International Journal of Physical Education, Sports and Health 2016; 3(6): 77-87

P-ISSN: 2394-1685
E-ISSN: 2394-1693
Impact Factor (ISRA): 5.38
IJPESH 2016; 3(6): 77-87

www.kheljournal.com
Received: 18-09-2016
Accepted: 19-10-2016

Dr. Animesh Hazari
Msc. Sports and Clinical Biomechanics Robert Gordon University, Scotland UK.
PhD Manipal University, Manipal India

Mehzabeen Warsi
Msc Sports Biomechanics Robert Gordon University, Scotland UK

Dr. Ioannis Agouris
PhD, Course Co-ordinator Sports and Clinical Biomechanics Robert Gordon University, Scotland UK

Correspondence
Dr. Animesh Hazari
Msc. Sports and Clinical Biomechanics Robert Gordon University, Scotland UK.
PhD Manipal University, Manipal India

Electromyography analysis of shoulder and wrist muscles in semi-professional cricket fast bowlers during bouncer and yorker delivery. A cross-sectional comparative study

Dr. Animesh Hazari, Mehzabeen Warsi and Dr. Ioannis Agouris

Abstract
Background & Objective: Cricket is one of the most popular sports, played in many countries. However due to aggressive in nature it could be more prone for risk of injuries to shoulder and wrist in fast bowlers. Thus the purpose of the study was to determine the EMG activity of shoulder and wrist injuries in fast bowlers while bowling 'Bouncer' and 'Yorker 'deliveries.
Method: A total of 17 healthy participants including 15 right- handed and 2 left handed fast-medium bowlers were recruited study under the purposive sampling method (n = 15, age = 27.3± 5.2 years, height = 173.1 ± 6.8 cm and weight = 75.1 ± 7.8 kg). High speed camera (EXILM CASIO-EX-FH 25) was used to synchronized with EMG device (model- m 320RX, 5VDC/1A/5W, myon AG Switzerland).
Result: A significant difference in RMS was found in shoulder and wrist muscles while bowling bouncer and Yorker in first and second phase with p value of 0.0 and 0.05 respectively. Freidman's test was used to yield the following result.
Conclusion: Based on the inferential statistics, cricket bowlers are highly exposed to risk of shoulder and wrist injuries. Yorker deliveries can lead to higher wrist injuries compared to shoulder injuries while bowling Bouncers.

Keywords: Biomechanics, fast bowling, EMG, shoulder and wrist, Yorkers and Bouncers

1. Introduction
Cricket is one of the oldest organised and the world's second most popular sport, played in many countries worldwide. Due to its fascinating and exciting nature it has captured the attention of millions of spectators. The popularity of the game can be estimated by its potential of attracting thousands of spectators to the stadium around the world and millions of people enjoy the game live on television.
The T20I is the shortest format of game that makes it more fascinating; on the other hand due to aggressive in nature it could be more prone for risk of injuries to shoulder and wrist in fast bowlers. These injuries can be attributed to the skills involved in the game. Bowling, batting and fielding are three key skills in cricket. Much of the biomechanical research into this sport has focused on bowling and batting (Bartlett 2007) [3]

1.1 Bowling and its Significance
Bowling is defined as to deliver a 156-g cricket ball towards a batsman or his wicket. The bowlers initiate bowling with a smooth and rhythmical run-up to generate linear momentum, which is transferred from lower extremities to the upper body over the front leg during the delivery stride (Ferdinands *et al.* 2014) [8]. Hand acceleration is produced by the proximal-to-distal sequence of joint rotations that is then generated by sequential proximal-to-distal muscle contraction (Hirashima *et al.* 2002) [12]. The most frequently used 'bowling deliveries' by fast bowlers are 'Bouncers' and 'Yorkers'. A Bouncer delivery that refers to a bowl targeted at the chest level of the batsman by dropping it in the middle of the cricket pitch whereas a Yorker is a ball, aimed at the toes of the batsman's in an area known as the block hole given by International Council of cricket (ICC). There are different zones of bowling classification given by the ICC. From the bowling perspective the cricket pitch is divided in Yorker length

(2m from batting stumps), Full length (next 4m area), Good length (next 2m) and Short length (Bouncer) which is anywhere in the middle or half of the pitch

1.2 Biomechanics of fast bowling

Fast bowling has been shown to cause non –contact shoulder and wrist injuries in fast bowlers (Bartlett 2007) [3]. The mechanism of these injuries can be explained on the basis of close biomechanical analysis of the joint including the functioning of the joint, muscles and ligaments and subject to the amount of stress they are placed on. Biomechanically fast bowling can be analysed as an action where internal shoulder rotator muscles concentrically contract during the acceleration phase of the throwing (phases of overhead throws are classified as wind up, cock-up, acceleration, deceleration and follow through) counterbalanced by eccentric contraction of the external rotators during the deceleration phase (RF & JR 2009) [17].

A typical fast bowl requires the arm to be rotated at an angular velocity of 60000°s-¹ placing great demands on the shoulder's integrity (Donatelli *et al*. 2000) [7]. The faster arm action places more stress on the shoulder joint, predisposing these bowlers to shoulder injuries. The muscle imbalance or dysfunction where the eccentrically contracting external rotators are not strong to balance the concentric contraction against the internal rotators are the most common predisposing factor for shoulder injuries in cricket fast bowlers (Aginsky *et al*. 2004) [1]. Similar mechanism can be used to explain wrist injuries in fast bowlers. In order to bowl with high speed the bowlers tend to jerk the wrist at bowl release to generate greater pace (Cook & Strike 2000) [6]. Furthermore, overuse (through repetitive) injuries are frequent and related to the physical demands of high-level cricket. Recently, the Australian Cricket Board (ACB) declared that high level fast bowlers exhibit a significantly enhanced risk of injury if their bowling workload exceeded more than 20–30 bowls during the period of 1 week (Orchard & James 2003) [16]. Similarly a study reported that 41% of the injuries that are sustained by cricket bowlers are due to frequent bowling (Stretch 2003) [19]. Given the known fact that Bouncers and Yorkers are the toughest deliveries to bowl but frequently used, it is assumed that they can be associated with high incidence of shoulder and wrist injuries in fast bowlers and therefore this study would hold its vital importance in contributing to the injury profile and its prevention by studying the electrical activity in the muscles around the shoulder and wrist joint while bowling a ‘Bouncer’ and ‘Yorker’ delivery.

1.3 Electromyography in fast bowling

The most common and recently used method to study muscular activity and its contraction pattern in fast bowlers is electromyography (EMG) (Ahamed *et al*. 2014) [2] Escamilla in 2009 proposed that Surface EMG is the science and basic technique used for the quantification of muscle activity during movement. In addition, it is a hassle free non-invasive and scientifically proven procedure that can be used to determine the timing and the amount of muscle activation throughout a given movement. To date, very few researchers have investigated the electromyography responses of the muscles with bowling arm motion. As per our search no study has been published that focuses on the EMG around shoulder and wrist while bowling using the Bouncer and Yorker deliveries.

There has been a significant increase in number of cricket matches being played with the introduction of T20I in the last few years; this correlates both an increase in the prevalence and incidence of injuries sustained by fast bowlers.

1.4 Aims and Objectives

The aim of the study was to detect the EMG activity in male fast bowlers in different phases of fast bowling with the following set objectives:

1. To quantify the EMG activity at shoulder while bowling a ‘Yorker’ and ‘Bouncer’ delivery.
2. To quantify the EMG activity at wrist while bowling a ‘Yorker’ and ‘Bouncer’ delivery.
3. To compare the difference in EMG activity while bowling a ‘Yorker’ and ‘Bouncer’ delivery

2. Methodology

2.1 Participants: A total of 17 healthy participants including 15 right- handed and 2 left handed fast-medium semi-professional bowlers were recruited who volunteered into study under the purposive sampling method. The sample size was determined in accordance with the previous study done by Ahmed *et al*. 2014 [2]. The participants were informed about the project via a formal invitation flyer, briefly explaining the project which was distributed to Aberdeen cricket club and Robert Gordon university Cricket club. Some of the players were also contacted through local contacts and friends. In order to insure that the participants were a good reflection of the cohort of interest namely professional cricket, players who had regularly played prior to the study and bowled either in school, college, university, or state-level cricket games were selected. The mean and the standard deviations (mean ± SD) of the demographics of the bowlers are as follows: n = 15, age = 27.3± 5.2 years, height = 173.1 ± 6.8 cm and weight = 75.1 ± 7.8 kg.

2.2 Ethical Statement: The protocol submission pack for review by the School Research Review Group (SRRG) was prepared and submitted following which an approved consent from SRRG and the Ethical committee was obtained for the given study.

2.3 Study Design: The cross–sectional, experimental design of the study took place in the Robert Gordon University Laboratory. The indoor set –up for the study was chosen due to unfavourable environmental condition outside and the equipment’s safety concerns. For the above reason a cricket pitch of appropriate dimensions (fig. 1a & 1b) was prepared in a big hall in order to simulate the ICC standards of a cricket pitch.

(a) Bowling end (b) Batting end

Fig 1: Simulated cricket pitch. ICC standard dimensions used.

2.4 Participant Familiarisation and Consent

The participants attended an orientation session half an hour prior to data collection. This was followed by a number of practices and warm up trials. The run-up for each participant was fixed to a maximum of 14 yards as a standardised method. A study of 19 club level fast bowlers, concluded that a run-up of 14 paces is sufficient to release the ball at 37 m s-1 that would be categorised into fast bowling (Bartlett *et al*. 1996) [4].

2.5 Experimental Overview

2.5.1 Preparation

As mentioned above an appropriate dimensions and standards were used to make a cricket pitch. A parallel length of 2012 cm was drawn using a black tape on either side at a width of 305 cm. From the batting stumps a horizontal line was marked at a distance of 2m to represent the Yorker length. A red tape was used to clearly demark this area 'Y' and make it easy for the bowlers to aim and drop the ball in that particular area while bowling a Yorker delivery. Similarly a horizontal line was drawn exactly in the mid of the pitch with a yellow tape marked 'B' to represent the Bouncer length. See figure 2a & 2b below.

Fig 2: (a) Yorker Area (b) Bouncer Area

2.5.2 Equipment Set-Up

After an appropriate cricket pitch was simulated, the equipments and tools that were required for the data collection were set up as described below. A coloured high speed camera (EXILM CASIO-EX-FH 25) was set up at a distance of 7m from the bowling end in line with the bowling popping crease and perpendicular to the cricket pitch to capture the bowling action from the sagittal plane. An adjustable aluminium standing frame was used to fix the camera at a height of 1.5 m. The lens of the camera was adjusted to maximise the size of the performer in the view finder for maximum accuracy for all video trials (Glazier *et al*. 2000) [10], apt to cover the entire bowling action with a good video clarity in an optical zoom mode. The EMG device was set up on a big wooden table from the batting end. One of the researchers operated the device and simultaneously observed the area of ball drop to be qualified as a good trial. The camera and the EMG device was synchronised in order to define a start phase using tap electrode as a reference by the other researcher on the camera at the bowling end. The EMG recording started at a count of three whereas the camera started recording few seconds prior to the bowling action and the EMG count. To ensure that only good trials was selected on both the devices without confusion, a paper with marked number of trials like B1...B18 and Y1..Y18 was used in front of the camera just before the bowling motion. Once a good tap and muscle signals were seen on the EMG device, that trial was noted and taken for data processing.

2.6 Data Collection

As a standard guideline for EMG data collection procedure was followed (Hermens *et al*. 1999) [11]. The participants were requested to expose the upper half of the body for placement of electrodes without friction between the dress and the underlying electrodes on the skin (Ahmed *et al*. 2014) [2]. The lower part of the body was dressed with loose and comfortable fittings. The particular area of the testing muscles was shaved using a disposable razor for each participant. This is an important process to reduce skin impedance (Merletti & Torino 1999).The EMG electrodes were placed as follows:

2.6.1 Sensor position and orientation: it is recommended to place the sensor halfway the (most) distal motor endplate zone and the distal tendon, therefore a distance of 25% from the distal end or the muscle belly as appropriate was taken for electrode placement along the lines of the muscle fibres. The pre-gelled Ag/AgCl circular surface electrodes were used on the respective shoulder and wrist muscles using double sided adhesive tapes. They provide a stable transition with low noise and are easily available commercially (Hermens *et al*. 1999) [11]. Bipolar surface EMG sensors with an IED (inter-electrode distance) of 20 mm were used on the given seven muscles. A maximal sEMG (surface emg) amplitude is expected with this IED (Hermens *et al*. 1999) [11].

Seven different channels that were used are described here. Channel 1- on contracted muscle belly of bicpeps brachii, Channel2- on the bulk of the middle deltoid, 3- supraspinatus above the spine of the scapula and horizontally placed at a distance of 25% from the distal end, Channel4- below the spine of scapula on the infraspinatus muscle along the line of muscle fibres, Channel 5- just below the angle of the scapula in an vertically oblique direction on the latissimus dorsi muscle belly, Channel 6- on the flexor carpi radialis muscle just below the poplitial fossa and Channel-7 on the bulk of the extensor carpi radialis brevis muscle 1 cm below the olecranon process. All the electrodes should were placed in the line of the muscle fibres unless stated otherwise. The entire process of electrodes preparation, placement, and orientation has been used in accordance with the guidelines given by and used in previous studies by Hermens *et al*.1999 [11] and shown in fig 3 below.

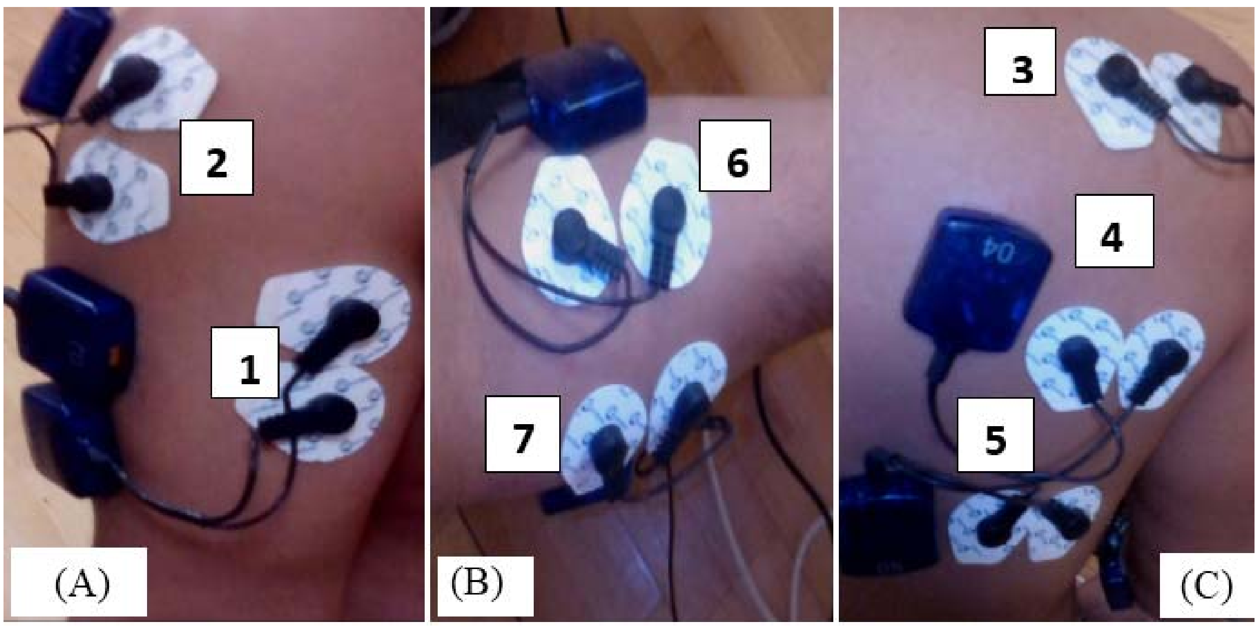


Fig 3: EMG electrodes and sensors placement. Numbers represents electrodes channels described above. Source-participant with permission.

In order to secure the electrodes firmly on the skin and reduce the movement of the sensors they were reinforced with adhesive tapes and bandages. Constant movement of sensors with respect to skin causes friction leading to faulty results (Hermens *et al*.1999) [11].

2.6.2 Bowling Trials

Before each participant started, a toss was done to decide whether the yorker or the bouncer would be bowled first. Although no batsman was present in this experiment, the bowlers delivered the ball towards the wicket at their maximal pace however there was no radar gun used in the study which could exactly measure the speed of the ball. Therefore the speed of the ball was estimated by an experienced cricket player with naked eyes to insure that the bowler qualified as relatively fast or medium fast to meet our inclusion criteria. This was also roughly confirmed by using the formula speed= distance/time where time was obtained from the camera to reach the known distance from bowler to batsman end. The ball was considered to travel in a linear motion and not in projectile motion for such assumption.

Each bowler performed a maximum of 18 trials for each type delivery (Yorker or Bouncer); out of which 6 successful trials were taken for data analysis from either cohort, (Ahmed *et al*. 2014) [2]. There was a 5-min gap between each over (6 deliveries) and a 1-min gap between each delivery (Ahmed *et al*. 2014) [2]. Given that each bowler bowled 12 good trials, a total of one hundred and eighty successful trials were taken and used for data analysis (n= 15, 6 Yorker*15+6 Bouncer* 15=180).

The corresponding motion and EMG signals from the respective muscle were recorded during each trial. Only the valid deliveries according to the law of ICC were considered. Some exclusion criteria during bowling was applied to build in due rigour into the trial method were the following: ball delivered outside the entire pitch, ball delivered outside the marked 'Yorker' and Bouncer areas observed by one of the researcher, no-ball (crossing the line of the bowling popping crease). These factors can be considered due to the rule and regulations of the game itself. Data was also screened for failure in methodology: unable to obtain a clear signal from the tapping electrode, miscommunication and mistiming among the researchers. Finally, EMG data from all 90 trials per bowling style were taken for analysis.

These measures were taken to optimise the quality of the nature gathered within the limits of the study design. The data was obtained in a controlled environment that simulated the cricket field. The players were either keen amateurs or semi-professional so their skills emulated professional players. There was confidence in the equipment used to measure EMG and the researcher's ability to operate them. The use of the EMG is considered to be a good clinical marker of muscle activity.

2.7 Data Processing & Analysis

All the successful trials were captured using a high speed digital coloured camera at a frequency of 240 Hz at a shutter speed of 1/2000 seconds. The device that was use to collect and analyse the muscle signals from the bowling trials was EMG myon, model- m 320RX, 5VDC/1A/5W, myon AG Switzerland.

The raw EMG signals were filtered at 10–400 Hz band pass filter using 2nd order Butterworth filter, with window period of 20 ms and the gain was fixed at 1,000 for all of the channels (De Luca *et al*. 1997).The filtered data was amplified at 2000 Hz and the obtained signals were broken down into different bowling phases respect to time in seconds.

The time of the tap on the reference electrode was noted and considered as time zero as well as the start of the first bowling phase on the Emg recordings. However the time zero and the start of the first phase on the camera were taken as the point time of forward foot contact. This was a necessary procedure to synchronize the two devices and define the phases. These phases were obtained by visualising and marking the time of start to end of the ongoing phase on the camera whereas the time difference obtained was added to the previous point of time to obtain the corresponding phase on the EMG device. A clear demarcation of the start and end for each of the phases was taken as follows.

Phase1 (Arm acceleration): Time from the forward foot contact to the point of time when the bowling arm was aligned vertical to the body, close to the ears and parallel to the wickets. Corresponding phase on the EMG was obtained by just adding the time difference between these events to the time zero obtained as explained above and the same process was followed for the subsequent phases.

Phase2 (Ball release & deceleration): The time from the end of first phase to the point of time frame when the ball was seen to release out of the hand.

Phase3 (Follow through): The time from the ball release to the point of the time when the leading foot touched the ground. Only this part of the EMG signals was considered for data processing and analysis. Therefore the EMG signals before the point of tap on the reference electrode was eliminated and the part of the data analysed in phases as defined above is as shown in the fig. 4b. Below.

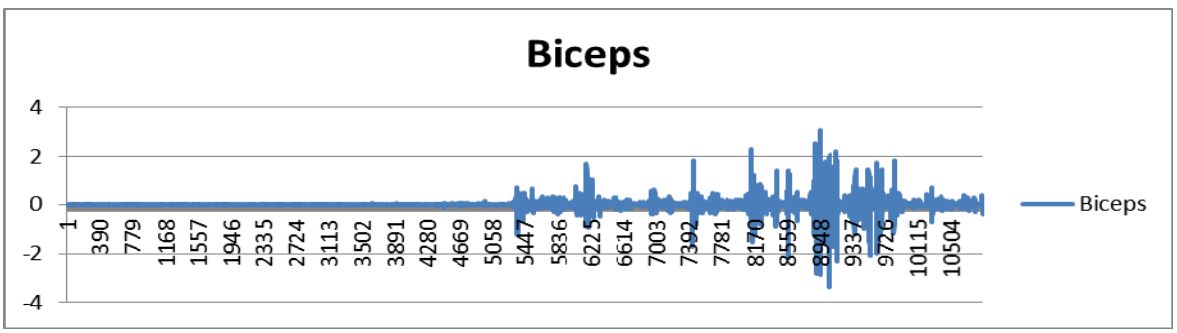


Fig 4a: Entire EMG signals obtained for one trial.

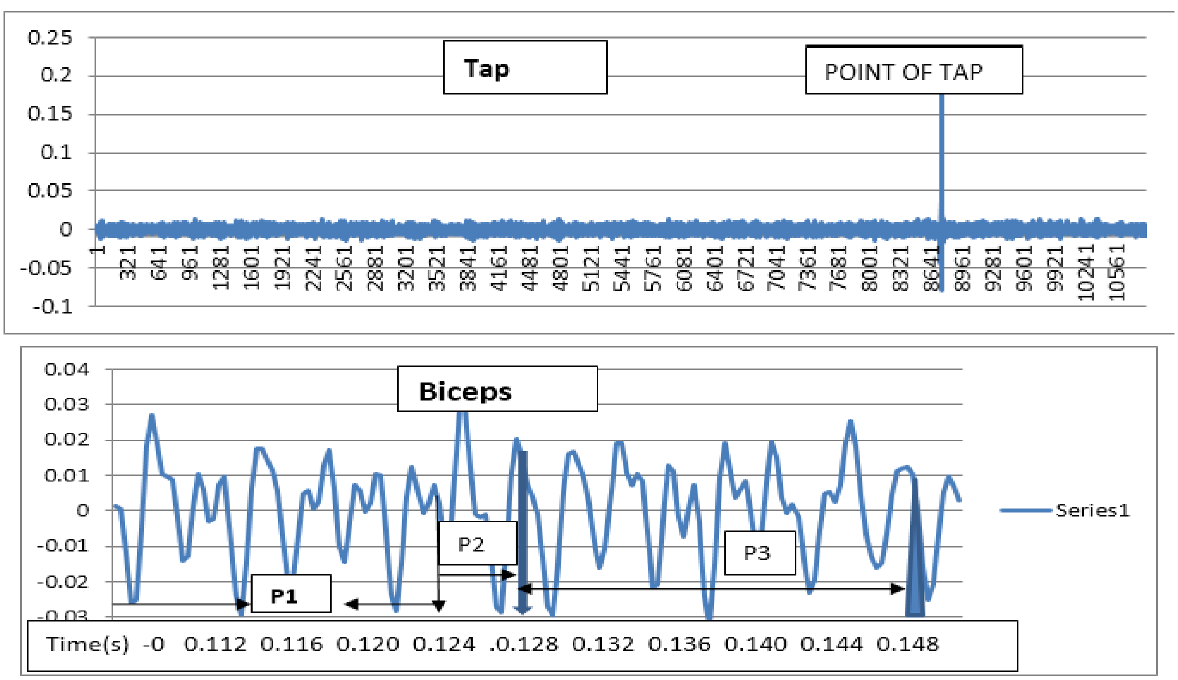


Fig 4b: part of the data analysed into phases P1, P2, and P3 X axis- time in seconds and Y axis- amplitude in millivolts.

The different phases of bowling on camera have been presented in the Fig.5below. As mentioned before, the camera was used to quantify the synchronisation between the bowling phases, EMG data processing and for the analysis of the bowling arm motion. Also, it was used to determine the trimmings of each of the phases using frame-by-frame assessment of the video (Ahmed *et al*. 2014) [2]. The timing of each phase was obtained by dividing the number of frame between two defined events with 240, as the frequency of the camera was set the same. For e.g. if the frame at foot contact of a bouncer trail was noted as 1000 and the point frame at bowl release was 1050 then the time between these two events was taken as (1050-1000)/240 seconds.

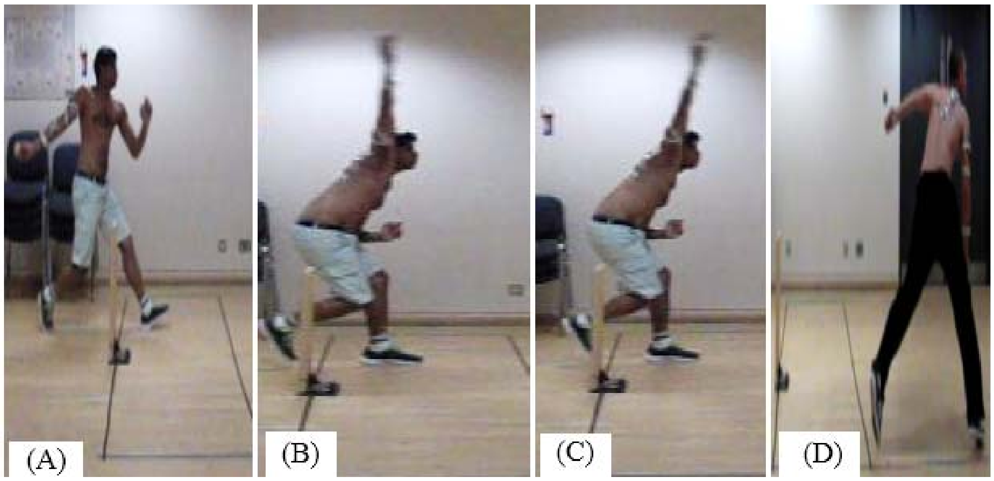


Fig 6: Phases of Bowling. a) Forward foot contact b) Mid position c) Ball release and d) Follow through. Source-original with permission.

The EMG variables taken for the proposed study were Root mean square (RMS). The variable was defined and added in the parameter, following which a pipeline was created in the EMG myon software to obtain RMS for each of the above mentioned phases. The left contact was taken as the start of first phase whereas the right contact represented the end of this phase. The second phase was defined from right contact to left off and the third phase was constructed using left off to right off option in the software. Due to the repeated measure study design the normalisation of the EMG data with maximum voluntary isometric contraction (MVIC) or the peak was not required in this study and thus not performed. (Halaki & Ginn 2012).

2.7 Data Reduction

The processed signals obtained after amplification was normalised for RMS using the highest average peak under the given formula:

$$\text{Normalised RMS} = \frac{\text{mean RMS for each phase}}{\text{Highest average peak}} \times 100$$

The given formula was adopted from the recently published article by Ball & Scurr 2014 which provides a scientific basis of using this normalisation method for dynamic activities using peak EMG. The obtained normalised RMS can be interpreted as the percentage of the highest peak (Burden *et al*. 2003).

2.8 Statistical analysis

Descriptive statistics, including the mean and standard deviation of the normalised RMS for each phase and bowling types were examined in each muscle. The descriptive analysis for the test of normality was done using Shapiro-Wilk test following which Friedman test was performed to establish the statistical significance and thus used to compare the normalized EMG between Bouncer and Yorker (Non-parametric equivalent for ANOVA as the data was not normally distributed). All other statistical tests were performed using SPSS v.21. Statistical significance was defined at $p<0.05$ (95% CI).

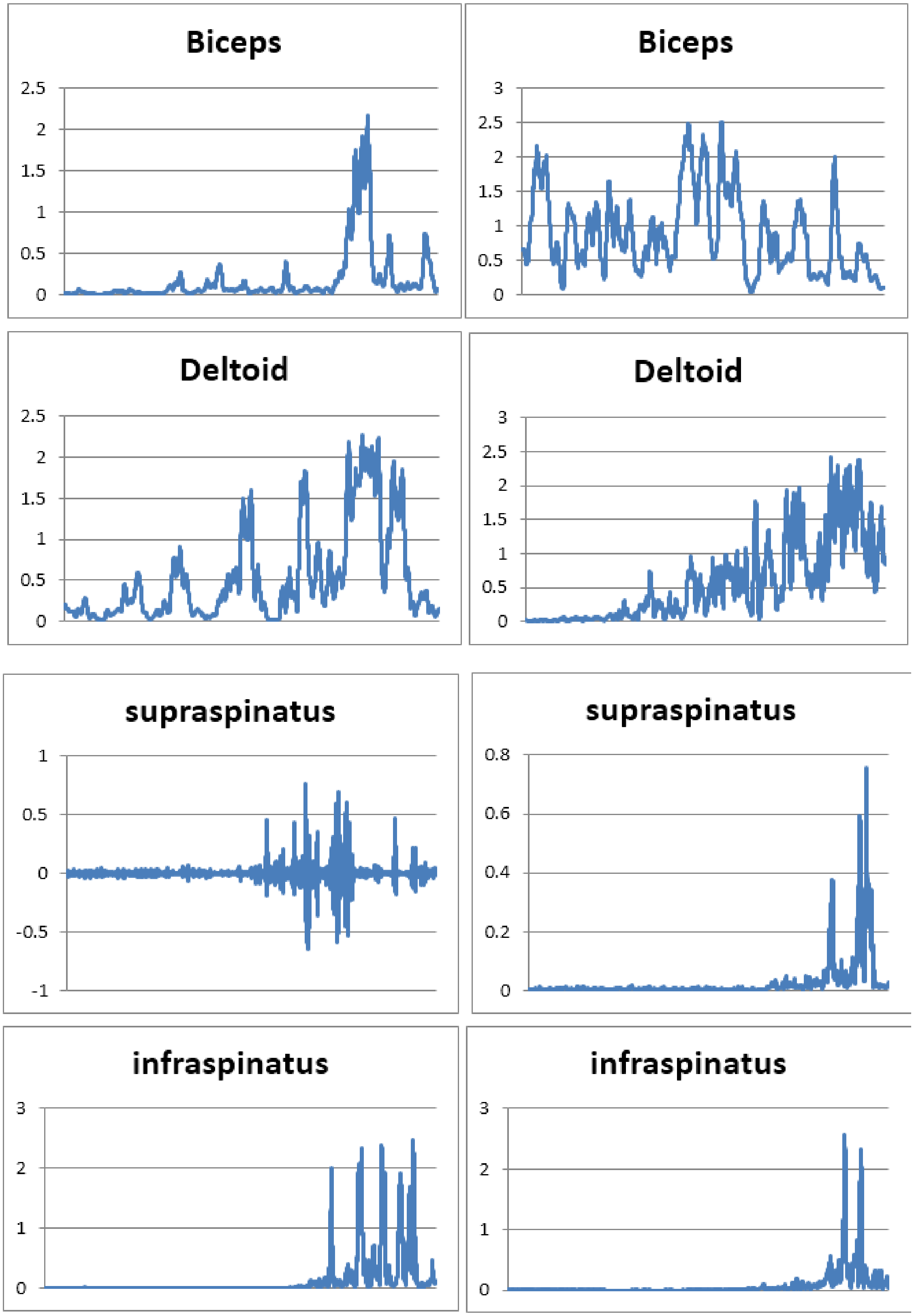
3. Results

The most important findings on muscle activity in a comparison between a Bouncer and Yorker delivery has been systematically in the given section. The following graphs and tables have been used to depict the room mean square (RMS) for all the seven muscles used in the study along with their mean and standard deviations. Also the descriptive values for each phase with the respective 'p' value derived from the non-parametric Freidman' test for establishing the statistical significance are summarised in the table 1 & 2 respectively.

Table 1: Compares the mean and s.d for individual muscles in the phases analysis.

RMS for individual muscles by electrodes channels.	Bouncer	Yorker	FIRST PHASE	Bouncer	Yorker	SECOND PHASE	Bouncer	Yorker	THIRD PHASE
1.Biceps	61.07± 25.64	45.29± 19.12		57.53± 29.02	51.05± 17.19		56.37± 28.49	50.43± 17.32	
2.Middle Deltoid	51.04±118.67	46.24±12.8		50.54±116.98	43.54±15.67		47.75±217.45	42.43±19.87	
3.Supraspin-Atus	50.56± 13.46	41.25±23.71		42.78± 17.89	29.54±20.67		25.88± 16.66	29.37± 20.97	
4.Infraspint-Atus	41.25±18.5	41.09± 21.02		50.24± 24.08	41.00± 25.53		44.31± 32.09	32.09± 21.73	
5.Latissimus Dorsi	49.40± 21.54	42.52± 22.19		43.76± 23.43	48.49± 25.53		37.54± 25.97	36.91± 24.19	
6.Flexor Carpi Radialis	46.53± 20.92	43.33± 25.86		41.56± 13.24	44.57± 25.95		42.61± 23.21	48.62± 21.67	
7extensor Carpi Radialis Brevis	52.30± 14.98	38.09± 16.48		49.09± 16.76	37.94± 15.93		39.19± 18.05	29.16± 14.13	

The table above clearly indicates that the biceps had the maximal electrical activity as percentage of peak amplitude in all the three phases. It is also evident by the corresponding graph in fig.6 below that shows the electrical activity for all seven muscles. The maximum values have been highlighted in red whereas the minimum values are shown by the green cells in the table above.



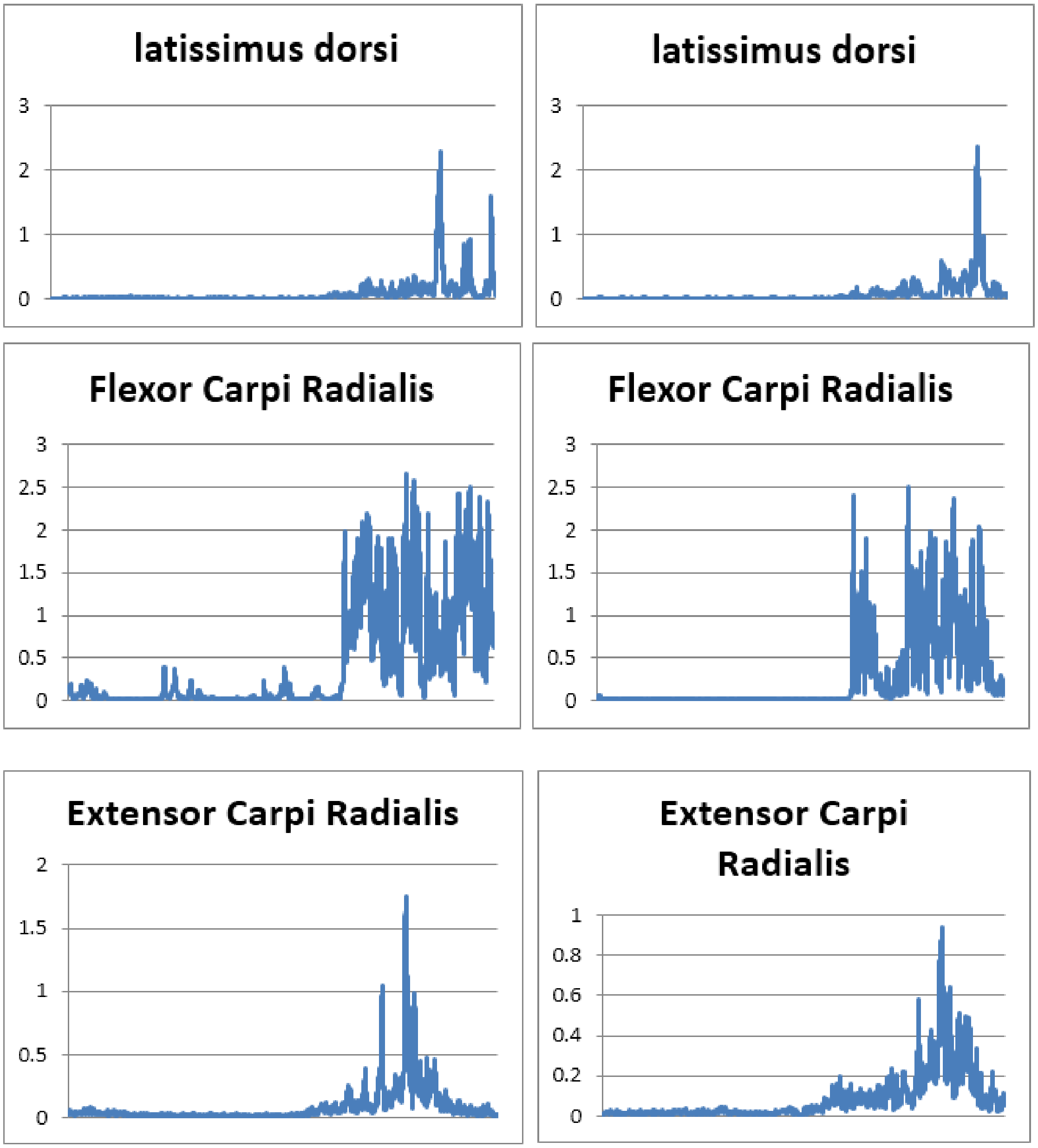


Fig 6: Raw EMG signals for all seven muscles. Column **A)** Bouncer & Column **B)** Yorker. X axis represent time in seconds and y axis shows the RMS in millivolts.

Table 2: Overall comparison between Bouncer and Yorker using Freidman's test.

RMS	MEAN ± SD	p-value (sig≤0.05)
Bouncer-1st Phase	45.88±18.4	.00
Yorker- 1st Phase	37.59±14.47	
Bouncer2nd Phase	41.69±16.45	.05
Yorker-2nd Phase	37.80±15.89	
Bouncer-3rd Phase	35.92±16.22	.25
Yorker- 3rd Phase	34.97±15.06	

It can be seen from the table 2. and fig.7 below that p valve shows a significant difference for phase1 & phase2 in a comparison between Bouncer and Yorker style fast bowling.

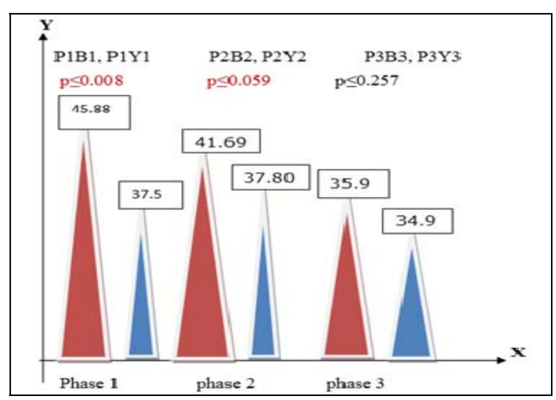


Fig 7: Represents normalised RMS. Y axis represents RMS% of highest peak in millivolts and X axis represents time in seconds. P1B1- phase 1st bouncer and P2Y1- phase 1St Yorker, P2B2- bouncer phase 2, P2Y2-yorker phase 2, P3B3-bouncer phase 3, and P3Y3-yorker phase3.

4. Discussion

Root mean square (RMS) is the widely used variable to interpret the EMG signals. The most significant findings in specific muscles have been quantitatively discussed in a phase analysis below:

4.1 Shoulder muscles

From table1.in the results section it can be seen that the biceps brachii muscle had the maximum electric activity in all the three phases of fast bowling for both types of deliveries bowled. The high electrical activity in this muscle can be interpreted by the higher value of RMS compared to other muscles with respect to a peak reference value taken for normalisation. An average increase by 10% was observed in this muscle for both Bouncer and Yorker compared to other muscles investigated. However the overall value was lesser for Yorker compared to Bouncer. The findings were similar to that suggested by Ahmed *et al*. in 2014 [2]. On the contrary the muscle was found to be more active in acceleration phase whereas Ahmed concluded that biceps showed higher activity in the ball release and follow through phase (82% of MVIC) and little activity in the first phase. A dramatic increase in shoulder activity was also reported by Andrews *et al*. 2008. On the above findings the argument of biceps brachii being the least active muscle according to (Shorter *et al*. 2010) could be discarded. The reason for the highest electrical activity of biceps brachii throughout could be due to high speed isometric contraction of the muscle at elbow during both the deliveries and high angular velocity at the shoulder joint. This could also suggest that there could be a high chance of shoulder injury in these participants as suggested and concluded by Shorter *et al*. 2010. As Biceps is one the major muscle for maintaining shoulder joint integrity, a high electrical activity in the biceps could be an indicator for underlying shoulder instability. Apart from these the difference in the RMS values for biceps in first phase (61.07% in bouncer and 45.29% in Yorker) is significantly high compared to other two phases (57.53% & 51.05% in second phase and 56.37% and 50.43% in third phase) which clearly suggests that a greater muscular force and acceleration was required to ball it. The reason for the above findings can again be attributed to constant isometric contraction of the muscle to maintain the elbow at a fixed angle of more than 15^0 to be called as legal delivery according to ICC. The other reason could be high angular velocity of elbow joint as suggested by Donatelli in 2000 [7]. The higher value of the obtained RMS also suggests greater number of motor units being recruited.

The other important thing that could be noticed was the higher value of RMS for this muscle in third phase compared to the second. The reason could be eccentric contraction of the muscle at elbow in the follow through phase. The eccentric contraction suggests higher number of motor unit's recruitments (Donatelli 2000) [7].

Also there was a significant activity in other muscles of shoulder like deltoid, supraspinatus and latissimus dorsii. Deltoid and supraspinatus are the prime abductor and external rotators of the shoulder joint. Given that the bowling arm motion requires a forceful abduction and external rotation similar result could be expected. However it should be noted that deltoid and supraspinatus are considered as the active shoulder stabiliser for dynamic action and over activity of deltoid would lead to excess upward translation of the humerus which could be a possible factor for shoulder impingement. The upwards translatory motion generated by deltoid should be counteracted by the rotator cuff muscles to maintain dynamic stabilisation. For e.g. the first phase of bouncer in table1 shows that the deltoid showed a maximum RMS (51.04%) which was effectively and efficiently counterbalanced by rotator cuff muscles like supraspinatus (50.56%) and infraspinatus (41.25%) for the bouncer. Similar results were found for Yorker also. On the above arguments, it can be proposed that overall a good dynamic stabilisation of the shoulder was maintained by the participants though there could be individual variability. Also the interferential pattern of the EMG signal for deltoid from the graphs in figure6 suggests that it was active throughout the arm motion. The higher the interferences in the raw signal, the higher no. of motor units would have been recruited (Bartlett 1996) [4]. The latissimus and infraspinatus are the prime internal rotators of the shoulder joint and showed lesser activity compared to external rotators in the first phase. This was not expected given the arm motion in acceleration phase and in accordance with previous literature. The reason for this variability was not known and therefore it should be carefully evaluated with kinematic analysis in future. However this indicates that there could be muscular imbalance between the internal rotators and the external rotators which indeed could be a predisposing factor various shoulder injuries in this phase of fast bowling as suggested by Aginsky *et al*. 2004 [1].

4.2 Wrist muscles

There was less muscular activity in wrist flexor (46.53%) compared to wrist extensor which showed a high burst of electrical activity (52.30%) while bowling bouncers in the first phase. However the result was different when compared to Yorkers. For Yorker deliveries the wrist flexors (flexor carpi radialis) showed a higher activity in comparison to wrist extensors (extensor carpi radialis brevis) which was expected due to greater speed and force generated at wrist while bowling a Yorker though the value of RMS for wrist flexor was overall less than that of a bouncer delivery.

4.3 Overall findings

It can be seen that the RMS had a linear decrease for all muscles from phase 1 to phase 3. Also the graph in figure 2 suggests that the RMS value was smaller for Yorker deliveries for most muscles compared to Bouncer deliveries. The reason for such findings can be attributed to the difference in angular velocities at shoulder and wrist in order to perform a greater thrust while bowling shorter and bouncer deliveries. A higher value would suggest a greater velocity and force generated thus a higher muscular activity should also be expected. Also a linear relationship with the required torque was found between the contraction force and the RMS value of the EMG signal (Fukuda *et al*. 2010). For smaller muscles the relationship between force and the EMG signal tend to be linear, whereas in bigger muscles that need a better motor recruitment, the same relationship tends to be non- linear, because the amplitude variations of the muscle electric signal do not correspond to the force variations (Fukuda et.al 2010).This could be the reason that in a bigger muscle like latissimus the RMS for Yorker (48.49%) was seen to be greater than Bouncers (43.76%) in the second phase. Similar result was found for flexor carpi radialis muscle where RMS for Yorker was greater than bouncer in the second and third phase of fast bowling. Overall the extensor carpi radialis brevis had the least electrical activity among all the muscles in all the three described phases of fast bowling which should again be considered as a factor for frequent wrist injuries in fast bowlers. Table 2. depicts the overall comparison of muscular activity for all muscles at three different phases of bouncer and Yorker indicated by the significant 'p' value. It is evident that there was a clinically significant difference in the first and second phase while bowling a Yorker and a bouncer with p values.00 and.05 respectively. The reason for this difference can be attributed to higher force and speed generated at shoulder while bowling bouncers and greater speed and wrist motions required for bowling Yorkers. The other reason could be the different position of the arm while bowling these two deliveries which could place some muscles at an anatomical and biomechanical advantageous position. For e.g. while bowling a bouncer delivery the release of ball was seen to be slightly delayed compared to the Yorker deliveries though the time for ball release phase was nearly the same. The delay in ball release allows the bowler to drop the ball short and fast with high velocity shoulder motion whereas the 'Yorker' deliveries demand a higher wrist position where the flexor muscles of the wrist are in efficient position to produce adequate speed and accuracy. This finding could be supported by the higher values of RMS obtained in the second and third phase of Yorker bowling in this study as mentioned before. In the third phase i.e. follow through a significant activity was seen in all muscles in accordance with previous study. Follow –through is considered as the most active stage with all the muscles firing intensely and the muscle pattern observed during the cycle were largely characteristics of attempts to decelerate the arm. (Moynes *et al*. 1986). From table1.it can be seen that the supraspinatus showed the minimum activity in the second and third phase of Yorker bowling. This suggests that the eccentric contraction of the supraspinatus (29.54% & 29.37% respectively) during the ball release and deceleration was less compared to strong contraction of latissimus and infraspinatus. The presence of an imbalance between the agonist and antagonist group is one of the major risk factors for developing shoulder injuries such as dislocation and impingement, with deficiency in the external rotator strength resulting in an injury (Aginsky *et al*. 2004) [1]. Thus the findings of this study suggested that fast bowlers are exposed to a greater risk of shoulder injuries while bowling a Yorker than a Bouncer as the difference in agonist antagonist muscle activity was seen more in 'Yorker'.

Bowling workload as a risk factor for overuse injury in Cricket has been previously analysed. Introduction of T20I has effectively increased the workload of fast bowlers in line with the no. of T20I matches being played (Orchard *et al*. 2013) [16]. As a known fact that Bouncers and Yorkers are the toughest deliveries but frequently used in T20I the study assumes that the fast bowlers are at a greater risk for shoulder and wrist injuries while bowling both Yorker and Bouncer though Yorker deliveries were found to be more injurious based on the above findings in the study. The significant p value in the first and second phase of fast bowling is a strong factor to support this assumption and care should be taken towards their prevention and rehabilitation. The study provides vital information to coaches and cricket players towards their fitness and effective training methods to reduce stress related to bowling 'Bouncers' and 'Yorkers'.

4. Future Scope

The findings of the study are novel and would hold strong significance in the area of cricket and similar sports activities. Given that there were some limitation in the study as listed below the study would be strengthen by some other mean of analysis including kinematics and kinetics. Thus there is a clear rationale for future research in the given topic.

5. Limitations

The speed of the ball was not determined accurately due to unavailability of the required equipment. Thus equipments like radar gun would make the study highly reliable. The kinematic and kinetic analysis would give a better insight into the injury profile associated with the given deliveries which was lacking in the study.

6. Conclusion

The findings of the study conclude that Biceps brachii has the maximum electrical activity of all shoulder and wrist muscles for both types of deliveries. In the comparative analysis of the Bouncer and Yorker, Supraspinatus showed significantly less activity in second and third phase for Yorker deliveries. Based on the inferential statistics, the study also concludes that there is a statistically significant difference in EMG activity in shoulder and wrist while bowling a bouncer and Yorker

7. Acknowledgement

This study was supported by Robert Gordon University, Scotland. I would like to acknowledge 2nd International Conference of Sports Medicine and Fitness held in Dubai in April 2016. A part of the paper was presented as the guest speaker in the conference.

8. References

1. Aginsky K, Lategan L, Stretch R. Shoulder injuries in provincial male fast bowlers - predisposing factors. South African Journal of Sports Medicine. 2004; 16(1):25-28.
2. Ahamed NU. Surface electromyographic analysis of the biceps brachii muscle of cricket bowlers during bowling. Australasian Physical and Engineering Sciences in Medicine, 2014; 37(1):83-95.
3. Bartlett R. Movement coordination and movement variability. Sports Biomechanics, 2007; 6(2):119-120.
4. Bartlett RM. The biomechanics of fast bowling in men's cricket: a review. Journal of Sports Sciences, 1996; 14(5):403-424.
5. Burden AM, Trew M, Baltzopoulos V. Normalisation of gait EMGs: A re-examination. Journal of Electromyography and Kinesiology, 2003; 13(6):519-532.
6. Cook DP, Strike SC. Throwing in cricket. Journal of sports sciences, 2000; 18(12):965-73.
7. Donatelli R. Assessment of shoulder strength in professional baseball pitchers. The Journal of Orthopaedic and Sports Physical Therapy, 2000; 30(9):544-551.
8. Ferdinands R, Kersting U, Marshall R. A new taxonomic system for the sub-classification of cricket bowling actions. Sports Technology, 2014; 6182:37-41. Available at: http://www.tandfonline.com/doi/abs/10.1080/19346182..893350.
9. Fukuda TY. Root mean square value of the electromyographic signal in the isometric torque of the quadriceps, hamstrings and brachial biceps muscles in female subjects. Journal of Applied Research. 2010; 10(1):32-39.
10. Glazier PS, Paradisis GP, Cooper SM. Anthropometric and kinematic influences on release speed in men's fast-medium bowling. Journal of Sports Sciences, 2000; 18(12):1013-1021.
11. Hermens HJ. European Recommendations for Surface ElectroMyoGraphy. Roessingh Research and Development, 1999, 8-11.
12. Hirashima M. Sequential muscle activity and its

functional role in the upper extremity and trunk during overarm throwing. Journal of sports sciences, 2002; 20(4):301-310.
13. De Luca CJ, Luca C De, De Luca CJ. The use of surface electromyography in biomechanics. Journal of applied biomechanics, 1997; 13:1-38.
14. Merletti R, Torino P. Standards for reporting EMG data. Journal of Electromyography and Kinesiology, 1999; 9(1):3-4. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1050641115001777.
15. Moynes DR. Electromyography and motion analysis of the upper extremity in sports. Physical Therapy, 1986; 66(12):1905-1911.
16. Orchard J, James T. Cricket Australia 2003 Injury report. Journal of Science and Medicine in Sport, 2003; 6(4):520-521.
17. RF E, JR A. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. Sports Medicine, 2009; 39(7):569-590. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=105395182&site=ehost-live.
18. Shorter K. A preliminary electromyographic investigation into shoulder muscle activity in cricket seam bowling. 28th International Conference on Biomechanics in Sports, (Mvc), 2010, 1-4.
19. Stretch RA. Injuries to South African cricketers. British journal of sports medicine. 2003; 37:250-254.