the dominant & non-dominant shoulders.*

Mean change in passive internal, external and total rotation ROM measurements on the dominant and non-dominant shoulders, following serving and groundstroke tasks, are displayed in Figures 3.1 and 3.2:

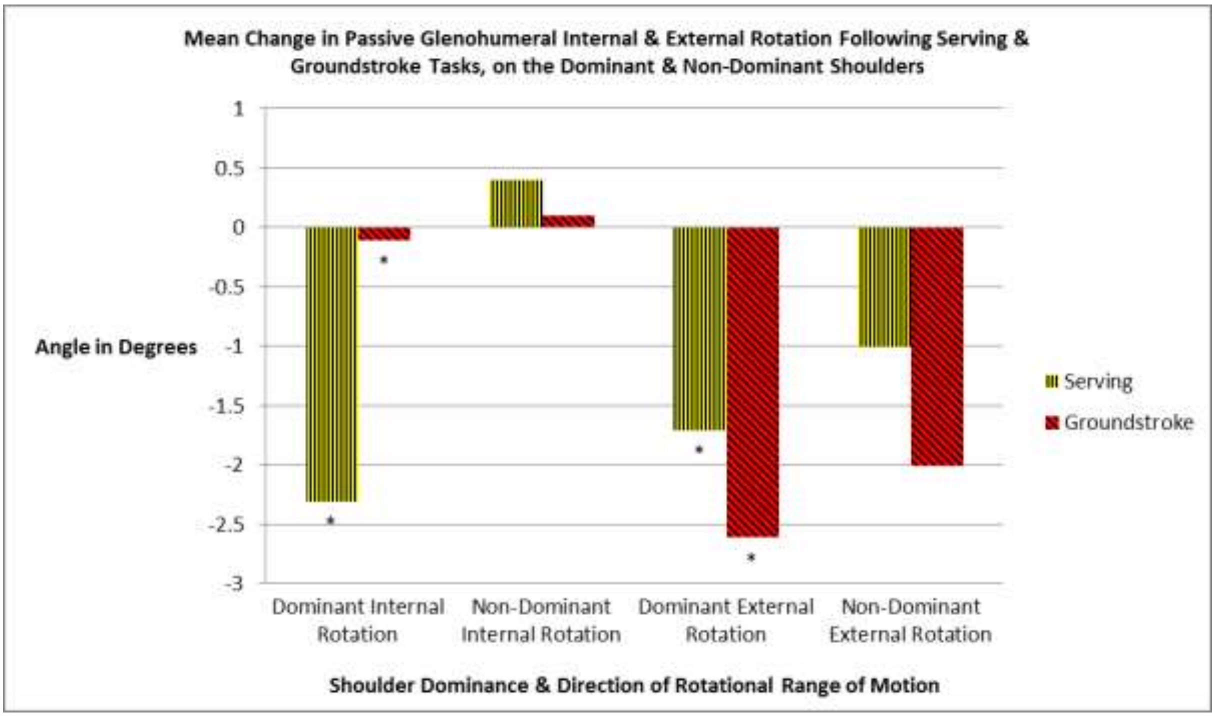

Figure 3.1*: Mean change in passive glenohumeral internal and external rotation following serving and groundstroke tasks, on the dominant and non-dominant shoulders (* p = 0.007 significant main effect of time).*

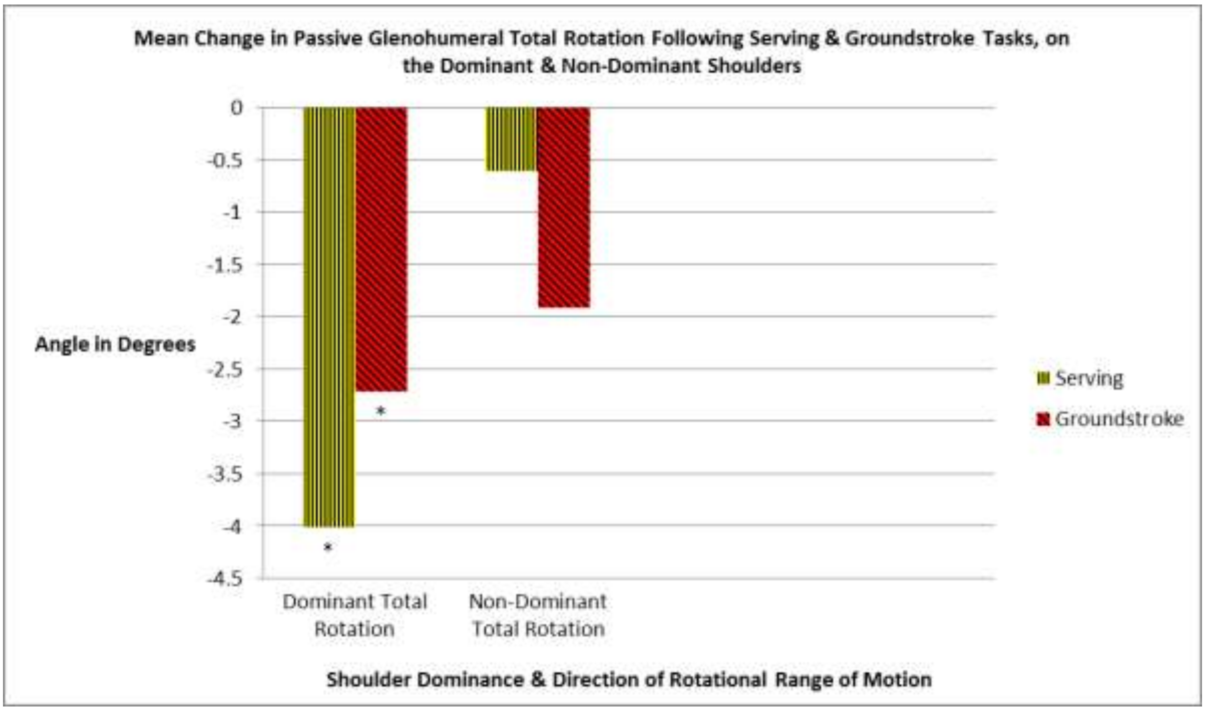

Figure 3.2*: Mean change in passive glenohumeral total rotation following serving and groundstroke tasks, on the dominant and non-dominant shoulders (* p = 0.007 significant main effect of time).*

The percentage of participants, whose mean passive internal, external and total rotation ROM measurements of the dominant and non-dominant shoulders were greater than, equal to or less than MDC, following serving and groundstroke tasks, are displayed in Table 3.3:

Serving	**MDC > (%)**	**MDC = (%)**	**MDC < (%)**
Internal Rotation Dominant	68	0	32
Internal Rotation Non-Dominant	64	0	36
External Rotation Dominant	64	0	36
External Rotation Non-Dominant	57	0	43
Total Rotation Dominant	57	14	29
Total Rotation Non-Dominant	57	0	43
Groundstrokes	**MDC > (%)**	**MDC = (%)**	**MDC < (%)**
Internal Rotation Dominant	61	0	39
Internal Rotation Non-Dominant	71	0	29
External Rotation Dominant	57	0	43
External Rotation Non-Dominant	64	0	36
Total Rotation Dominant	54	7	39
Total Rotation Non-Dominant	71	0	29

Table 3.3: *Percentage (%) of participants, whose mean passive internal, external & total rotation range of motion measurements of the dominant & non-dominant shoulders are greater than (>), equal to (=) or less than (<) minimal detectable change (MDC), following serving & groundstroke tasks.*

This study compared the immediate effects of serving to groundstrokes on shoulder rotational ROM in tennis players. There was no significant interaction effect between the factors of tennis task (serving and groundstrokes) and time (pre and post), on either the dominant ($F(1,27) = 0.659$, $p = 0.424$) or non-dominant shoulder ($F(1,27) = 0.571$, $p = 0.456$). These findings demonstrate that there was no difference between serving and groundstroke tasks on shoulder rotational ROM over time.

On the dominant shoulder there was a significant main effect of time ($p = 0.007$) with an observed power of 0.8, demonstrating that internal, external and total rotation decreased following both tennis tasks (Table 3.2, Figure 3.1 & Figure 3.2). Conversely on the non-dominant shoulder no significant main effects were found. These findings demonstrate that on the dominant shoulder rotational ROM decreased following both tennis tasks over time, but this change was not evident on the non-dominant shoulder.

4. Discussion

This study aimed to determine if serving in tennis affects shoulder passive rotational ROM in tennis players. The immediate effects of serving were compared to groundstrokes on both dominant and non-dominant shoulders, to establish whether shoulder rotational ROM change could be attributed specifically to serving.

There was no significant interaction effect between tennis task and time, demonstrating that there was no difference between serving and groundstroke tasks on shoulder rotational ROM over time. This was evident for both the dominant and non-dominant shoulders. Change following exposure to tennis has been hypothesised to occur specifically as a result of the follow through of the serve, which requires the dominant shoulder to decelerate through eccentric action of the external rotators (Martin *et al*, 2016; Moore-Reed *et al*, 2016; Kibler *et al*, 2013). However findings from these studies did not directly compare serving and groundstrokes, suggesting their claims cannot be supported. This has not been confirmed from the findings of this study where serving and groundstrokes were directly compared.

On the dominant shoulder there was a significant main effect of time, with internal, external and total rotation decreasing following both tennis tasks. The percentage of measurements greater than MDC (demonstrating with 95% certainty that changes in shoulder ROM were attributed to tennis tasks rather than measurement error), was 61 – 68% for internal rotation, 57 – 64% for external rotation and 54 – 57% for total rotation (Table 3.3). This was much greater than those reported by Moore-Reed *et al*, 2016 using a digital inclinometer. A decrease in dominant shoulder internal and total rotation, in comparison to the non-dominant shoulder, has been found in studies of both junior and senior tennis players as a normal variation (Schmidt-Wiethoff *et al*, 2004; Ellenbecker *et al*, 2002). This secondary finding of change in shoulder rotational ROM over time could also be attributed to normal variation, as a control group was not used in this study when comparing serving to groundstrokes. It could also be attributed to general physical activity. However as this change was not evident at the non-dominant shoulder, it could be suggested that tennis may be an important factor in causing this change.

The short term changes to dominant shoulder rotational ROM over time are in agreement with other studies, investigating the immediate effects of playing competitive tennis on professional players (Martin *et al*, 2016; Moore-Reed *et al*, 2016). In both these studies reductions in passive internal and total rotation following matches were found, although range reductions were variable. Unlike the current study, neither reported significant reductions in passive external rotation. This could be due to differences in the experimental designs, with the tennis tasks in these studies being full duration competitive matches. Similarly, it could be hypothesised that these short term changes over time could be attributed to muscular tightness from repetitive contractions, based upon the amount of change and that only the immediate effects were measured (Martin *et al*, 2016; Moore-Reed *et al*, 2016).

It is acknowledged that whilst the majority of participants' shoulder rotational ROM measurements decreased following both tennis tasks, a minority increased, whilst some remained relatively stable. According to the overall average, participants did not develop a pGIRD (loss in dominant shoulder internal rotation that is greater than 18 – 20 degrees, with a corresponding loss of TROM of greater than 5 degrees, when compared with the non-dominant shoulder) or ERD (loss in dominant shoulder external rotation that is greater than 5 degrees, when compared with the non-dominant shoulder); which have been identified as risk factors for shoulder injuries in overhead athletes (Wilk *et al*, 2015; Kibler *et al*, 2012a; Wilk *et al*, 2011). Instead an aGIRD occurred (loss in dominant shoulder internal rotation that is less than 18 – 20 degrees, with a corresponding loss of TROM of less than 5 degrees, when compared with the non-dominant shoulder), which is considered a normal variation (Manske *et al*, 2013).

No previous studies have compared the immediate effects of serving to groundstrokes on shoulder rotational ROM and therefore no previous data was available for power calculations. As a consequence retrospective power calculations were performed, which suggest the sample size was sufficiently powered. The study could not be undertaken during competitive match conditions as its purpose was to compare serving to groundstrokes. For this reason the findings are only generalisable to training sessions on indoor hard-court surfaces using Babolat balls. Further research might establish the effects of different court surfaces and tennis balls on shoulder rotational ROM.

Whilst the RPE of tennis tasks was piloted in advance and found to have a similar RPE, they were not exact and were not recorded during the study. It is important to recognise though that RPE can be adversely affected by over and under reporters, as well as recall bias (Chen *et al*, 2002). It is acknowledged that the duration of the serving task took longer than the groundstroke task, but both tasks involved serving and hitting 120 balls respectively. This was based on 3 set match statistic averages on serving from a study by Myers *et al* (2016) and the International Tennis Federation (ITF) Professional Circuit Live Scores Website analysed during July 2016. Future research might establish whether training / match RPE and duration have an effect on shoulder rotational ROM. This might reduce the potential risk of shoulder injury from a pGIRD or ERD, through manipulating exposure to these variables if found to have a significant effect.

This study has demonstrated that exposure to different tennis strokes results in immediate significant reductions in passive shoulder internal, external and total rotation ROM on the dominant shoulder but not the non-dominant shoulder of professional and university level tennis players. These are within normal ranges that do not present risk factors for shoulder injuries in overhead athletes. When comparing the effects of serving to groundstrokes there are no significant differences between the strokes on shoulder rotational ROM over time. Contrary to previous suggestions, change in shoulder rotational ROM cannot be attributed specifically to the serve.

Appendix A

WARM UP FOR PARTICIPANTS

The warm up will last 15 minutes. Shoulder range of motion measurements will be undertaken immediately following the warm up.

- Two laps of the tennis court jogging.

- Two widths of the tennis court doing double leg bottom flicks.

- Two widths of the tennis court doing double leg high knee raises.

- Two widths of the tennis court doing alternate leg split lunges with torso rotations.

- Two widths of the tennis court doing alternate leg lateral lunges.

- Three static hamstring stretches on each side outstretched on the bench, holding for 15 – 30 seconds.
- Five side lying thoracic opening outs on each side.
- Five leg crossover dynamic pectoral stretches on each side.
- Three static sleeper stretches on each side, holding for 15 – 30 seconds.

- Three static latissimus dorsi stretches on each side outstretched on the net, holding for 15 – 30 seconds.
- Eight double arm shoulder external and internal rotations, with shoulders in neutral and elbows bent at waist level, standing front on to the net against a green resistance band attached to the net.

- Eight double arm shoulder external and internal rotations, with shoulders and elbows at 90 degrees, standing front on to the net against a green resistance band attached to the net.

References

Abrams, G., Renstrom, P., & Safran, M. (2012). Epidemiology of musculoskeletal injury in the tennis player. *British Journal of Sports Medicine*. 46, 492-498. doi: 10.1136/bjsports-2012-091164.

Chen, M., Fan, X., & Moe, S. (2002). Criterion-related validity of the borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. *Journal of Sports Sciences*. 20, 873-899.

Dines, J. S., Bedi, A., Williams, P. N., Dodson, C.C., Ellenbecker, T.S., Altchek, D.W., Windler, G., & Dines, D.M. (2015). Tennis injuries: Epidemiology, Pathophysiology and Treatment. *Journal of the American Academy of Orthopaedic Surgeons*. 23(3), 180-189. doi: 10.5435/JAAOS-D-13-00148.

Ellenbecker, T., & Wilk, K. (2017). *Sport Therapy for the Shoulder: Evaluation, Rehabilitation and Return to Sport*. (1st ed). United States of America, Human Kinetics.

Ellenbecker, T., Roetert, P., Bailie, D., Davies, G., & Brown, S. (2002). Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *The American Journal of Sports Medicine*. 34(12) 2052-2056. doi: 10.1249/01.MSS.0000039301.69917.0C.

Fernandez, J., Mendez-Villanueva., A & Pluim, B. (2006). Intensity of tennis match play. *British Journal of Sports Medicine*. 40, 387-391. doi: 10.1136/bjsm.2005.023168.

International Tennis Federation. (n.d). ITF Professional Circuit Live Scores. Retrieved July 2016, from http://itfprocircuit.tennis-live-scores.com/scoreboard.aspx.

Johnson, C. D., & McHugh, M. P. (2006). Performance demands of professional male tennis players. *British Journal of Sports Medicine*. 40, 696-699. doi: 10.1136/bjsm.2005.021253.

Kibler, B., Kuhn, J., Wilk, K., Sciascia, A., Moore, S., Laudner, K., Ellenbecker, T., Thigpen, C., & Uhla, T. (2013). The disabled throwing shoulder: spectrum of pathology – 10 year update. *The Journal of Arthroscopic & Related Surgery*. 29(1), 141-161.

Kibler, B., Sciascia, A., & Thomas, S. (2012a). Glenohumeral internal rotation deficit: pathogenesis and response to acute throwing. *Sports Medicine and Arthroscopy Review*. 20(1), 34-38. doi: 10.1097/JSA.0b013e318244853e.

Kibler, B., Sciascia, A., & Moore, S. (2012b). An acute throwing episode decreases shoulder internal rotation. *Clinical Orthopaedics and Related Research*. 470, 1545-1551. doi: 10.1007/s11999-011-2217-z.

Kibler, W.B., Chandler, T.J., Livingston, B.P., & Roetert, E.P. (1996). Shoulder range of motion in elite tennis players: Effect of age and years of tournament play. *The American Journal of Sports Medicine*. 24(3), 279-285.

Koo, T., & Li, M. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine.* 15, 155-163. doi: org/10.1016/j.jcm.2016.02.012.

Lintner, D., Noonan, T., & Kibler, B. (2008). Injury patterns and biomechanics of the athlete's shoulder. *Clinics in Sports Medicine*. 27, 527-551. doi: 10.1016/j.csm.2008.07.007.

Manske, R., Wilk, K., Davies, G., Ellenbecker, T., & Reinold, M. (2013). Glenohumeral motion deficits: Friend or foe. *International Journal of Sports Physical Therapy*. 8(5), 537-553.

Martin, C., Kulpa, R., Ezannoa, F., Delamarche, P., & Bideau, B. (2016). Influence of playing a prolonged tennis match on shoulder internal range of motion. *The American Journal of Sports Medicine*. 44(8), 2147-2151.

Moore-Reid, S., Kibler, B., Myers., Smith, B. (2016). Acute changes in passive glenohumeral rotation following tennis play exposure in elite female players. *The International Journal of Sports Physical Therapy*. 11(2), 230-236.

Moreno-Perez, V., Moreside, J., Barbado, D., & Vera-Garcia, F. (2015). Comparison of shoulder rotation range of motion in professional tennis players with and without history of shoulder pain. *Manual Therapy*. 20, 313-317. doi: org/10.1016/j.math.2014.10.008.

Myers, N. L., Sciascia, A. D., Kibler, W.B., & Uhl. T.L. (2016). Volume-based interval training program for elite tennis players. *Sports Health*: *A Multidisciplinary Approach*. 8(6), 1-5. doi: 10.1177/1941738116657074.

Norkin, C. C., & White, D.J. (2003). *Measurement of Joint Motion: A Guide to Goniometry*. (3rd ed). Philadelphia, F.A. Davis Company.

Pluim, B.M., Staal, J.B., Windler, G.E., & Jayanthi, N. (2006). Tennis injuries: Occurrence, aetiology & prevention. *British Journal of Sports Medicine*. 40, 415-423. doi: 10.1136/bjsm.2005.023184.

Reid, M., & Duffield, R. (2014). The development of fatigue during match-play tennis. *British Journal of Sports Medicine*. 48, 1-6. doi: 10.1136/bjsports-2013-093196.

Reid, M., Elliott, B., & Alderson. J. (2007). Shoulder joint loading in the high performance flat and kick tennis serves. *British Journal of Sports Medicine*. 41, 884-889. doi: 10.1136/bjsm.2007.036657.

Schmidt-Wiethoff, R., Rapp, W., Mauch, F., Schneider, T., & Appell, H. (2004). Shoulder rotation characteristics in professional tennis players. *International Journal of Sports Medicine*. 25(2), 154-158. doi: 10.1055/s-2004-819947.

Van Der Hoeven, H., & Kibler, W.B. (2006). Shoulder injuries in tennis players. *British Journal of Sports Medicine*. 40, 435-440. doi: 10.1136/bjsm.2005.023218.

Wilk, K., Macrina, L., Fleisig, G., Aune, K., Porterfield, R., Harker, P., Evans, T., & Andrews, J. (2015). Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers. *The American Journal of Sports Medicine*. 43(10), 2379 -2385. doi: 10.1177/0363546515594380.

Wilk, K., Macrina, L., Fleisig, G., Porterfield, R., Simpson, C., Harker, P., Paparesta, N., & Andrews, J. (2011). Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *The American Journal of Sports Medicine*. 39(2), 329 – 335. doi: 10.1177/0363546510384223.

Wilk, K., Reinold, M., Macrina, L., Porterfield, R., Devine, K., Suarez, K., & Suarez, K. (2009). Glenohumeral internal rotation measurements differ depending on stabilisation techniques. *Sports Health*. 1(2), 131-136. doi: 10.1177/1941738108331201.