Surface EMG-based Profiling and Fatigue Analysis of the Biceps Brachii Muscle of Cricket Bowlers

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Abstract: Cricket bowling action is a complex repetitive task involving multiple muscles. In this paper we present a protocol to analyse accumulated localized fatigue in muscles during cricket bowling action. Biceps Brachii (BB) muscle in case of fast delivery for a novice player is analysed to illustrate the methodology. Synchronized video recording with the surface EMG signal was captured from the medial position of the BB muscle to enable segmentation of the EMG signal in six intervals corresponding to the six phases of the bowling action. This enables study of the activation pattern of the muscle along with the fatigue trend during bowling. Both integrated EMG and Mean Power frequency (MPF) are used as measures to analyse fatigue. Though we have plotted the trends for a single muscle, a similar exercise should be repeated for all important muscles involved. Analysing localized fatigue in individual muscles is important for injury prevention as well as player performance development. It can help to see how individual muscle fatigue contributes in declining performance during cricket bowling. Such an analysis can also be used to support minimum bowling overs and suitable inter-over breaks for a specific bowler with regard to injury prevention and optimal performance.

1 INTRODUCTION

As sports are becoming more and more competitive the maximum player performance has become inevitable in order to outsmart others in this competition. The repetitive muscles activity results in the fatigue accumulation in the muscles. The fatigue in the muscle results in the retarded muscles efficiency and that is why the detection of fatigue in athletes is a crucial task. The literature reviews in this area suggest that a lot of attempts had been made to model fatigue accumulation and fatigue graphs have been plotted using non-invasive biopotential techniques such as Electromyography (EMG). This paper aims at EMG profiling of cricket bowlers of Fast category and using it for performance development of cricket bowlers in combination with other captured sensory data.

The study includes the processing of EMG signals as well as video data from a subject to correlate the two and bring them in a form that enables us to see how individual muscle fatigue contributes in declining performance during cricket bowling. The two sources of data have to be synchronized first in order to develop correlation between them. EMG signals were recorded using Shimmer device, which is a commercially available device for acquiring bio-potential data. The data is logged and stored in Structured Query Language (SQL) based database with configurable sampling rate. Whereas, videos were recorded using high speed camera set up and interfaced to VICON software by NEXUS.

This paper contributes with increase in the Quality of Fast Bowling by giving a detailed interpretation of the results concluded from recorded data. Detection of partial range of performance can be done while analysing the data, the level of muscle fatigue can be interpreted using results. A degradation in the quality of bowling in fast bowling, over the successive bowls is an indicator of the rising level of fatigue in muscles. In this way weak muscles can be identified that are contributing to the decreasing performance and deteriorating the quality of bowling. Such trends can help us indicate severe injuries in players and reduce such injuries by timely measures.

With the help of the protocol defined in this paper, profiling will indeed help in Player development by supporting a sports trainer who will be analyzing current acquisition data with player profile. If trainer identifies that muscle activation has reduced, dedicated muscle exercises will be advised. If there is a flaw in technique, that can be identified using video

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analysis, then player will be working on correcting the techique of bowling action that will lead to player development.

The compact model for a bowling data cannot be materialized due to inter-subject variability and wide range of bowling actions. The solution to this is that instead of developing a single model for Fast bowlers, individual profiles of players should be built, and each player should be analyzed based on his own profile. For setting some standard for comparison a profile of an elite can be logged but caveat will still be inter-subject variability.

2 RELATED WORK

A lot of research has been carried out in the field of sports kinematics and EMG. Our study expands on the present work by integrating EMG techniques with existing bio-mechanical techniques.

Surface Electromyography (EMG) is the science and basic technique used for the quantification of muscle activity during movement which is popular being a non-invasive technique. It is a hassle-free procedure that can be used to determine the amount of muscle activation throughout a given movement and its activation timings and is an essential tool in biomechanical and biomedical investigations. Normally the EMG signal is between 5-450 Hz window. The importance of muscles is based on the EMG activity shown by them. Based on above discussion, muscle showing the higher trend during fast cricket bowling should be selected. Therefore, Biceps Brachii (BB) muscle has been opted for the analysis.

The studies by (Schmidt et al.,1999) and (Lloyd et al.,2000) observe only the physical movement of upper extremities. Since sports techniques are much more elaborate than joint angles, EMG signals can be used to provide more information and insight into different actions, as well as their relation to muscle fatigue and injuries. EMG signals refer to the electrical signals generated when a muscle contracts, and are measured using EMG sensors.

During the delivery of the ball, the most upper limb muscles; BB, pectoralis major, deltoid, trapezius, latissimus dorsi, infraspinatus, trapezius, serratus anterior, and supraspinatus muscles are mostly active. (Ahamed et al.,2014)

The EMG frequency decreases with time, indicating an increasing degree of fatigue. This provides us with a useful method of injury prevention. The relationship between EMG and fatigue is, as (Florimond,2008) has written, that "muscle fatigue is accompanied by a decrease in motor unit firing rate and conduction velocity." This result has been observed in many studies, including those by (Raez et al.,2006). Thus, the median and mean frequencies decrease as fatigue increases therefore, muscle fatigue index has been defined using the mean and median frequency of the EMG spectrum. The muscle fatigue index decreases as contraction time increases. While both median and mean frequencies may be used as the fatigue index, as per (Florimond,2008), median frequency is less sensitive to noise and more sensitive to biomechanical factors so using mean power frequency can be used for analysis.

Furthermore, as another indicator of fatigue, the EMG amplitude is also found to increase with fatigue. This is due to additional fibres being used to generate the same level of force. EMG amplitude is used to indicate fatigue when movement is required, in exercises (Florimond,2008). Similar results have been drafted by (Shorter et. al. 2010) for interpretation of injury which is done through muscle activity.

(Ahamed et al.,2014) have defined phases of a bowling action as Run-up, Pre-Delivery Stride, Mid Bound, Back-Foot Contract, Front-Foot Contract, Release of the Ball and Follow through and compared different activation trends during these phases.

3 METHODOLOGY AND PROTOCOL

This study focuses only on BB muscles but same or similar procedure can be used to analyse fatigue in other muscles such as latissimus dorsi and soleus muscles also. We plan to design a protocol for professional players and then increase number of subjects under study.

3.1 Subject Preparation

The subject is given an overview of the experiment if he is interested a consent form is to be signed by the subject. Then the Subject Data Performa is filled in order to have an idea of BMI and exercise history of the subject. The subjects are specifically inquired about any history of neuromuscular injury. The initial biceps envelop recordings are made and trial EMG of subject is recorded using bicep curls experiment to see that recordability of the muscle of the specific subject.

A Bicep envelop is formed using measurement tape and the electrode positions are marked. A typical Bicep envelop has been shown in Figure 1. The bold positions in Figure.1 are medial and lateral points, on has been marked. For reference an electrode position has been marked near bony structure of elbow. The skin must be shaved and cleansed with alcohol so that the EMG signal is noise free. After that the skin is abraded with skin cleaning gel and alcohol swabs are rubbed at skin contact point to remove dead skin cell and to have better data capturing.

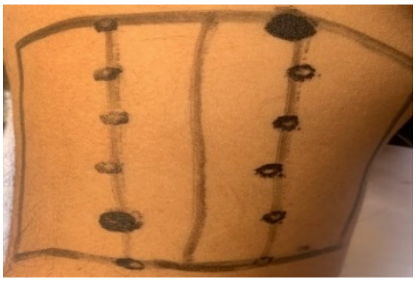

Figure 1: Biceps Envelop for Electrode placement.

For the scope of this paper the data acquired from Medial Channel has been reported. The electrode placement on subject has been shown in Figure 2.

Figure 2: Electrode Placement on a Subject.

3.2 Protocol of the Experiment

Each bowler must perform 3 overs as a trial. As there are six deliveries in an over hence 18 bowls per trial will be recorded. Players should not be exhausted or should not have muscular tension prior to the trial. Subjects should remain hydrated throughout the trail. A rest period of up to five minutes is given between the each over so to mimic the actual inter-over rest of a cricket match. The Run ups for each delivery should be constant.

3.3 Phases of Cricket Bowling

Following are the phase segmentation as described in by (Ahamed et al.,2014) we segmented our deliveries in six segments.

a) Run-Up (RU)
The ball is held in the palm with the arm hanging straight down and the shoulder at 0º degree abduction neutral rotation.

b) Pre –delivery Stride (PS)
Biceps muscle gets slightly contracted through the external torque provided by low-load weihted ball. This torque also enables elbow movement and the 90º abduction of shoulder muscles with max external rotation

c) Mid Bound (MB)
Shoulder provided forward elevation and the arms are lifted at greater than 90º angle backwards at ear level.

d) Back and Front-foot Contact (BFC)
Combined phase of Foot contractions. The end of the stride will be identified by the contact of the back foot with the crease.

e) Release of Ball (RB)
The point where the ball will be released and the arms will be in a vertical condition. The elbow extension strength at 100º – 120º of elbow joint continues until the ball is released.

f) Follow-Through (FT)
The action after the ball release until the final interval of arm motion dissipating the deceleration forces, is a follow through.

Figure 3: Video Segmentation Results in Phases.

4 EXPERIMENTAL METHOD

The subject identification is important for the experiment. For this experiment Novice subjects are required who have at least 90 kph pace and level of maturity in their line, length and bowling action during a cricket bowling. The reason for selecting a Novice Subject is a better fatigue development in the subjects of this category due to less muscle endurance.

Data Acquisition was conducted in ICC Biomechanics Lab LUMS. EMG data lead us to detailed muscle activity analysis while Video Data was helpful in segmenting the deliveries of trial into respective phases by picking the corresponding segment in EMG data as given by the phase-wise segmentation of Video of deliveries.

4.1 Set-up

With the help of Shimmer device multiple Biopotential signals can be measured simultaneously in real-time. ConsensysPRO software is helpful in streaming for live visualization. The raw EMG data can be logged in the personal computer storage and also to an SD cards. Consensys Software interfaces EMG data via Bluetooth and it is stored and compiled in the form of definite sessions by labelling descriptions and creating new Subjects for each trial. Each over has six balls, so 18 sessions are stored per trial. Consensys enables to visualize the live acquisitions of data. The sampling rate of the software must be matched with the hardware Shimmer device in order to have synchronized data. After data logging in Consensys the data is exported in the form of Excel file which can be readable in MATLAB. For this experiment the interfacing and analysis was performed on MATLAB. It was the main software used for data cleaning, pre-processing and data analysis. From these corresponding points, data was labelled using frame by frame video and the corresponding per second reading of the data. This project combines EMG with existing bio-mechanics protocols. This addition of EMG can help the bio-mechanics field expand its horizons in terms of player injury profiles and fatigue analysis

4.2 Data Synchronization

The data from the phases was identified by looking at the video after the correlation of EMG with the video data. Shimmer device is used to acquire the EMG data and is attached via electrodes on the Subject's biceps muscle. For this experiment we have selected sampling rate to be 1024 samples per seconds.

Two high speed cameras, one was placed at the back side and one was placed side-ways, recorded the video data. The Video data is segmented into frames using a MATLAB program. The Frame rate of high-speed cameras is 125 fps whereas Sampling rate of Shimmer is equal to 1024 samples per sec. So, each frame of video data almost equals to 9 samples of EMG data. First the delivery of a trial is segmented in the subsequent phases as depicted in Figure 3 and the starting and ending samples of Video are noted. Based on the number of frames of video recording and their relative fraction in the trial, the corresponding EMG samples are then calculated using the same fractional ratio in EMG data. Using this technique and segmentation of video data, the EMG signal is then segmented in the corresponding windows of samples using frames of Video Data.

Each window of samples corresponds to the segmented phase-wise activity of a cricket delivery. There were some synchronization problems in few deliveries, which were eliminated using the visual cue analysis for phase segmentation in EMG data.

4.3 Data Processing

The processing starts from importing Raw EMG data in MATLAB. A Moving average filter with window size of 100 samples is applied, which has Low Finite Impulse Response (FIR) hence is used to smoothen the signal. After data smoothening, a Band pass filter of pass band 5-450 Hz is applied using a MATLAB program. The resultant is a denoised and smoothen signal. After this the phase segmentation through Video Data analysis is incorporated. The phases wise time domain plots are then used to visualize the activity in each phase. The mean activity of each phase is then plotted per ball in order to validate the data as given by the literature review.

The data was changed into its frequency domain transform and from there, mean frequencies were calculated. Mean Power Frequency (MPF) of each phase is also computed an analysed. The Integrated EMG (IEMG) and MPF activity of each bowl is computed and cumulative plots per over and per trials are also plotted.

The Integrated EMG (IEMG) is the cumulative sum of the absolute value of EMG signal.

$$IEMG = \sum_{n=0}^{N} |E(n)|$$

The E(n) is the discrete activity function of EMG signal obtained from the sensor, normally in mV, and summing this activity function over a definite interval having N samples gives IEMG of this interval. In continuous case summation will be mapped to integration, but as far as the scope of this project is concerned the data is discrete. As the muscle activity increases more and more muscle fibers are being activated and |E(n)| increases, therefore the value of IEMG increases as subject's activity is increased. There is also a normalized version of IEMG which is called as Sample Normal IEMG and defined as IEMG per sample of a given data of N samples

$$Sample\ Normal\ IEMG = \frac{IEMG}{N}$$

The Mean activity within a phase gives the average unipolar IEMG of that phase per unit sample. By definition, it is same as Sample Normal IEMG. Mean activity of EMG data having N number of samples is defined as

$$Mean\ Activity = \frac{\sum_{n=0}^{N} |E(n)|}{N}$$

Mean Power Frequency is the average frequency of a signal, which is calculated as the sum of product of the EMG power spectrum and the frequency divided by the total sum of the power spectrum.

$$MPF = \frac{\sum_{i=fmin}^{i=fmax} fi\ Pi}{\sum_{i=fmin}^{i=fmax} Pi}$$

where, *fmax* is the maximum frequency of the data and *fmin* is the lowest one. And P(i) denotes the power spectrum of the signal. There is a noticeable decreasing trend in the MPF of an exercise. As the fatigue point approaches the MPF shifts towards the lower frequencies.

5 RESULTS

Once we had our data and it was processed, we analysed the data to produce three distinct studies and results; Phase-wise time segmentation, IEMG Analysis and MPF analysis A detailed description of these studies is given below:

The phase-wise segmentation of the trial was performed using video analysis data as explained in section 4.2 in detail. A typical phase segmentation is shown in Figure 4 where the red lines shows partition of respective phases. Ball wise time domain segmentation of some deliveries of the trial are given Figure 5.

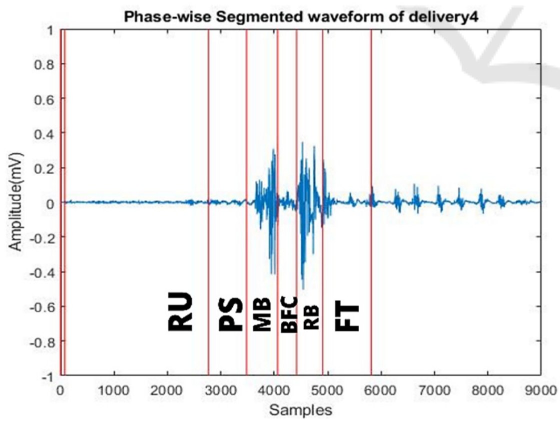

Figure 4: Labelling of six phases of a typical delivery.

By definition, the mean activity is the same as sample normal IEMG. There is a gradual increase in the activity as the deliveries progress in the trial. Figure. 6 provides a detailed Medial mean phase activity of the trial. It can be observed that there are significant activity trends in MB, BFC and RB phases.

After delivery wise phase segmentation analysis, the averages of all phases have been computed over the trial and plotted in Figure. 7. The results elucidates that the RB phase is the most active phase of cricket bowling followed by BFC and MB as concluded by (Ahamed et al.,2014).

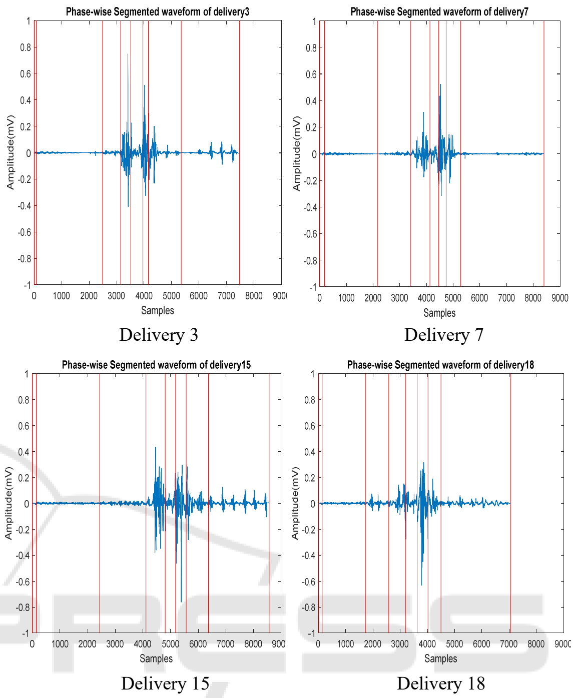

Figure 5: Segmentation in six phases of different deliveries in the same sequence as identified in Figure 4.

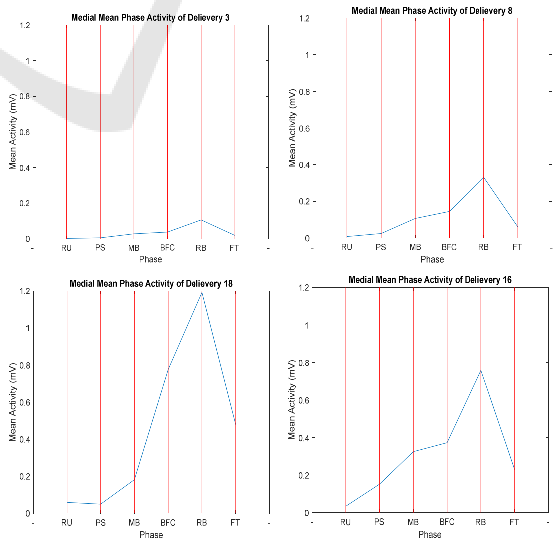

Figure 6: Phase-Wise Mean Activity of individual Delivery 3 (a), Delivery 8 (a), Delivery 16 (a), Delivery 18 (a) of Trial.

We computed the Average of Phase-wise Mean activity of 18 Deliveries in Figure. 7, which helps in player profile analysis and it gives the insight of activity in each respective phase of cricket bowling. The reason of not averaging different subjects in this average is inter-subject variability. Due to Inter-subject variability we cannot model all fast bowlers using same model rather we have to analyze individual player profiles (Rushda et al., 2020).

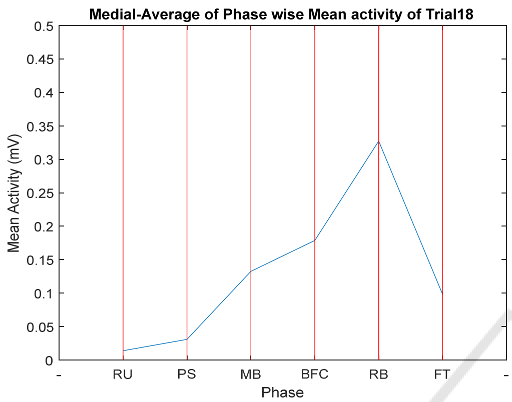

Figure 7: Average of Phase-wise Mean activity (in mV) of 18 Deliveries.

In Figure.8, complete trial IEMG of Medial channel data is plotted. The general trends overwise shows an increasing trend since, more action potentials are being activated. The gap between the overs stabilize the activity and due to this 5 to 7 minutes, rest IEMG decreases before the onset of new over. The red line marked in the graphs of Figure.8 shows the over partition.

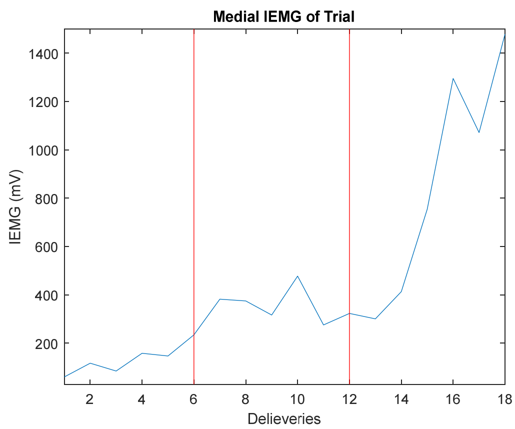

Figure 8: Delivery-wise IEMG trends for complete Bowling Action.

The MPF trends are consistent for the segments of the delivery in which there is relatively high activity is observed. The Best window is the window of 1500 samples in a delivery having maximum activity as shown in Figure 9. It is normally MB, BFC and RB phases of the delivery. The reason for taking best window is that MPF trends are significantly decreasing in the areas of high activity i.e. best window, in a trial.

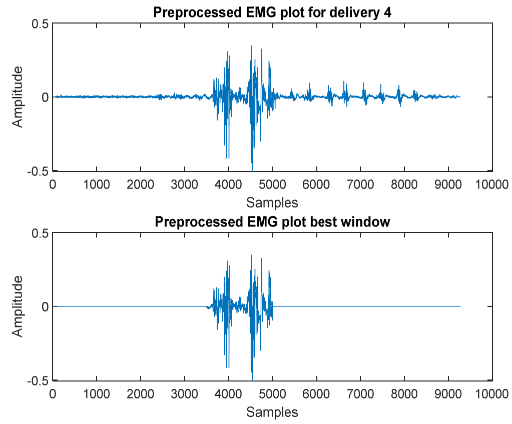

Figure 9: Time Domain Best window plot of Delivery 4.

Best window MPFs of complete trial has be plotted in the Figure. 10 while in Figure.11 phase-wise MPF trends over the complete trial are plotted.

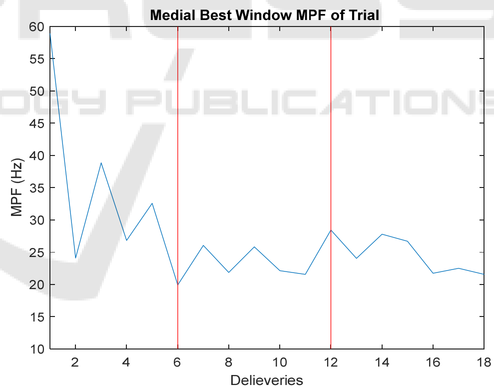

Figure 10: MPF trends of Best Window of complete trial.

Referring to the Figure.10 and Figure.11 the plots are depicting that during all the phases of a cricket bowling MPF values have different starting values. This is due to the fact, that in different phases different amount of power is required and therefore, the MPF values have different values during each phase. Another useful insight due from Figure.10 and 11 is that in all the phase of trial Medial side, the MPF has a decreasing trend. With the onset of new over, i.e.; at 7th and 13th delivery due to inter over resting time the muscle activity is relaxed hence MPF results are showing slight increases at those points, but the

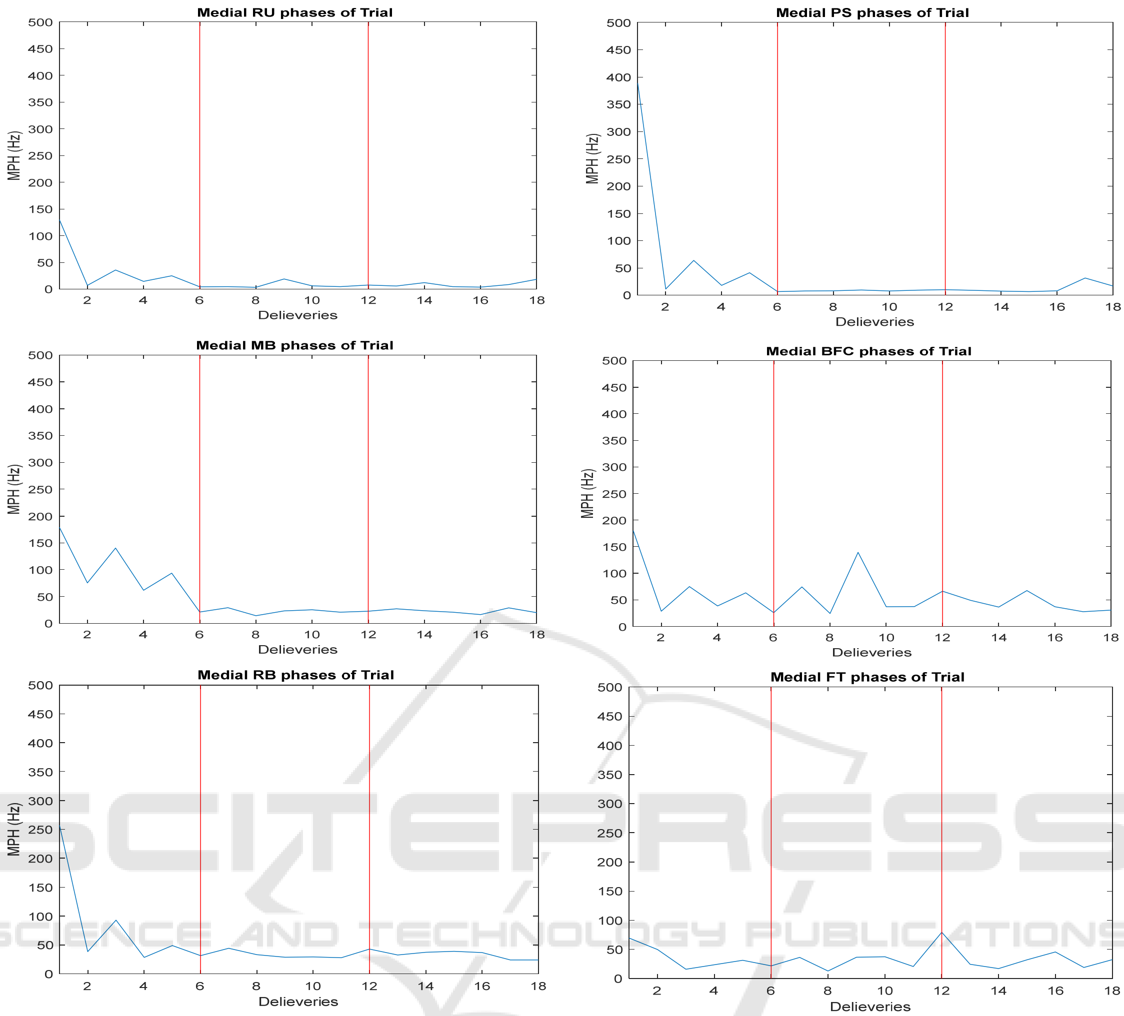

Figure 11: Separate MPF trends of six phases per trail.

overall trend is decreasing as supported by literature review.

6 DISCUSSION AND INTERPRETATION OF RESULTS

MPF has been used as fatigue index, like stated in (Hwaang et. al., 2016) that as fatigue sets in the muscle the value MPF decreases to the 60% of its initial value. This 60% point can be taken as failure point or onset of fatigue. From Figure 10 and 11 it is clear that in case of Novice subject the fatigue sets in during the first over in BB muscle. BB muscle is active during fast bowling. BB muscle is relatively more active during MB and RB phases of cricket Bowling trial. Significant differences between the phases of fast bowling were found. The entire results support our hypothesis and validate the trends as explained through literature reviews.

The Figure 8 depicts that the IEMG trends are increasing with the increase of number of deliveries of the trial. During the overs especially if best windows of each deliveries are considered MPF activity is decreasing. Same trends were visualized when we analyse phase-wise MPFs trends or best activity phases.

Mean phase activity trends follow the same pattern as describes by literature review. This provide a basic understanding of the BB muscle activation pattern during a typical cricket bowling. By the better understanding of activity trends and identification of important phases, using video analysis, a Sports trainer can focus and analyse the phases RB, BFC and MB because being the phases of higher activity makes them more prone to injury.

7 CONCLUSIONS

The main objective of this paper was developing a protocol to set up a support system for data acquisition for a trainer or cricket coach. After the detailed literature review and interviews of Cricket Coaches protocol of the acquisition is being set up. After that phase-wise analysis of deliveries was performed which validate the results from literature reviews and elucidate that RB and MB phases are the relative active phases of a normal delivery and during phases as muscles are mostly active it makes the bowler more prone to injuries and it makes sense because during Release of Ball bowlers jerk to pull out maximum speed of the ball and resultantly they injure themselves. So, the coach must study kinematics specifically in high activity phases in order to expound the patterns of muscles activity and relate it with injury. These patterns can also be used during the rehabilitation and fast recovery of an injured player.

The compact model for a bowling data cannot be materialized due to inter-subject variability and wide range of bowling actions. The solution to this is that instead of developing a single model for Fast bowlers, individual profiles of players should be built, and each player should be analysed based on his own profile. For setting some standard for comparison a profile of an elite can be logged but caveat will still be inter-subject variability therefore, individual profiles of players should be analysed.

Chances of incurring injury during bowling is enhanced when a fatigued muscle exerts itself during a bowling action. The above procedure can be used to study phase-wise muscle activation pattern during a bowling action and study the lowering of fatigue index with repeated bowling actions. Based on choosing a predefined threshold and the experimental data acquired from a player, a safe number of allowed overs and inter-over gaps can be selected for a player.

Fatigue related degradation in repeated performance can be identified by collecting localized fatigue data from multiple muscles during repeated performance. Video monitoring and processing allow computation of body kinematics in different phases of bowling actions. Correlating this with fatiguing pattern of individual muscles involved in the kinematics can indicate which individual muscles should be specifically focused for further training.

Improvement in bowling performance can be planned better. Fast and slow fatiguing trend of a muscle also indicate if the muscle can be invoked for more power for better kinematics. Any lack in the desired kinematics of a cricket bowling action can be associated with either the lack in muscle capacity or just the need of further training in a bowling technique. In case of former the involved muscle capacity shall be further improved before proceeding with the latter.

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